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A KNOWLEDGE MANAGEMENT FRAMEWORK FOR IDENTIFYING INNOVATION POTENTIALS FROM USE PHASE INFORMATION

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1. Introduction

Companies are continuously looking for ways to make their products more attractive and effective. One strategy that is frequently deployed is to gather as much information as possible in order to understand how the user interacts with the product. However, the real challenge lies in how to effectively process this information to identify potential for improvement and opportunities, that is, to identify innovation potentials.

In this paper, we propose a use-phase knowledge management framework that offers a targeted and systematic approach for identifying innovation potential from use-phase information. The proposed framework is derived from knowledge management and innovation management principles that aid in organizational learning. The approach used in this paper combines and builds on these principles and tailors them to elicit knowledge from the use-phase of product-service systems. The knowledge gained is used to identify innovation potentials to offer better product and service solutions that meet the continuously changing requirements.

This paper starts with an extensive literature review that elaborates on the knowledge management pyramid and how knowledge management (KM) principles have so far contributed towards organizational learning. Next, a Use-phase Knowledge Management Framework is proposed; the framework describes how information can be systematically converted into knowledge and consequently, innovation potentials can be identified. To demonstrate the applicability of the framework, it is applied to an academic case study of an e-bike sharing system that is under development in the authors' institute as part of the Collaborative Research Center SFB768.

2. Literature review

2.1 From data to knowledge

The core of innovation lies in knowledge; to effectively drive innovations it is important to understand where, how and in what form knowledge can be gained. It is important to distinguish between the components of what is often referred to in modern literature as the Knowledge Management Pyramid: data, information, knowledge and wisdom. Several researchers and philosophers have debated on the similarities and differences between data, information and knowledge. One of the issues in distinguishing between these entities is that these are relative to each other, and therefore, cannot be defined in absolute terms. Ahmed et al. [1999] promulgate that data, information and knowledge can be distinguished from each other through two stages, namely awareness and interpretation. If observers are aware of data and its context, then this data has some meaning and becomes information. If observers can interpret information, such that it can be applied, then this information becomes knowledge. Theirauf [1999] considers data as an unstructured collection of facts and figures, information as structured data and knowledge as information about information. Davenport and Prusak [2000] argue that data must be contextualized, categorized, calculated and condensed, to become information. Bali et al. [2009] characterizes information as data together with relevance and purpose. Ackoff [1999] feels that information lies in the answers to who-, what-, where-, when-, and how many-type questions. Knowledge is perceived as a combination of framed experience, values, contextual information, expert insight, and grounded intuition that provides an environment and framework for evaluating and incorporating new experiences and information [Davenport and Prusak 2000], [Gamble and Blackwell 2001].

2.2 Principles of knowledge management

The coordination and exploitation of organizational knowledge assets through a systematic process, for acquiring, organizing, sustaining, applying, sharing and renewing different forms of knowledge of employees, so as to enhance organizational performance, create value, add benefits and enhance competitive advantage is called Knowledge Management (KM) [Davenport and Prusak 2000], [Drucker 2009]. KM involves understanding: the various sources and types of knowledge, the know-hows to promote a culture conducive to learning, sharing and creating knowledge, know-hows to make the relevant knowledge available to the right people at the right time, know-hows to generate or acquire new relevant knowledge, know-hows to manage all of these factors so as to enhance performance in light of the organization's strategic goals and short-term opportunities and threats. KM is beneficial because it is intended to: help firms learn from past mistakes and successes, better exploit existing knowledge assets by redeploying them in areas where the firm stands to gain something, e.g. using knowledge from one department to improve or create a product in another department, modifying knowledge from a past process to create a new solution, promote a long-term focus on developing the right competencies and skills and removing obsolete knowledge, enhances the firm's ability to innovate and enhances the firm's ability to protect its key knowledge and competencies from being lost or copied. Several systematic processes are prescribed for implementing KM in organizations. In the context of organizational memory, Walsh and Ungson [1991] propose the following sequence of stages: acquire, retain and retrieve knowledge. Bukowitz and Williams [2000] propose a KM model that will help define a strategy for an organization to build, enhance or cut-off knowledge assets. Based on tactical needs (triggered by opportunities or demands in market) or strategic needs (triggered by shifts in macro-environment), knowledge assets are added or removed. The strategic needs are assessed and accordingly, knowledge-based assets are built or divested. After assessing the tactical needs, if they can be met within the resources available, then existing knowledge assets are retrieved and used or the required assets are built. However, if the tactical needs cannot be met within the resources, then the lost opportunity is utilized to learn and contribute to the existing knowledge assets. Gamble and Blackwell [2001] propose a theoretical framework in the form of a KM matrix which is divided into 4 stages. Firstly, the organization must locate the sources of knowledge. This must be followed by the organization of this knowledge, which will help in the assessment of the strengths and weaknesses and ascertain the relevance and reusability. Then the knowledge must be socialized, where various techniques are used to help share and disseminate it according to the needs. Then this knowledge is internalized by applying, deciding and acting on it. Botha et al. [2008] propose a three-pronged model comprising the categories of knowledge creation and sharing, knowledge organizing and capture, and knowledge sharing and dissemination, with mutual overlap and interactions between them. Frost [2010] proposes a broad framework for knowledge management comprising discovery and detection, organization and assessment, sharing, reuse, creation and acquisition of knowledge. In the first step, the knowledge and the patterns in the available information that can potentially contain undetected or unseen knowledge within an organization are discovered. This is followed by the organization and assessment of knowledge, to better manage and to identify potentials and shortcomings, respectively. The organized knowledge is then shared with the right people at the right time. This sharing can be either push or pull, depending on whether knowledge is provided or sought by the relevant stakeholder. Knowledge in appropriate form is then shared in the organization. The shift in condition between the possession of knowledge and the act of knowing through practice, action and interaction causes the creation of new knowledge, and thus, overlaps with knowledge sharing. In the next step on acquisition, an organization tries to acquire knowledge from external sources.

2.3 Sources of knowledge

The main sources from which an organization acquires knowledge are: customers, suppliers, competitors, partners/alliances, merges/acquisitions and other expertise.
According to Pahl et al. [2006] the main stages in the lifecycle of a product are: product planning and task setting; design and development; production, assembly and testing; marketing, consulting and sales; use, consumption and maintenance; and recycling or disposal. The use phase can potentially provide information and knowledge with which the succeeding generations of product can be improved to gain better acceptance with customers and succeed in market.One potential source of knowledge acquisition is the use-phase of a product/product-service system. However this, to the authors' knowledge, has not been hitherto addressed.

3. Knowledge management for driving innovation

Stakeholders are constantly looking for ways to innovate by introducing new better products and services that identify market niches or meet market needs. Knowledge management has often been described as a catalyst for innovation [McAdam 2000]. Effective application of knowledge management principles makes the available information more explicit and hence assist in coming up with new ideas to solve known as well as unforeseen problems.
Innovation management is an area that is increasingly gaining precedence in the development process. To innovate effectively, companies are tapping into the different innovation sources to detect opportunities for introducing new ideas in order give their product a competitive edge. One potential source of information is the data that can be gathered as the product is being used, that is, during its use phase. The use-phase is also often referred to as the operation phase. Nowadays, the emergence of concepts such as the Internet of Things has motivated product manufacturers to gather data during the product deployment or use-phase. This data, if properly understood, can be a driving force for innovations. The data can, for example, expose trends about how a product is used in ways that differ from its original intended purpose. Hence, the insight gained from the use-phase can aid companies in making the right decisions about product strategies that can effectively meet the changing user needs and even come up with new solutions to meet the user needs. However, there is currently a lack of methodologies to manage the collected data, and use it to provide insight about how to improve the products and services bundles and to identify innovation potentials.

4. A framework for identifying innovation from use-phase information

In this paper, we propose a knowledge management framework that offers a targeted and systematic approach for identifying innovation potential from use-phase information. In the context of this paper, we refer to innovation as new strategies or new solutions that bring value to stakeholders.
As shown in Figure 1, the Use-phase Information Management (UPIM) framework is iterative in nature to highlight the continuous nature of innovation. It is made up of several stages that perform the following tasks:

- Obtaining information from various sources during the use-phase,
- Perceiving or understanding the information by defining KPI to provide a relevant context,
- Evaluation of the KPIs under various analysis scenarios using dynamic system models,
- Identifying innovation potential from the insight gained,
- Sharing the information with relevant stakeholders as requirements, design recommendations, etc.

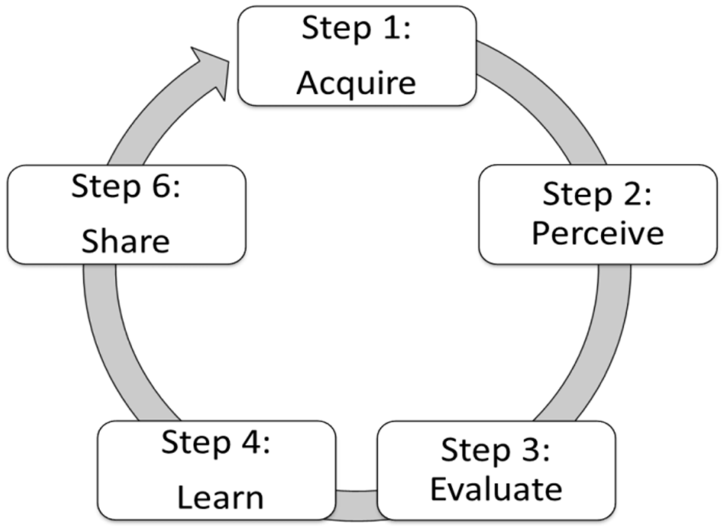

Figure 1. Use-phase knowledge management framework

In the following sections, the Use-phase Information Management (UPIM) Framework will be applied to a smart mobility e-bike sharing system that enables flexible mobility without fixed costs. The ebike-sharing systems offers the use of public electronic-bikes that the individuals can use to make trips within a designated perimeter. The users pay per use of the bike for the duration of the trip.

The e-bike is referred to as PSSycle. The PSSycle is a demonstrator under development in the Collaborative Research Centre SFB 768 in the authors' institute. The foundation of the PSSycle is a pedelec (pedal-based electric bicycle) with additional features that include an integrated software locking system, additional cycling assistance power, and a connected on-board computer for enabling user services such as payment for service, location of other bikes, retrieval and return locations.

The PSSycle represents a use-oriented product-service system (PSS) which means that, unlike the traditional approach where the product and service have decoupled ownership, the PSS provider has the product ownership, and uses the product to deliver the service to the customer. The building blocks of the PSS are hardware, software and services.

4.1 Stage 1: Information acquisition

The initial stage is to acquire use phase information, that is, to gather or obtain data from the various elements of the PSS. Since product-service systems are a type of socio-technical system, the information acquisition architecture includes components from both the social and technical domains. Figure 2 shows a high level of the information acquisition architecture of the e-bike sharing system and their high level interconnectivity. Each of the identified subsystems is linked to a stakeholder network that provide its functionality, e.g., the booking service is linked to electronic payment means, banks, etc. A detailed description of the interconnectivity and the underlying stakeholder network is beyond the scope of this paper.

- The identified sub-systems in the information acquisition architecture are:
- The User and the means by which the user interacts with the system,
- The Operational Infrastructure for enabling operations necessary to run the e-bike sharing,
- The Physical Infrastructure on which the bike operates
- The E-bike made up of hardware, software and services offered by the bike

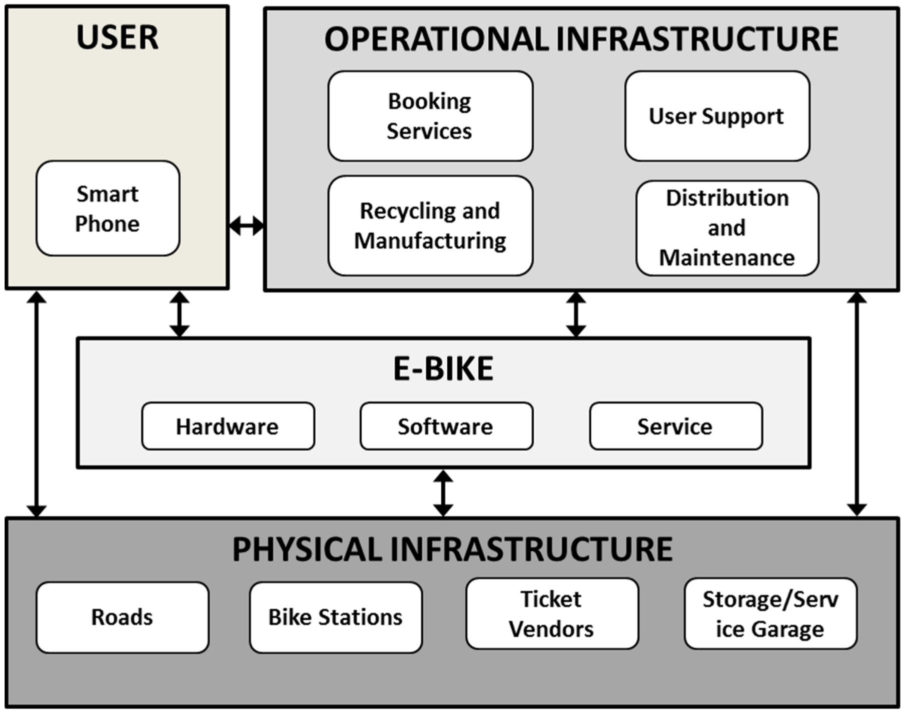

Figure 2. Information acquisition architecture for an E-bike sharing system

Information acquisition takes various forms. Information can be acquired using technical means such as telematics, sensors and data loggers. Other, non-technical forms of acquisition are by understanding the voice of customers using questionnaires, interviews, etc.

4.2 Stage 2: Perceiving acquired information

This stage is about providing the extracted information in a meaningful context that reflects the system goal achievement and service strategy.

For example, one of the main goals of the e-bike sharing system is user satisfaction. Since user satisfaction is subjective and cannot be quantified by a single value, it is necessary to identify the key performance indicators (KPI) that contribute to user satisfaction.

One factor that increases user satisfaction is the availability of the bike at bike stations as users expect mobility to be available at all times. Hence a KPI for measuring user satisfaction "Bike Availability", that is, is the number of available e-bikes per station and user.

To predict a more accurate value of user satisfaction, a weighted function of different KPIs that contribute to user satisfaction can be derived that include cost, wait time, access time, etc.

4.3 Stage 3: Evaluate

PSSs are highly interconnected complex systems, where it is difficult to predict the output or understand the implications of adjusting on or more of the system behaviour. Dynamic modelling tools such as agent based modelling offer a virtual, risk-free means for understanding the behaviour of these systems. In this paper, an agent-based model has been developed to represent the e-bike sharing system during use to understand certain behavioural aspects such as fluctuations of demand, bike distribution within the service perimeter, repair and service operations, etc.

The agent-based model represents an academic case study of an e-bike sharing system that enables smart mobility between the city of Munich and Garching in Germany. Figure 3 shows the model set up. The model parameters were projected on to the map of main routes between Munich and Garching. Several Bike stations have been allocated to various central locations in Munich and Garching. The diagram also shows a service vehicle on its way to pick up an e-bike and deliver it to a bike station.

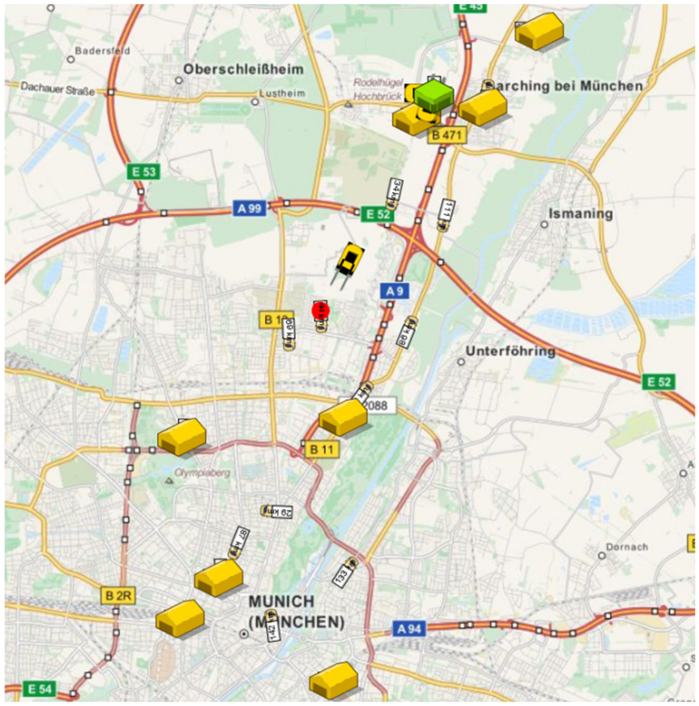

Figure 3. Map of PSSycle operation

The model can be used to effectively evaluate and optimize the KPIs identified in the previous stage. The dynamic models run various analysis scenarios. The analysis scenarios represent consistent and focused excerpts from the use-phase, and include problems that may arise during PSS usage. For example, previously identified KPIs such as "Bike Availability" can be optimized by matching the customer demand to the optimum number of bikes that need to be allocated to the various locations. Problems that may arise during usage such as failures of service vehicles are also investigated by the dynamic system model.

For this particular case study, the agent-based model was used to optimize the number of bikes at the bike stations and to identify the most intensively used routes.

4.4 Stage 4: Learn

Learning in this context is about coming up with concrete recommendations for improvements or solutions to unforeseen circumstances, thus identifying innovation potentials. This stage, investigates the implications of the outcome of the analysis scenarios and to come up with solutions to counteract the negative effects.

There are several implications of optimizing the number of bikes at the different locations such as:

- The times in which additional service vehicles are needed to relocate the e-bikes
- Number of charging units at bike stations
- Identification of need for additional bike stations
- Identification of unnecessary bike stations

4.5 Stage 5: Share

The final stage of the framework is to deliver the knowledge gained to the relevant stakeholders. The information acquisition architecture in Figure 2 can serve as a starting point for identifying with whom to share the information. In the case of bike availability, the recommendations for optimal bike allocation affect both the operational and physical infrastructures. Recommendations for improvements are conveyed to the "Distribution and Maintenance" as bike allocation is their responsibility. Also, the "Charge Stations" in the physical infrastructure must be updated to meet the demand.

5. Case study results and discussion

The agent based model identified several agents in the system, namely, the user, the bike and service vehicle, service garages and rental stations. The action of each agent was described in the agent based model. Figures 4, 5 and 6 depict the state charts that describe the behaviour of the user, the bike and the service vehicle respectively.

The user state chart shown in Figure 4 describes how any individual becomes a potential user as a result of advertisement of the bike sharing system or by word of mouth. These factors influence the demand of the bike, that is, the number of people who want to rent the bikes. During usage, the ebikes can break down occasionally and need to be picked up by the service vehicles. Figure 5 shows the service vehicle states for bringing a bike back for repair. When a message is received that a bike has broken down, the service vehicle is dispatched to collect it and bring it to the service garage.

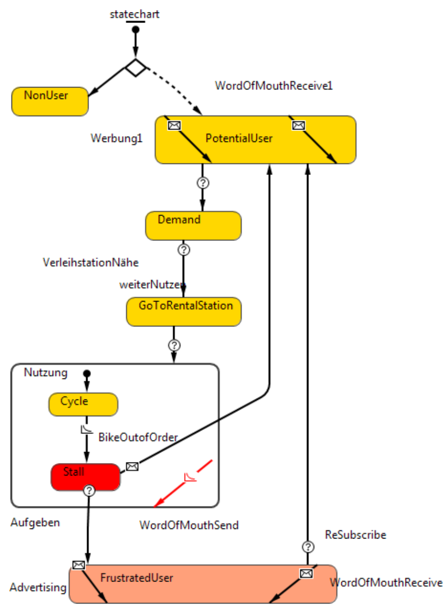

Figure 4. User state chart in agent based model

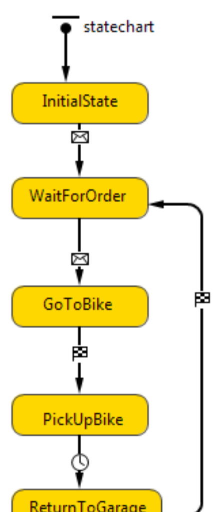

Figure 5. Service vehicle state chart

Figure 6 shows the various stated of the ebike. The ebike can be either used as a normal bike, or it can offer assisted cycling. When a break down occurs, the ebike gets taken to the service garage for maintenance and repair where it awaits the new rental at the rental station. In this particular case the rental station.

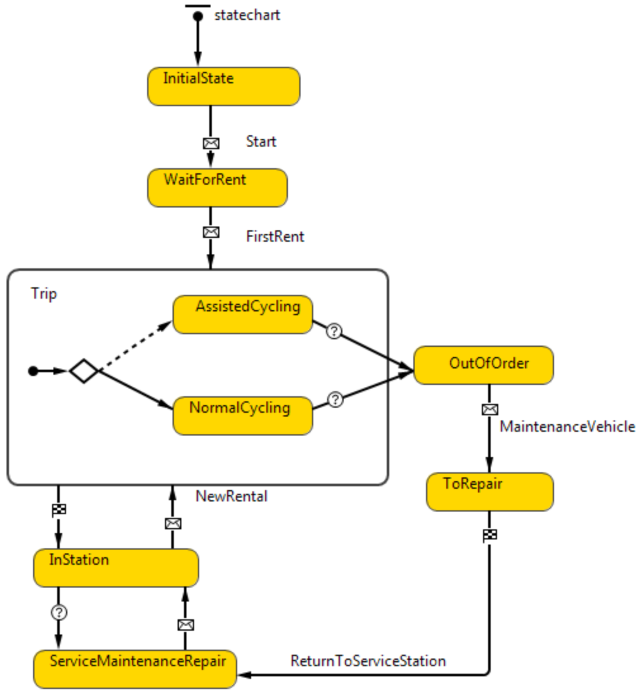

Figure 6. Ebike state chart

To run the simulation, a Gaussian distribution for predicting the bike demand from the various stations is used. In reality, this number can be obtained from sensing the number of requests received by the booking services and the locations from which the bookings were requested. Service vehicles are periodically sent out to collect bikes left along the routes and bring them back to the bike stations; the number of service vehicle in the "Storage and Service Garage" was initially set to 5.

Figure 7 shows the number of vehicles in the service garage (top) and the vehicles that are on the way (bottom) along the y-axis and the increasing frequency of the service vehicle operations along the x-axis. The graph shows that there is always at least one vehicle remaining in the service garage. From these results one can deduce that it is reasonable to have 5 service vehicles, as 4 are needed for reallocating the bikes and 1 as a back-up in case of vehicle failures or unexpected increase in demand.

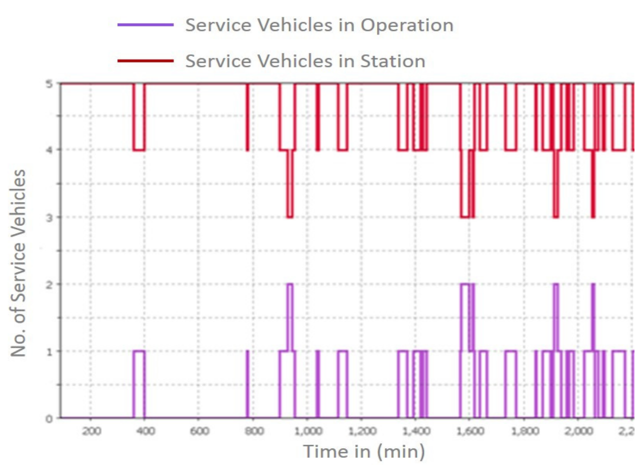

Figure 7. Frequency of service vehicles

Monitoring the number of bikes at the different stations aids in the decision making process of the optimum number bikes to allocate to each station.
The simulations in Figure 8 show that Munich Central Station is used very frequently and it can occasionally run out of bikes, whereas Garching Central Station has more bikes and less demand. Thus, the service vehicles must relocate the bikes to the more frequently used locations.

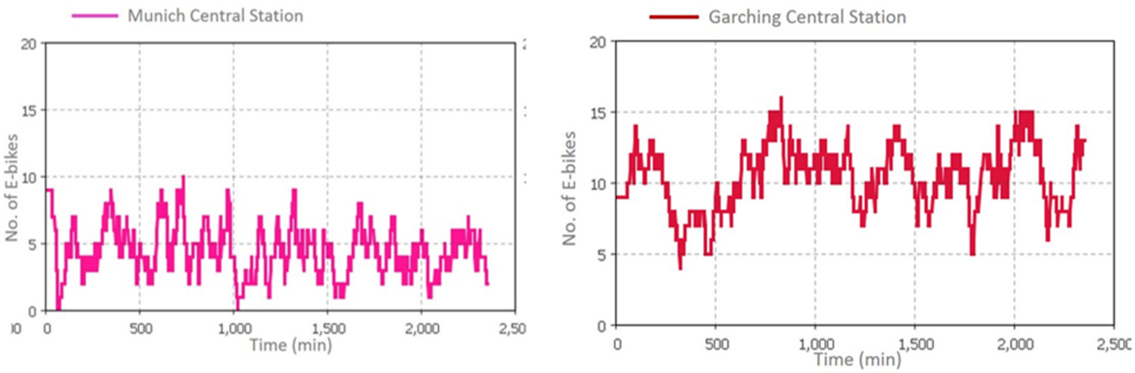

Figure 8. Bike availability in munich central station and garching central station

The case study so far concentrated on identifying innovation potentials in the service aspects of product-service systems, namely in how the product is allocated to the different bike stations and the number of bikes that need to be moved.
The methodology can also be used to offer improvements suggestions for the product design and development process.
The aim of this paper was to demonstrate that the application of knowledge management principles can be very effective in systematically identifying innovation potentials from the use-phase in product-service systems. For a comprehensive derivation of innovation potentials, future studies will focus on defining additional KPIs to represent user satisfaction as well as other aspects that are relevant to the core product and service strategies, such as sustainability, quality, etc.
Future work will also focus on using a model-based systems engineering approach such as domain specific language (DSL) to represent the system components as well as their interconnectivity. To do this a meta-model of the system will have to be constructed. Another alternative is to use a standard language such as Systems Modeling Language (SysML). The model-based systems approach will thus serve as a common platform for representing the entire sociotechnical system and provides means of looking at the system from different viewpoints.

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