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TOWARD A DESIGN APPROACH FOR INDUSTRIAL INDOOR LOCATION-BASED SERVICES (I²LBS)

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Abstract

In the context of the ongoing industrial digitization, location-based services (LBS) can play a key role in improving internal company workflows and processes and the associated supporting activities. A lack of standardized indoor-positioning technologies and complex integration with the existing infrastructure are two of the main barriers for the implementation of LBS. In this paper, we present an approach for the design of industrial indoor LBS or (I²LBS), which supports companies during the early design and planning phase, taking into account their unique prerequisites.

Keywords: location-based services, indoor positioning, design methods, features, internet of things (IoT)

1. Introduction

The evolution of information and communication technology (ICT) is the main driver behind the digital transformation of the corporate and the private world. In this context, paradigms such as the Internet of Things (IoT) and *Industrie 4.0* have emerged and been subject to substantial scientific and commercial exploitation. Although these paradigms stem from different backgrounds, they share some of the same core principles. IoT is a term that is closely related to the advent of Radio-Frequency Identification (RFID) in the late 1990s (Xu et al., 2014; Perera et al., 2014). Nowadays, the term is used to describe the vision of a worldwide network of globally interconnected devices that are uniquely addressable (Fortino and Trunfio, 2014). *Industrie 4.0*, a term coined in Germany in 2011, aims at the incorporation of digital technologies into industrial processes such as manufacturing to achieve an interconnection of machines, tools, work pieces as well as storage and transport systems to improve processes both internally and along the value chain. This is made possible through advanced processing, sensor and communication technology (Bauernhansl, 2014). At their core, both paradigms aim at the amalgamation of the physical and the digital world, the resulting systems of which are referred to as cyber physical systems (Broy, 2010). In the private space, the digitization of every-day life is visibly evolving. Communication devices and digital services have become an essential part in most of our lives. Context-awareness plays an important role in providing convenient modes of interaction and delivering relevant information for a given situation (Perera et al., 2014). Context can be broken down into primary context and secondary context, where primary context refers to time, location, identity and activity and secondary context refers to personal context, technical context, spatial context, social context and physical context, which are derived or deducted from the primary context information (Küpper, 2007).

Mobile services that put the location in the focus are referred to as Location-based services (LBS) and can be considered a sub-group of context-based services. The availability of mobile devices and accessibility of GPS (and similar satellite-based positioning technologies) have led to a widespread use of these location-based services in the B2C space. Due to technical limitations, the use of LBS was limited to outside areas in the past (Gu et al., 2009; Zhu et al., 2014). The recent emergence of accessible indoor positioning solutions, however, makes the implementation of indoor location based services feasible. Example application spaces include shopping malls, hospitals or warehouses. One area where LBS have not yet reached a solid foothold, are industrial applications. In the context of *Industrie 4.0*, however, Indoor Positioning Systems and Location-Based Services become a key enabling technology (Uckelmann and Wendeberg, 2015). With the exception of intra logistics, most companies do not use indoor positioning systems and location based services to improve their internal value added activities due to factors such as unclear potential benefits and lack of standards (Conti et al., 2016). In this paper, we present an approach for the design of industrial indoor location-based services (I²LBS) that are tailored to the needs of manufacturing companies. The presented approach aims at supporting companies during the early planning and implementation phase. As part of our research, we have conducted an extensive literature review, identified and analysed existing LBS applications (B2C, B2B and current research projects) and interviewed industry representatives about the potential uses of indoor positioning systems and the resulting location-based services. Within our research, we address the following research questions:

- How can the unique potentials of Location-based service be captured in industrial applications?
- Which elements need to be considered when designing industrial location-based services?
- How can the conceptualization process for industrial location-based services be supported?

We discuss the foundations of location-based services including a technical overview, the characteristics of indoor positioning as well as the challenges associated with the industrial implementation of LBS in Section 2 of this paper. Additionally, we present a categorization of I²LBS and provide application examples for each category. We present our 4-phase design approach in Section 3, describing each phase along with the associated tools and methods. We subsequently present a case study for the validation of our approach in Sections 4 and conclude the paper with a summary and outlook.

2. Location-based services

Location-based services emerged with the increasing availability of mobile phone services and the subsequent usage of cell-ID for emergency services. Since then, the concept of LBS has evolved into an essential part of mobile services in the B2C-sector (Küpper, 2007; Ryschka et al., 2014). Prominent examples of commercial location-based services include Google maps for navigation, the check-in service Foursquare but also Facebook friend finder. There exist many different definitions and synonyms for location-based services with most of the early definitions originating in the telecommunication sector. Service, in the context of LBS, refers to an IT service as opposed to traditional service offerings of companies (Küpper, 2007; Werner, 2014). The common ground for all definitions is the location, which is the core element of LBS. According to Junglas and Watson, LBS are services that take into account the position of an entity (Junglas and Watson, 2008). This very broad definition does not consider additional features or details of the LBS. Many authors focus on the consumer market where the user plays a central role. In this context, Gärtner et al. define LBS as a service that uses the knowledge of where a user of an information device is located (Gärtner et al., 2007). For our research purpose, we use the following definition:

> *A location-based service is defined to be a service relying on the following three aspects: the ability to infer the location of one or more mobile entities, the ability to communicate information, and the ability to use location data in order to provide the service. (Werner, 2014, p. 5)*

In his definition, Werner takes into account the possibility of using LBS for individual entities as well as for the interaction of multiple entities. He not only pays attention to the communication that has to take place to enable the service, but also the central importance of the position for the provision of the service. In doing so, he generally uses the term position information without restricting it further and possibly excluding individual position determination methods or position dimensions.

2.1. Components of location-based services

From a technical point of view, location-based services can further be broken down into several components that fall under one of three aforementioned categories: localization, communication and service provision. Figure 1 shows the high-level components that make up LBS.

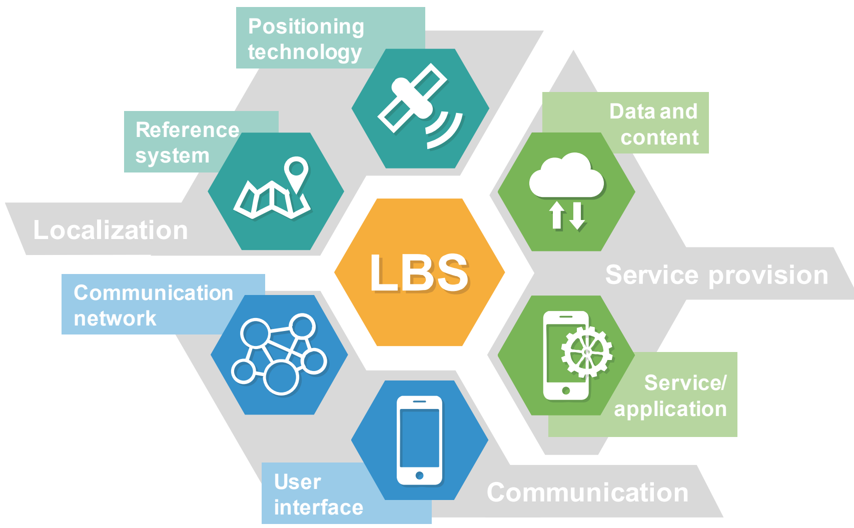

Figure 1. Components of location-based services, expanded from (Falkowski et al., 2016)

Localization comprises the positioning technology (e.g. GPS satellites) or a combination of multiple positioning technologies and a reference system, which maps the input signal to a formalized position. Examples for reference systems include 2D-maps (e.g. building plan), 3D-maps (e.g. virtual model of a shop floor) or a database (e.g. list of available conference rooms). **Service provision** is achieved by an IT service, i.e. a software application along with all the data required for the service. **Communication** requires an adequate communication network (e.g. LTE or WiFi) and a user interface (e.g. smart phone or computer). The implementation of location-based service requires the specification of each component along with a close consideration of the existing infrastructure and other requirements for a specific use case.

2.2. Indoor positioning and LBS

The availability of Global Navigation Satellite Systems (GNSS) is a driving factor for the success of location-based services. With the incorporation of GNSS receivers into computing devices such as navigation systems and smart phones, a reliable and accurate method for position determination became available to the general population. The major drawback of satellite-based positioning systems, however, is the fact that they do not reliably work inside enclosed spaces such as tunnels or buildings due to the requirement of line-of-sight (Werner, 2014; Brena et al., 2017). As a result, extending the reach of location-based services to indoor environments requires the use of alternative positioning technologies. Unlike GNSS, which has become the standard technology for outdoor localization, there exist many different positioning technologies intended for indoor use (Basiri et al., 2017; Brena et al., 2017). Torres-Solis et al., for example, classify the available indoor positioning systems by their underlying physical operating principle: Radio frequency, photonic, sonic waves, mechanical and other (Torres-Solis et al., 2010). Examples for radio-frequency-based systems include RFID, WiFi-based positioning systems, Ultra-wide band (UWB) or Bluetooth beacons, that all have specific advantages and limitations. There exist many surveys on available indoor positioning systems and their specific characteristics and limitations (Liu et al., 2007; Gu et al., 2009; Mautz, 2009; Zhu et al., 2014; Brena et al., 2017). What is missing, however, is a structured approach that helps with the selection of an appropriate technology for a specific use case, which we address in our current research.

2.3. Challenges for industrial LBS

There are various reasons why location-based services have not yet found a solid foothold in industrial applications. Many researchers have published surveys on indoor positioning technologies that compare their capabilities (Brena et al., 2017). Few researchers, however, consider these technologies together with the potential applications for an industrial context. The majority of existing LBS research focuses on commercial and not on industrial applications (Peng and Nguyen, 2010). Healthcare is one important application area where real time locating systems (RTLS) are actively investigated (Fisher and Monahan, 2012; Kamel Boulos and Berry, 2012; van Haute et al., 2016). The work that does consider industrial applications seems to be mostly limited to the area of logistics. According to a study conducted by the EU-funded *i-locate* project in 2016, the top three barriers for using indoor locations based services for the questioned organisations were privacy, the lack of standardized indoor positioning systems and the integration with the IT infrastructure (Conti et al., 2016). Privacy in LBS is the subject of ongoing research and needs to be addressed on various levels (legislation, regulation, policy, implementation etc.) (Chow and Mokbel, 2009; Shin et al., 2012; Abbas et al., 2014). In order to overcome the latter two barriers, however, we see a clear need for a systematic design approach for industrial location-based services that help companies find the appropriate solution for their unique situation.

2.4. Industrial indoor LBS examples

We differentiate between two distinctive application areas for industrial location-based services, the shop floor and the office. At the shop floor level, LBS can support value-creation processes and supporting processes such as logistics, maintenance or quality control. At the office level, the integration of LBS can improve interaction and information processes. Although the prerequisites and characteristics of the two areas can differ substantially, our approach considers both of these areas. The main reason is the aspect of scalability.

Table 1. LBS categories mentioned by different authors

LBS categories / Author	Industrial LBS					Non-industrial LBS				
	Asset management	Information provision	Security	Wayfinding	Process Analytics	Entertainment/ Gaming	Marketing/ Commerce	Social networking	Location-Sensitive Billing	Other
Werner, 2014	■	■	■	■		■	■	■		
Peng and Nguyen, 2010	■	■	■		■					
Schiller and Voisard, 2004	■	■	■	■		■	■		■	■
Steiniger et al., 2008	■	■	■	■		■	■		■	
Ryschka et al., 2014	■	■	■	■		■	■		■	
Küpper, 2007	■	■				■	■			■
Basiri et al., 2017	■	■	■	■		■	■			
Liard, 2012	■		■		■					■
Seitz, 2013	■	■	■	■		■		■		■
Conti et al., 2016	■	■	■	■	■		■	■		■
Bernardos et al., 2007	■	■		■				■		

■ Mentioned by author
□ Not mentioned by author

The objective of our approach is specifying the optimal LBS solution for a given situation while also considering additional use cases, without limiting oneself to a single scenario. In order to structure the potential scenarios, however, we researched possible classifications for industrial location-based services. Table 1 presents the comparison of the different categories for location-based services from different authors. Based on this literature review, we have identified five distinctive categories for the characterization of industrial location based services. Table 2 lists some example applications for each category, taking into account the industrial background.

Table 2. Industrial location-based services categories

Industrial LBS category	Shop floor examples applications	Office example applications
Asset management	Location based tool configuration	Automatic resource check out and tracking system
Information provision	Automatically provide maintenance instructions for the closest machine	Virtual sticky notes: Providing key information (e.g. meeting notes) based on the current location
Security	Lone worker monitoring	Access control based on physical location of personnel
Wayfinding	Guiding maintenance personnel to a specified destinations	Guiding clients/guests to a meeting room
Process Analytics	Monitoring the usage of storage areas and traffic routes	Monitoring the occupancy rate of meeting rooms

For the purpose of this article, we describe two use cases that can be implemented in an industrial environment. The first example is location-based tool configuration, falling under the asset management category. On a manufacturing shop floor with an assembly line production, workers need to use specific tools for reoccurring assembly tasks. Depending on the product and the assembly step, the tool needs to be configured in a specific way. One example is the automotive assembly process, where a torque wrench is set to different torque levels depending on the component that needs to be tightened. Since the assembly process is highly standardized, the location of the assembly step and the location of the component is predefined. As part of the proposed I²LBS, the tool is equipped with an indoor positioning receiver and additional computational hardware that allows for an automatic reconfiguration depending on the current location of the tool, thereby reducing the potential of errors and facilitating the traceability of the assembly tasks. The second example is what we call virtual sticky notes and can be classified into the information provision category. In a typical office environment, e.g. a research and development department, collaboration between experts is essential. Due to the high mobility of the personnel, however, inquiring or passing on relevant information can be cumbersome and most people stick to using email as the main means of communication. This can result in a loss of information or an untimely reaction because people cannot handle the amount of incoming emails. To address this problem, we propose using an indoor location-based service that enables the provision of information based on the current whereabouts of the addressee. Similar to leaving physical notes (i.e. sticky notes) for a co-worker to remind them of something important or ask for specific piece of information, the proposed I²LBS can leave digital notes at designated spots. Once the addressee enters the designated area, they receive a notification containing the information on their smart phone. The advantage to email or other forms of messaging is the restriction to a physical location, which acts as an information filter. By placing the virtual note at a location were the addressee can directly react to it, e.g. in front of one's own office asking them to come in, we facilitate collaboration and communication. These two use cases demonstrate the different characteristics that I²LBS can have, which also results in substantially different requirements. Our approach enables a structured design of such use cases with the aim of deriving technical requirements and selecting the appropriate technologies.

3. I²LBS design approach

With the previously described challenges in mind, we developed an approach for specifying indoor LBS applications, focusing on the early conception phase. Our first step was an analysis and classification of existing LBS use cases that are relevant for industrial scenarios. In addition to identifying relevant applications, we compared existing classifications for location-based service use cases and derived the five previously mentioned categories for industrial location-based services (see Section 2.4). Based on these categories, we identified common features and created a feature model for each category, taking into account the possible combination of different features relevant for each category, based on the approach by Kühn et al. (2014). The overall approach for specifying industrial location-based services covers four phases: Weak point identification, LBS use case selection, requirement specification and technology selection. Figure 2 shows a phase/milestone diagram for the developed approach.

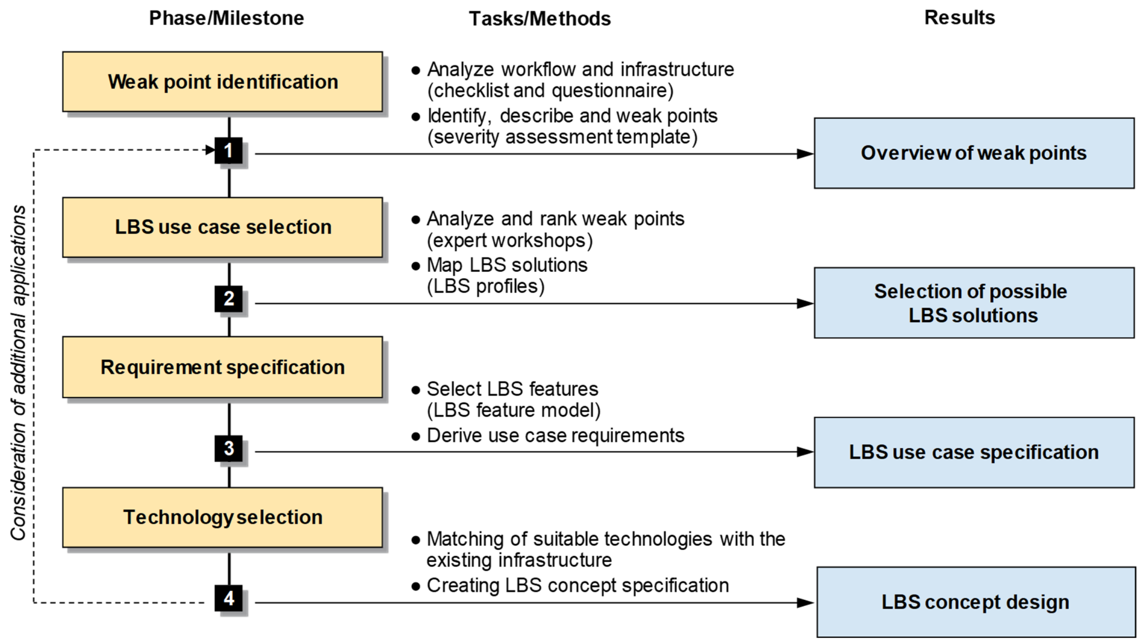

Figure 2. Phase/Milestone diagram for the design of industrial LBS

The result of our approach is an LBS concept design that can serve as the basis for an implementation contract. This facilitates the selection of potential contractors since the essential boundary conditions are determined in the course of applying our design approach. In the following paragraphs, we describe the different phases, along with the necessary tasks and methods, in detail.

3.1. Phase 1 - weak point identification

In the first phase of our design approach, we consider the current situation of the company, focusing on a selected area of interest, such as the manufacturing shop floor. We assume that existing processes have already been modelled and can now be analyzed with regard to possible LBS implementations. Following a systematic procedure, we consider non-value added activities to uncover problematic tasks or weak points within the overall process. Our method does not rely on a specific process notation but depending on the notation used and the level of detail of the process model, additional information might be required for the identification of possible weak points. We have created a questionnaire to acquire this additional information, which can be used for interviewing personnel involved in the process. The goal is to uncover the real-life process flow and not just an optimal reference process. It is therefore crucial to analyze certain process steps with the help of specific set of questions that target the non-value adding aspects of the activity. Figure 3 shows an excerpt from the questionnaire.

The questions aim at further detailing an activity/ a process step. If a question applies to a certain activity, the respective answer will help with identifying weak points. Some answers directly point out weak points (e.g. no designated storage for key resources) whereas others need to be processed further to pinpoint a specific weak point. It is important to note that the possibility for a problem to occur (e.g. a potential time delay) can in itself already be a weak point. Along with the process analysis, we document the existing IT-infrastructure for the area of interest, which covers both hardware and software solutions already in use at the site. The documentation uses a standard checklist covering all relevant aspects of the infrastructure. Using a severity assessment, we rate the identified weak points based on the likelihood of occurrence and its impact and describe the weak point in a standardized template. At the end of the first phase, we have a list of all the identified weak points and a documentation of the current infrastructure.

No.	Question
1	**Process steps requiring the (physical) interaction of multiple staff members**
1.1	Is there a specific meeting point that is always used for the task/action?
1.1.1	↳ If not: What are the steps for arranging the meeting?
1.2	Does the interaction take place on a regular basis (e.g. on a schedule)?
1.2.1	↳ If not: How is the meeting arranged?
1.3	Do the involved staff members have fixed work spaces (e.g. office desk)?
1.3.1	↳ If so: Can they be contacted (e.g. through mobile communication devices) when not at their regular work space?
1.3.2	↳ If not: What is the usual process of contacting and/or locating them?
2	**Process steps requiring the use of specific assets (e.g. tools)**
2.1	Is the asset usually kept at a specific place?
2.1.1	↳ If so: Does the asset need to be booked/reserved?
2.1.2	↳ If not: What is the process of finding the asset if it is not at the designated place?
2.2	Does the asset need to be configured depending on the location of use?
2.2.1	↳ If so: What is the process of configuring the asset?
3	**Process steps requiring specific information (e.g. documents)**
3.1	Is the information linked to a certain location and/or situation (e.g. meeting notes, maintenance
3.1.1	↳ If so: What is the process of acquiring the required information?
3.2	Is the information available digitally?
	↳ If so: Where is the information stored?

Figure 3. Questionnaire excerpt

3.2. Phase 2 - LBS use cases selection

The goal of the second phase is the selection of suitable LBS solutions that address some or all of the previously identified weak points. The first step is the prioritization of weak points, in order to narrow down the problem space. We propose conducting workshops with all relevant stakeholders to enable a mostly objective view on the list of weak points when considering all opinions. As part of the workshops, the experts can go through the severity rating and discuss possible solutions. If a weak point can be addressed through a simple non-technical solution (e.g. reorganizing certain tasks, splitting-up responsibilities) they should be eliminated from the list. At the end, only the critical weak points remain for further consideration. The experts then classify the weak points into one or more predefined types: **Long search times, long waiting time, high error rate, insufficient transparency, ineffective collaboration, waste of resources/ high resource redundancy, safety risks.** This classification supports the identification of possible LBS solutions. We have created profiles for common LBS use cases for the different industrial LBS categories that also list the type of weak points that it addresses taking into account the RTLS-MUDA concept by Uckelmann and Wendeberg (2015). Figure 4 shows the profile for location-based tool configuration.

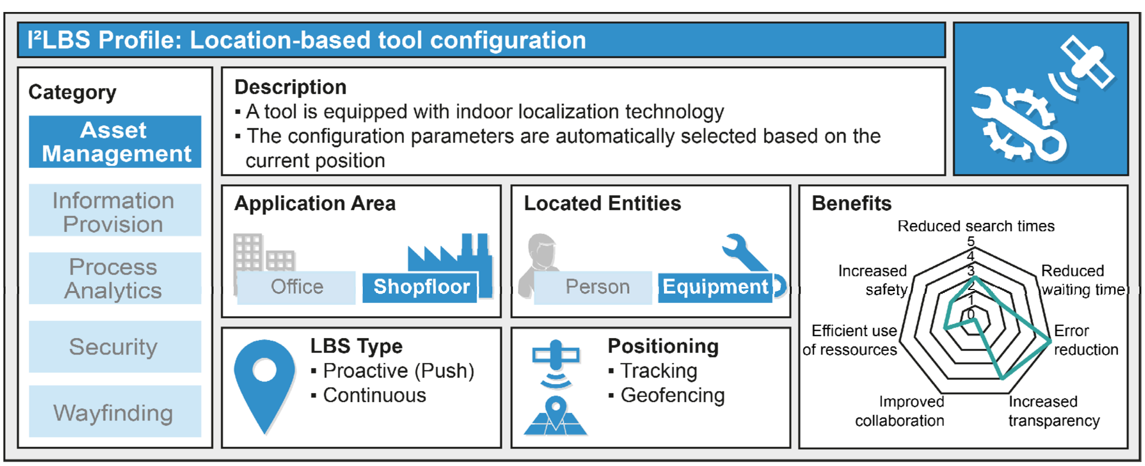

Figure 4. I²LBS profile for the use case: Tool configuration

At this stage, the LBS use cases describe the general goal and working mode without going into a technical specification. This allows for a solution-neutral selection of use cases. Since a single LBS use case can address multiple weak points, it is possible to rank the selected use cases based on their effectiveness, i.e. the use cases that addresses the most critical weak points gets attributed the highest effectiveness. Since the use cases are not directly linked to specific technologies, the implementation effort can only be estimated at this point.

3.3. Phase 3 - requirement specification

Phase 3 aims at fleshing out the selected use case selected in the previous phase and specifying the requirements. For the first step, we use a feature model of the selected use case category, which comprises all the possible feature options, in the form of a feature tree. Together with the company, we can now specify the LBS use case by selecting the required features. Figure 5 shows the excerpt of a feature tree for the asset management category.

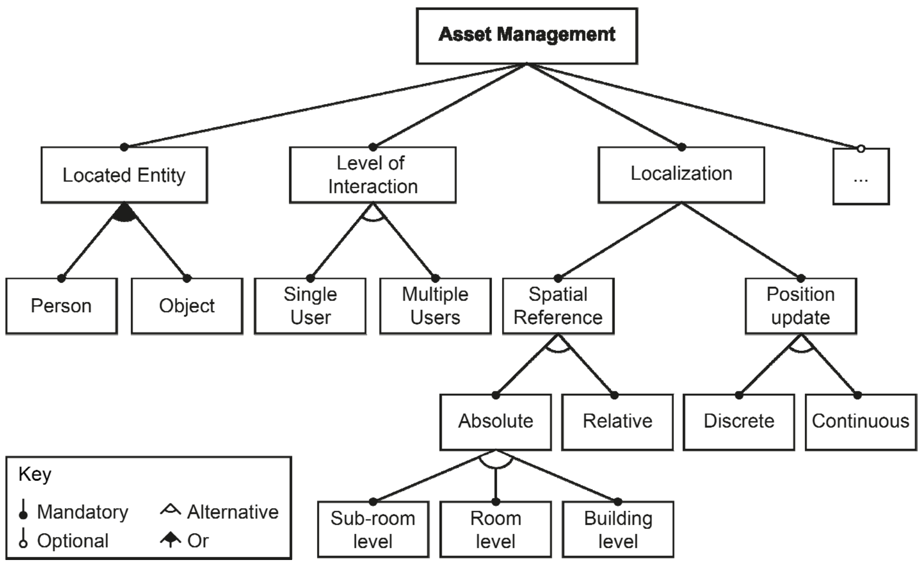

Figure 5. Extract of the feature model for the asset management category

By selecting a use case profile, we have already narrowed down the features for the use case but there is still further refinement necessary. By going through the list of mandatory and optional features, we can fully specify the functionality for the individual use case. Based on the selection, we can derive functional requirements.

3.4. Phase 4 - technology selection

In the last phase, we select suitable technologies that match our requirements and fit the existing infrastructure. The technology comprises positioning and communication technologies as well as front and back end hard- and software. For the technology selection, we are developing a technology morphology, which is linked to the use case feature models. This enables us to narrow down the technology options based on the use case specification and the infrastructure restrictions. The final LBS concept design comprises all service features along with the appropriate technologies. With this final specification, it is also possible to go through another reiteration of the use case selection to identify other use cases that can be implemented with the currently specified system.

4. Case study

As an example application for the presented I²LBS design approach, we consider a repair process based on case study, which we conducted with one of our industry partners. Figure 6 shows an excerpt form the process model created for the case study.

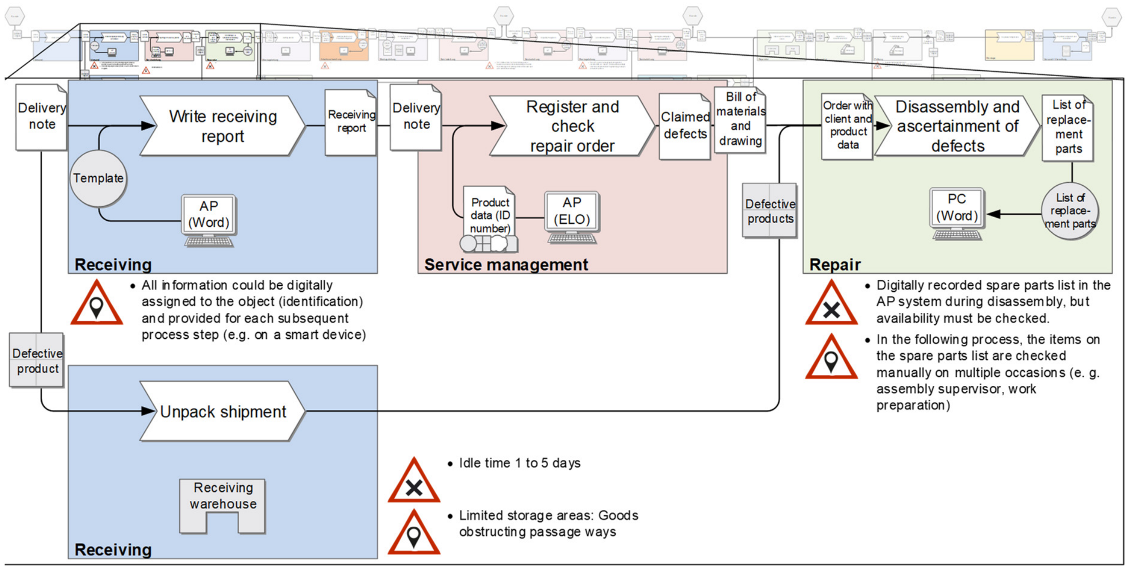

Figure 6. Excerpt from the process model of the exemplary repair process

The excerpt from the process model for the repair process shows the process steps from receiving the defective product to the disassembly of product. The process has been visualized using the OMEGA modelling method (Gausemeier and Plass, 2014) and provides a starting point for validating our design approach. In **phase 1**, we identified the weak points and potentials for the integration of LBS within the repair process and analysed the existing infrastructure. With the help of the questionnaire, we identified nine weak points in the process that could be remedied by an LBS implementation. We marked the occurrence of media disruption in the process model and added them to the list of identified weak points. In the course of workshops with relevant stakeholder from the company, we ranked all weak points and identified the two most severe weak points:

- **Insufficient transparency:** Workers involved in the repair process need to gather information on a defective work piece at various points in the repair process. The information includes the damage report, bill of materials and list of replacement parts required, among other things. Although most of this information is stored digitally at some steps of the repair process, most documentation handling is still paper-based resulting in media disruption.
- **Long search times:** The mechanics responsible for the repair work pick the defective products from a first-in, first-out storage area. The repair process comprises multiple steps involving different mechanics at various work areas. Once the repair process has started, the shop floor managers have no way of knowing at which process step a given product is currently located, since there is no registration system in place.

With the help of the infrastructure checklist, we assessed the current availability of information processing equipment, software tools as well as restrictions concerning the building, use of radiofrequency etc. Some of the main takeaways were the availability of WLAN access with sufficient coverage of the shop floor, the use of an ERP software suite for order processing and an overall static shop floor layout with only minor changes over time. These aspects need to be taken into consideration for the requirement specification in the later phase. Based on the weak points from phase 1, we identified two appropriate LBS profiles from our solution catalogue in **phase 2**:

- **Discrete asset localization:** The position of an asset is recorded at discrete intervals (e.g. designated process steps) and the information transferred to an information storage system (e.g. central server)
- **Proximity asset information:** Information about an asset can be accessed through a mobile computing device (e.g. tablet) when brought into the proximity of the asset.

Based on this selection, we derived the relevant feature tree elements in **phase 3**. As part of a workshop with company stakeholders, we selected the most suitable feature options. Figure 7 shows an excerpt from the feature selection.

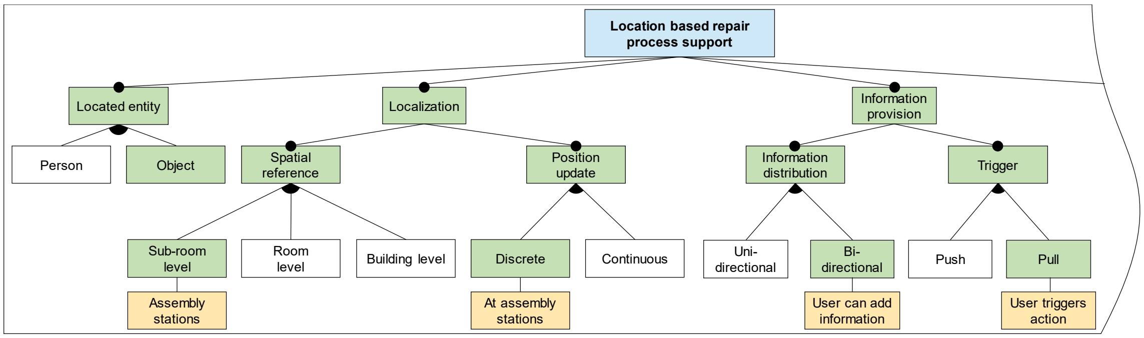

Figure 7. Excerpt from the feature tree for the case study

The feature selection along with the results from the infrastructure checklist serve as the basis for the use case requirements. As an example, the features *sub-room level spatial reference* and *discrete position update* imply a gate-based localization, which requires the distribution of terminal devices across the shop floor. This can be achieved with various technologies, which are selected in the subsequent phase with the help of the technology morphology. For the use case, we have designed an I²LBS *concept* build around distributed Bluetooth beacons NFC tags, which can be attached to the product to be repaired, and tablets used as NFC readers and as the user interface. Although some WLAN access point are already available on the shop floor, there are insufficient devices to be used for indoor positioning. To stay within the budgetary restriction, we chose Bluetooth beacons to achieve a discrete position update. The beacons are attached to the assembly stations and the signal emitted by the beacons is read by the tablets which identify the position from the beacon ID. The workers use the tablets to scan the attached NFC tag containing the identification information for the work piece. The current location (i.e. repair station) is then send to a central database. Depending on the location and the required task, additional information (e.g. spare parts list and location) will be displayed on the tablet. As a result of the I²LBS, the repair process can be streamlined and the overall transparency improved.

5. Summary and outlook

The design of LBS is no trivial task due to the complexity of the use case configuration and the vast selection of possible technologies for the implementation. We have developed a structured design approach for which supports the planning of industrial location-based services, consisting of a procedure model and supporting methods for the individual steps. Starting with the identification of weak points in existing company work flows with the support of a questionnaire and an infrastructure check list, we select suitable I²LBS application cases from our solution catalogue. The selected applications are further detailed using a feature model, which facilitated the specification of requirements. In the last step of our approach, we select suitable positioning and supporting technologies based on the requirements and the infrastructure constraints. Our approach helps capture the potentials of LBS for industrial application by considering weak points in existing work flows and matching them with possible LBS solutions. The approach addresses not only the technological aspects of LBS but also the features that need to be implemented, thus ensuring that only suitable technologies are considered subsequently. The procedure model serves supports the designer throughout the conceptualization and design of an I²LBS. Our exemplary case study shows the applicability of our design approach for the area of industrial production. In further work, we will focus on developing a tailor made process modelling and analysis method that directly incorporates the identification of non-value added activities and allows an application of our approach even without any pre-existing process analysis. In addition, we will continue the development of the LBS technology morphology, which we will integrate together with our LBS feature model into a software tool that can support the design process.

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