Advanced Logistic Systems – Theory and Practice, Vol. 18, No. 1 (2024), pp. 15-22.
https://doi.org/10.32971/als.2024.002

BUSINESS MODELS ON THE BASIS OF DIGITAL INFRASTRUCTURE DATA

STEVE SCHULZ[1] – SEBASTIAN TROJAHN[2]

Abstract: *The project Ready for Smart City Robots (R4R) is developing strategies for the detailed capture of infrastructural environmental parameters. These are intended to be utilized for autonomous mobility and logistics applications on pedestrian and bicycle paths. The project evaluates the quality and completeness of data for Smart City concepts, using examples from (autonomous) micro-mobility in logistics and transportation. The results encompass the following areas: firstly, the identification of necessary environmental information for environmentally friendly, automated last-mile logistics, along with a continuous data collection method for up-to-date information. Secondly, the examination of various integration scenarios for autonomous delivery services and an autonomous bicycle rental system in rural areas. This includes the development of application scenarios and the scientific support of the prototype construction of the necessary technical prerequisites for the data/sensor boxes. The following outlines the business model potentials for data collection, autonomous micro-mobility, sharing services, and Smart City applications.*

Keywords: *business models, smart city, digital infrastructure*

1. SCIENTIFIC OBJECTIVES AND RESEARCH QUESTIONS

1.1. Motivation

In terms of public services and living space appeal, generating cost-effective open, multimodal maps holds significant societal potential [1]. There's an urgent need to bridge the gap in access to new mobility options between large cities and smaller town or rural areas. Densifying traditional rural public transportation is economically challenging. New mobility services, driven by autonomous systems (shuttle buses, micromobility), can mitigate the growing accessibility divide between rural and urban areas. However, challenges like longer distances, infrastructural issues (railway crossings, lacking pedestrian/cycling paths), and demographics must be considered [2]. The project addresses these by collecting microscopic traffic data, assessing suitability for scenarios, and considering public acceptance. The intended mapping material becomes a key component for fostering interconnected intermodal mobility in rural areas. Regarding autonomous delivery robots, the project establishes the foundation for elderly well-being through delivery via autonomous micromobility. Local retailers (pharmacies, grocery stores, post offices) competing with regional car-dependent options can enhance their offerings' attractiveness and scope through autonomous delivery services. The assumption is that various local providers will collectively use delivery robots for economic success, requiring efficient logistical planning. This benefits local retailers, increases rural appeal for young people, and supports older individuals in their daily lives. Beyond the two cases, the project creates a method enabling municipalities to continuously collect high-quality data on

[1]Dr., Anhalt University of Applied Sciences, Bernburg, Germany
Steve.Schulz@hs-anhalt.de
[2]Prof. Dr., Anhalt University of Applied Sciences, Bernburg, Germany
Sebastian.Trojahn@hs-anhalt.de

infrastructure, traffic, and the environment with minimal financial effort. This significantly improves access to new Smart City concepts and procedures, especially for financially constrained municipalities.

The motivation for new city logistics concepts often arises from addressing challenges related to delivery, especially in urban environments [1, 2]. Traditional delivery methods face limitations in densely populated areas due to traffic congestion, limited parking, and environmental impacts. This is where new technologies, particularly autonomous robots, come into play as potential solutions. In the context of the R4R project [3] (Robots for Resilient City Logistics), the response to these challenges involves the deployment of autonomous micromobility and delivery robots. These technologies aim to enhance logistics operations in urban areas, making them more efficient while minimizing environmental impacts. By focusing on autonomous systems like shuttle buses and delivery robots, the project aims to improve the availability of delivery services and address issues related to delivery logistics. This approach contributes to creating a more sustainable and resilient city logistics system that aligns with the demands of modern urban environments.

1.2. Goals

The Ready for Robots project has a twofold objective: firstly, to generate environmental data for the planning and operation of autonomous micromobility, addressing gaps in digital area representation. It involves comparing a community-based approach, utilizing a cyclist app, with an integrated sensor solution for rental bikes [3]. The focus is on assessing enrichment with multimodal and time-variable information. The project's scientific contribution lies in identifying relevant environmental data for eco-friendly automated last-mile logistics. It also entails comparing bicycle-related collection strategies in both small urban and rural areas, evaluating data-based planning and simulation for autonomous applications within the data collection catchment area. In the realm of autonomous delivery robots, the project establishes a foundation for providing essential services to the elderly through autonomous micro-mobility. Local retailers (pharmacies, grocery stores, post offices) in competition with car-accessible regional shopping options can enhance their offerings by introducing autonomous delivery services. The assumption is that various local providers will equally utilize delivery robots for economic success, necessitating efficient logistical planning. The transfer of delivery service availability not only benefits local retail but also enhances the appeal of rural areas for young people and supports older individuals in their daily lives. Furthermore, the project introduces a procedure enabling municipalities to continuously and cost-effectively collect high-quality data on infrastructure, transportation, and the environment. This significantly improves access to new concepts and methods in the Smart City domain, especially for financially challenged municipalities. On a parallel track, the project includes the development of general process models for specifying data requirements for autonomous micromobility in mobility and smart city concepts. It encompasses the technical and organizational development, implementation, and evaluation of various aggregation strategies for necessary environmental data. Over a span of 2.5 years, the project tests (bike) sharing approaches in former lignite mining areas. The existing traffic simulation environment is expanded to incorporate elements of autonomous micromobility, facilitating feasibility assessments. Towards the end of the project, two scenarios based on autonomous micromobility are implemented. This includes the creation of a toolchain for modeling and planning, along with a smart city portal for monitoring in rural areas and small to medium-sized towns. Additionally, one or two business models are designed for establishment, catering to both data collection and use case.

1.3. Research Question

The research questions and objectives of the project focus on the development of autonomous micromobility and data-based applications. The project is divided into three phases: conceptualization of data aggregation, implementation and execution of data collection, and evaluation based on use cases.

In the first phase, the differentiation of requirements for rural and urban areas and the extraction of relevant information from different data sets are important considerations.

The second phase emphasizes citizen motivation, stakeholder participation, and quality assurance of data collection. The involvement of citizens and the protection of their data are key concerns for long-term acceptance and utilization.

The third phase involves simulation to analyse the suitability of a mobile robot system in real-life scenarios, with careful consideration of ethical and legal aspects. The research questions and objectives provide a solid foundation but require continuous critical reflection to align with project objectives.

2. APPROACH

2.1. Data reference and sources

The project aims for a comprehensive, distributed form of data collection that, in contrast to point-based surveys (such as laser scanning), reveals time-specific phenomena in the survey area. This includes not only infrastructural features (path widths, visibility of paths), temporary elements, but also pedestrian frequencies, environmental data, and critical driving maneuvers. It is assumed that the cargo bike solution will provide faster and qualitatively better results due to uniform bicycles and sensor systems. The community approach will require a longer lead time but will generate more extensive raw datasets through camera evaluation. Data collection is driven by the analysis of available public and governmental datasets and systematically planned based on the available OSM map material. High-resolution, manually created 3D scans are used to assess the quality and meaningfulness of the data.

The project uses two different strategies to record environmental parameters: the community-based approach and rental bikes. The users' mobile phones on the handlebars serve as sensor carriers for the community-based approach, while highly integrated special sensor technology is used for the rental bikes. GNSS sensors, inertial navigation systems, cameras, microphones, environmental sensors and distance sensors are used in both strategies. The data is pre-processed and extracted on the server side in the sensor hardware, which reduces the communication bandwidth. The transmission of data is user-controlled in a community-based approach, while the rental bikes automatically upload pre-filtered data and features. The data to be extracted includes height differences along the route, surface quality, riding manoeuvres, minimum widths, temporary obstacles, pedestrian traffic, air quality and distances to obstacles. This efficient data collection and processing enables precise analysis of the environmental parameters, taking into account user comfort and technical requirements. The use of different data collection strategies contributes to the versatility of the data set and enables comprehensive analyses within the scope of the project.

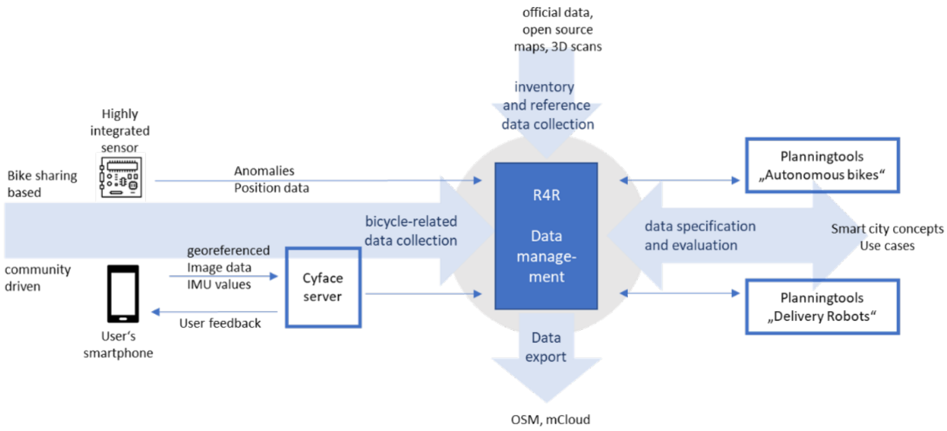

Figure 1. Different ways of Data Collection; modified based on Prof. Zug (TUBAF), project application R4R [3]

The project extends the Lanelet2 concept, originally developed for automotive autonomous applications, by incorporating additional non-geometric aspects and temporally effective attributes. Various filtering and extraction tools have been implemented for the data collection strategies:

1. In the cargo bike rental system, the detection of motion anomalies is implemented using AI methods directly on the embedded hardware. This significantly reduces data exchange and storage requirements.
2. The mobile phone application compiles image and sensor data for a route into a data package, which is then sent to the project server via the mobile network or Wi-Fi, according to the user's preference. The analysis is then conducted on a powerful server for image data evaluation and fusion.
3. The technical challenges lie not only in the generation of information sets but also in the implementation of scalable methods for aggregation, analysis, and evaluation. The project builds on the experiences of partners Cyface (Movebis project [4]) and the Bergakademie (AK^2 project [5]).

2.2. Selected Sensors

The project encompasses a variety of scenarios through the use of different sensors for data collection, targeting various aspects of the urban environment. Examples of the sensors used are diverse: Cameras and municipalities enable the capture of visual information about lanes and sidewalks, while IMUs provide details on road roughness, the substrate, and longitudinal inclinations (compare Table I). Ultrasound sensors, positioned left and right, serve to record stationary elements, traffic volumes, and count individuals. The illumination sensor assesses the visibility of bicycles under different lighting conditions, while the microphone captures ambient noise levels. The GPS sensor tracks the traveled distance, duration, and number of users. Additional unspecified sensors could monitor environmental parameters such as temperature, air quality, or communication functions. This broad range of sensors allows for comprehensive data collection in the urban environment. The obtained data is not only relevant for scientific research purposes but also forms the basis for innovative business models. Conceivable services include real-time traffic monitoring, urban planning optimization, navigation services, or environmental monitoring. Aspects such as data protection, data quality, and availability play a central role in shaping these business models.

Table I.

Priority of collected Data

Possible data to be recorded	***Priority***
Number and dimensions of lanes (roads, footpaths, lanes)	2
Roughness road	1
Information on the "stationary" equipment of the side area (benches, number of parking spaces, obstacles, plants, type of curbs, outdoor advertising, parking spaces for scooters and bicycles, bicycle racks,)	1
Condition of the substrate (material, roughness, damage)	1
Gradient of the path (road, cycle path, footpath), height/crossing kerb	2
Information about road gradients	1
Lighting situation to see wheels	3
Ambient volume	2
Temperature	3
Air quality (CO2, particulate matter)	2
Traffic volumes in vehicles/time interval or pedestrians/time interval at the boundaries of the simulation environment	1
Breakdown of traffic volumes into vehicles/period and pedestrians/period at junction approaches (straight ahead, right, left)	1
Counting values for people who use the side room for their stay (see differentiation above)	1
Front and rear (safety) distance to other road users	3
Distance traveled in km, duration, number of users (active/passive)Frequency of use, what are preferred routes	1
Onboard unit - digital bell	3

3. BUSINESS MODELS

A business model is the fundamental framework that describes how a company generates, offers, and captures value [6]. It consists of various interconnected elements, including the value proposition, customer segments, distribution channels, customer relationships, revenue streams, key resources, key activities, key partnerships, and cost structure [6]. Through the effective integration of these elements, a company creates a robust business model that forms the basis for long-term success and sustainable value creation. Business models vary significantly depending on the industry, market, and company strategy [6].

3.1. Business Model development

In the context of business model development, several key research questions arise [6–8]. Firstly, regarding the monetization of collected environmental data, the question is how to effectively utilize and monetize this data with data processors, mobility service providers, or other stakeholders [6–8].

Secondly, it is crucial to explore how the sustainability of business models can be ensured to guarantee long-term value creation and continuity. Citizen acceptance and participation are pivotal factors for success [6–8].

Therefore, the third research question focuses on the influencing factors on user behavior regarding data collection and how business models can be designed to encourage high participation and acceptance [6–8].

Fourthly, it is essential to investigate how existing and potential data protection and regulatory guidelines influence business model development and how companies can respond [6–8].

The fifth research question pertains to the role of partnerships and ecosystems. What types of partnerships are necessary to successfully implement business models, and how can these be established and maintained?

Lastly, concerning the sixth research question, exploration will be conducted on how companies can realize innovative approaches and differentiation in their business models to stand out from competitors and provide long-term value [6–8].

The scientific exploration and presentation of results aim to deepen the understanding of the economic viability and value of collected environmental data for various stakeholders in the context of autonomous micromobility and Smart City applications.

3.2. Potential Business Models

The aforementioned sensors are used to record various environmental parameters and enable comprehensive data collection for the given scenarios. There are potential business models in the field of sensor integration, data analysis and use for the optimization of mobility solutions and urban infrastructure (see Table II)

The "R4R DeliveryExpress" is a subscription-based automated delivery service in Koethen, designed to offer citizens a convenient and reliable solution for regular purchases. Customers use a mobile app to order various goods, which are then delivered to their doorsteps by autonomously driving robots.

Key features include flexible delivery time windows, contactless deliveries for customer safety, and exclusive offers for subscribers from partner companies. Emphasizing environmental sustainability, the service utilizes eco-friendly robots, contributing to reduced traffic congestion and environmental impact.

Revenue streams come from customer delivery fees, commissions from partner businesses, and potential advertising partnerships with local companies for additional income. The technology and business model could be licensed to other cities, and data collected from deliveries and customer preferences can be used for data analysis and consulting services.

Based on existing automated delivery service providers in Tallinn (Estonia), a requirement of 181 robots was calculated for a city the size of Koethen. Assuming an average delivery distance of just under 2.3 kilometers and a capacity utilization of 50%, the payback period for all investment costs for robots and infrastructure is around 7.5 to 10 years with a turnover of between €0.75 and €0.95 per delivery.

Challenges include addressing regulatory aspects related to autonomous robots and ensuring the technical reliability and safety of the delivery system. Initial expenses involve robot acquisition and maintenance, software development, ongoing research, and collaboration costs with local businesses. Marketing investments are also essential to raise awareness and attract customers to the innovative "R4R DeliveryExpress" service.

Table II.

Possible data to be recorded

Possible data to be recorded	***Data characteristics***
Geometry	Number and dimensions of lanes (roads)
	Number and dimensions of lanes (footpaths)
	Number and dimensions of lanes (cycle paths / cycle lanes)
	Dimensions of the side room
	Information on the "stationary" equipment of the side area (benches, number of parking spaces, obstacles, plants, type of curbs, outdoor advertising, parking spaces for scooters and bicycles, bicycle racks,)
	Information on the "dynamic" equipment of the side area
	Condition of the substrate (material, roughness, damage)
	Gradient of the path (road, cycle path, footpath)
	Height of underpasses (tunnels, bridges, etc.)
	Information on longitudinal road gradients
Context of the environment	Lighting situation
	Ambient volume
	Network coverage
	Temperature
Traffic regulation	Information on speed limits for cars/cyclists/cyclists/...
	Allocation of areas to activities (moving, stopping, parking, staying, entering and exiting buildings) differentiated according to cars, trucks, light commercial vehicles, buses, streetcars, cyclists, pedestrians, micromobiles (differentiated according to autonomous rental bikes and delivery robots)
	If necessary, further information on the functions of the stay (waiting for public transport, standing conversations, sitting on benches or in street cafés, sitting on steps, playing, making music, sports activities, window shopping, etc.)

4. SUMMARY

The research project aims to collect and utilize comprehensive environmental data through autonomous mobile robots. This includes aspects such as road and sidewalk conditions, traffic volumes, and environmental factors. In three phases, requirements were specified, aggregation strategies developed, and two micro mobility scenarios prototypically evaluated. During the project duration, suitable data and sensors were identified. Potential digital business models were outlined, including real-time traffic monitoring, urban planning optimization, and environmental monitoring. The data not only forms the basis for research but also holds potential for innovative business models, with data privacy and quality playing a central role. The project aims to enhance urban mobility and quality of life through intelligent use of environmental data. As it progresses, it could open new perspectives for the use of autonomous technologies and data foundations.

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