KNOWLEDGE-BASED ON SITE PROCESS OPTIMIZATION USING RFID TECHNOLOGY

Mathias Kadolsky, Research Assistant, Mathias.kadolsky@tu-dresden.de
Yaseen Srewil, Research Assistant, Yaseen.srewil@tu-dresden.de
Raimar J. Scherer, Professor and Institute Head, Raimar.scherer@ tu-dresden.de
Institute of Construction Informatics, Dresden University of Technology, Germany

ABSTRACT

Current field practices at construction sites still rely on manual processes for asset tracking and information handling. The result is that the information of construction processes and process states are often incomplete and not available on time. Thus, the planners are confronted with an information gap preventing efficient process planning, delays in the execution of tasks and inefficient productivity on site. Therefore, to make a convenient decision for a potential alternative solution of process planning and to perform this alternative solution, methods for continuous monitoring of all resources and analyzing of the upcoming processes are required. In this paper an approach is presented, that comprises a knowledge-based process optimization system using RFID-technology. The aim of this approach is to bridge the information gap by using RFID-technology for a continuous information stream and to manage and to analyze this information stream by using a knowledge base and a process simulation software. Here, the focus of this paper lays on the knowledge base, which represents the core of the system. It is an efficient tool for the flexible description of building parts, resources, processes and RFID-technology for ensuring the logical connectivity between the different description elements.

Keywords: RFID, process modelling, knowledge management, ontologies.

1. INTRODUCTION

The planers on the construction site have to organize site activities to avoid execution delays, increase productivity, minimize construction accidents, and improve delivery of the project on time, as well as ensure execution quality. However, many current field practices at construction sites still rely on manual processes for asset tracking and information handling, which increases craft labor hours between 16 and 18% (Torrent and Caldas 2009). The result is that the information of construction processes and process states are often incomplete and not available on time. Therefore, to make a convenient decision for a potential alternative solution of process planning and to perform this alternative solution, methods for continuous monitoring of all resources and analyzing of the upcoming processes are required. The aim of such methods is to enable the possibility of (1) detecting the location and availability of resources and building components, (2) gathering and integrating this information and deriving the current states of processes and (3) determining the next appropriate steps for process optimization at an early stage.

The objective of this research is to provide a knowledge based system supporting the planners in making decisions for the next on site process steps on time. At this, the focus of the paper is on techniques that ensure a nearly continuous flow of information to identify and localize resources and on process modelling solutions necessary to formalize the acquired information and to create the foundation for methods optimising process planning on the basis of time. These solutions comprise: (1) To allow a continuously monitoring of all relevant building components and resources throughout all construction phases a methodology is required for detecting their positions and their states undisturbed, automated and in real-time.

In this approach the Radio frequently identification (RFID) technology is preferred to collect the necessary information as a type of automatic identification technique. RFID technology has a high potential to bring great benefits in construction industry through improving real-time information, visibility, traceability, and continuous monitoring. This technology expected to create a digital link between the virtual models and the physical objects in the construction process that can improve knowledge management from design to construction operation at job site. RFID system consists of typically; RFID tag, reader and middleware. This system created by adding a unique electronic RFID tag to the physical objects including the ID and model attributes. The users access by means of mobile technology in real-time and in any location to update the information such as product states, components location and work instruction.

(2) The information gathered with RFID technology serve the purpose to keep the planning processes continuously current and to enable an early stage alternative planning. For this, all relations have to be described in exhaustive manner to avoid poor economic planning.

There exist a vast number of formal description methods for the specification of business processes.

Here, the best-known Business Process Modeling Notation (BPMN) and the Event-Driven Process Chains (EPC) lack the possibility to include the description of resources and building components in the process modeling in a way that the state of processes can be derived from a set of inference rules. Furthermore, these description methods are not suitable for interoperable use.

Due to this reason, in this approach a knowledge base is provided whose core component is realized by an ontology. The ontology offers the opportunity to define a vocabulary and a set of rules required for the description of building components, resources and processes and for ensuring the connectivity between the different description elements.

(3) With the integration of RFID-information in a semantic knowledge base the processes of a building project become transparent and from the derived process data delays in the current construction progress can directly be detected because of the lack of resources or late completion of construction work.

But in order to initiate an alternative process at an early stage upcoming delays have to be detected.

So in this approach predictive methods are applied operating on the process data of the knowledge base and estimating the duration of execution of current and forthcoming processes. There, the continuous actuality of process data improves the quality of estimation.

The research is partly funded within the FP7 European Project Trans-IND (New Industrialised Construction Process for transport infrastructures based on polymer composite components).

2. REVIEW OF RELATED WORK

RFID technology has recently become one of the leading asset management technologies. During last several years, more attention has been paid to the investigation of the RFID technology in construction industry. The early research was envisioned the potential application of RFID technology in construction such as concrete handling, cost coding and material control. Song et al. (2006) proposed a solution for tracking and location material and equipment on construction site based on RFID and global position system (GPS) technologies. Likewise, Goodrum et al. (2006) implemented the technology for tool tracking on construction site. Jang and Skibiwisiki (2009) introduced a new tracking architecture based on an embedded system for tracking construction asset (material, equipment, etc) by combining radio frequency and ultrasound signal. Klaubert et al. (2010) developed an approach based on Product data management (PDM) systems and near field communication (NFC). The concept combines the best-evaluated solutions for data management and data retrieval to generate total system for construction progress. On the view of Data-integration most of the research has focused on developing middleware systems to improve event-processing responsible for analysing, aggregating and filtering RFID data streams (Mylyy 2006 and Kim et al. 2006). Ontology-based systems are rare to be found. In this context Li et al. (2008) proposed a middleware system using an ontology for describing RFID-infrastructure.

3. RFID APPLICATION FOR ON SITE PROCESSES

Construction companies are continually challenged with ensuring that expensive assets are secure and have maximum utilization. The use of technology to improve job-site processes and asset management tool is not completely new. Barcode and labelling solutions have used since decades for tracking material not only in construction but also in industry. However, applying barcodes in construction suffer from several restrictions and drawbacks of having a short read range and durability (Goodrum et al. 2006). The major advantage of RFID technology over bar coding is more robust and able to provide both the bond between information and materials and output in electronic form that is immediately usable for unique identification or hyperlink to a database (Tulla et al. 2009).

This paper focuses on prefabricated components ship and assembly at the construction site. As the components move through the various work steps of being fabricated, stored, transported and erected at construction site. Therefore, a substantial re-entry and data synchronise at each phase is required. The fibre-reinforced polymers (FRP) as modern construction material for bridge construction presented as example for these fabricated components. Since, these components have a high initial material cost and weakness of exciting industrialised building system (IBS) which based on inefficient manual on site process and they are very sensitive to errors (Srewil 2010). Therefore, this work is driven by the "need" for accurate records of components and their status on construction site. RFID technology is one of the best solutions to detecting and monitoring bridge components on large construction site.

1 Prototype System Description

RFID technology can be classified mainly as passive tag, active or semi-active tag system. The passive tags receive power to transmit data from reader. They have cheap price, small data storage capacity up to 256 bits and short read rang (few centimetre to 2-3 meters). The active tags use a built-in battery to transmit data. Typically they are expensive, high data storage capacity and having a read rang of 20 meters to 100 meters (Erabuild 2006). Selecting the most appropriate RFID system for a particular application needs to understand this technology. All RFID systems work on the same basis and encompass the same components, but differ when it comes to frequency bands, system range and system operation (Dizaddak et al. 2008).

In this approach, the construction components tagged with a passive UHF RFID system regarding to the construction elements features, boundary conditions and their functionality in asset management tools. The link between the components from digital catalog (virtual models) and the physical objects is realized using the same ID for both. Furthermore, propose the appropriate readers that can be used in the different product phases.

For tracking construction components in different phases, a holistic approach is required as illustrate in figure 2.The RFID tag is attached to the selected element whereas the system provide the same unique identification (ID) as in the digital catalog for each component written onto RFID tag. A RFID reader / writer can capture the ID and necessary data for each item. Meanwhile, a RFID reader will be installed at manufacturing site (off site) to register RFID tags and then tags information is synchronized to the server to change the status of element if any. Another reader is installed to tracking and tracing the components in the transportation phase. At transporting phase, the reader keeps tracking the components and enables the location identification with combination of GPS tool and the possible delivery time. As soon as the components are arrived at the job-site, the RFID readers on the gate read tags information and synchronize to the central server. The job-site gate uses to control access to the construction site and to record the arrival and departure of trucks, egress material and personal. The information stored in central database. This gate typically encompasses four stationary readers. The critical factor here is the reliable identification at large distances with various tag position and orientations (Wolf-Rüdiger and Gillert 2008)

2 Localisation Techniques

For logistic purpose in this approach, the job-site will be dividing into job sectors. Each sector is labelled with an active UHF RFID tag. After creating job-site sectors, the project schedule is reviewed and the sectors schedules are prepared. One or more of these sectors may be used for fill area, components and material laydown areas (figure 1). This is a great tool to help in job-site layout and planning for increase job-site productivity. Each machine in construction site mounts with RFID reader. Therefore, the machine and components are driven into accurate job-site section. The components, which labelled with passive tags, arrived at the proper job-site sector. Each element is recorded and identified by the foreman using a portable reader. This accurate data can be wirelessly transmitted to a database with instant web based access to the database that contains the total scope of work.

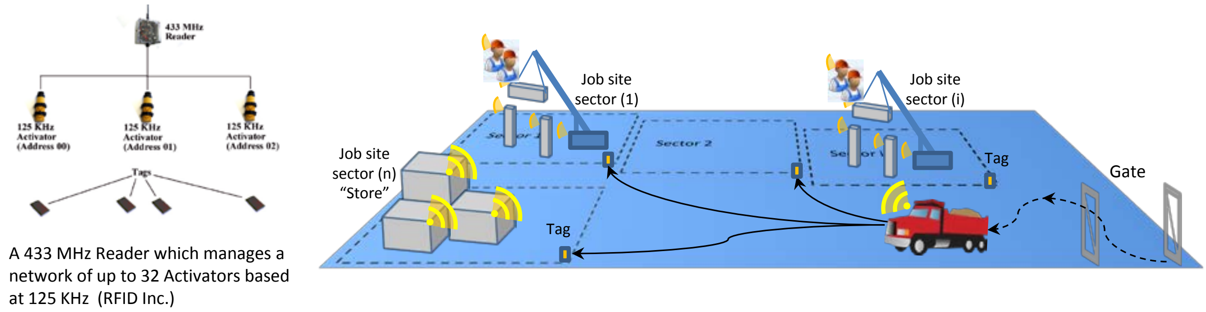

Figure 1: Products delivery to the exact job-site sector based on RFID label technology

3 Supporting Techniques

According to the RFID's ability tracked construction elements and equipment in this environment, the use of two different readers and two types of tags would be necessary. The two reader types are stationary RFID reader used to construction site gate and portable RFID reader mounted to the machine and for foremen at job-site. Furthermore, two types of RFID tag proposed a passive UHF RFID tag and active UHF RFID tag to solve the following automation identification problems:

- Passive tags mounted to the shipping construction components, containers, etc. Operating at (865.6-867.6) MHz and complying with ISO18000-6C (EPC Gen 2) or ISO18000-6B standards.
- Active or semi active tags identified job-site sectors (for example, tags operating at 433 MHz).

A solution based on control of the communications by the reader (so-called reader-talks-first or RTF protocols) will be used to communicate the RFID tags in different sectors. The benefits of RTF solution include the following (Bolic et al. 2010):

- No hard limit on anti-collision capability.
- Less so called "tag pollution",
- Ability to dynamically respond to changes in the read scenario.

An instance for RTF protocols solution can be seen in the figure 1, a 433 MHz Reader which manages a network of up to 32 Activators based at 125 KHz. The Reader will turn on each Activator in sequence in very short bursts of time, if there is a Tag or Tags within the Activator's vicinity (1-7.5 meter range dependent on Activator type), said Tag will be excited by the 125 KHz wake up signal and then begin to transmit its data via 433 MHz back to the Reader at distances of 18 to 60 meters (Reader dependent) (RFID Inc, n.d).

4. SYSTEM ARCHITECTURE

The primary task of the suggested approach for a knowledge-based process optimization using RFID-technology is to support the planer's decisions making namely the current and upcoming on-site processes.

Therefore the cooperation of all partners involved in the logistic processes is required. This concerns the several component manufacturers, the transport companies and the rental companies for construction vehicles and construction equipment. To keep the processes constantly correct and up to date it is essential to receive their information about the location and the state of the necessary resources. This information, which can be generated by RFID-technology and its application as described in the last paragraph, is consolidated and managed in a knowledge base appropriate for this purpose.

The actual optimization of the processes is realized by means of process simulation. Thereby the potential applications of simulation range from early detection of bottlenecks to analysis of alternative processes to derivation of optimization measures. Here, the required simulation model is generated from the data which has been introduced to the knowledge base and the additional data produced by inference techniques.

To cope with the formulated requirements in this approach a system consisting of three components is proposed: RFID-Management-component, knowledge-base and process optimization component. Figure 2 illustrates the RFID information system.

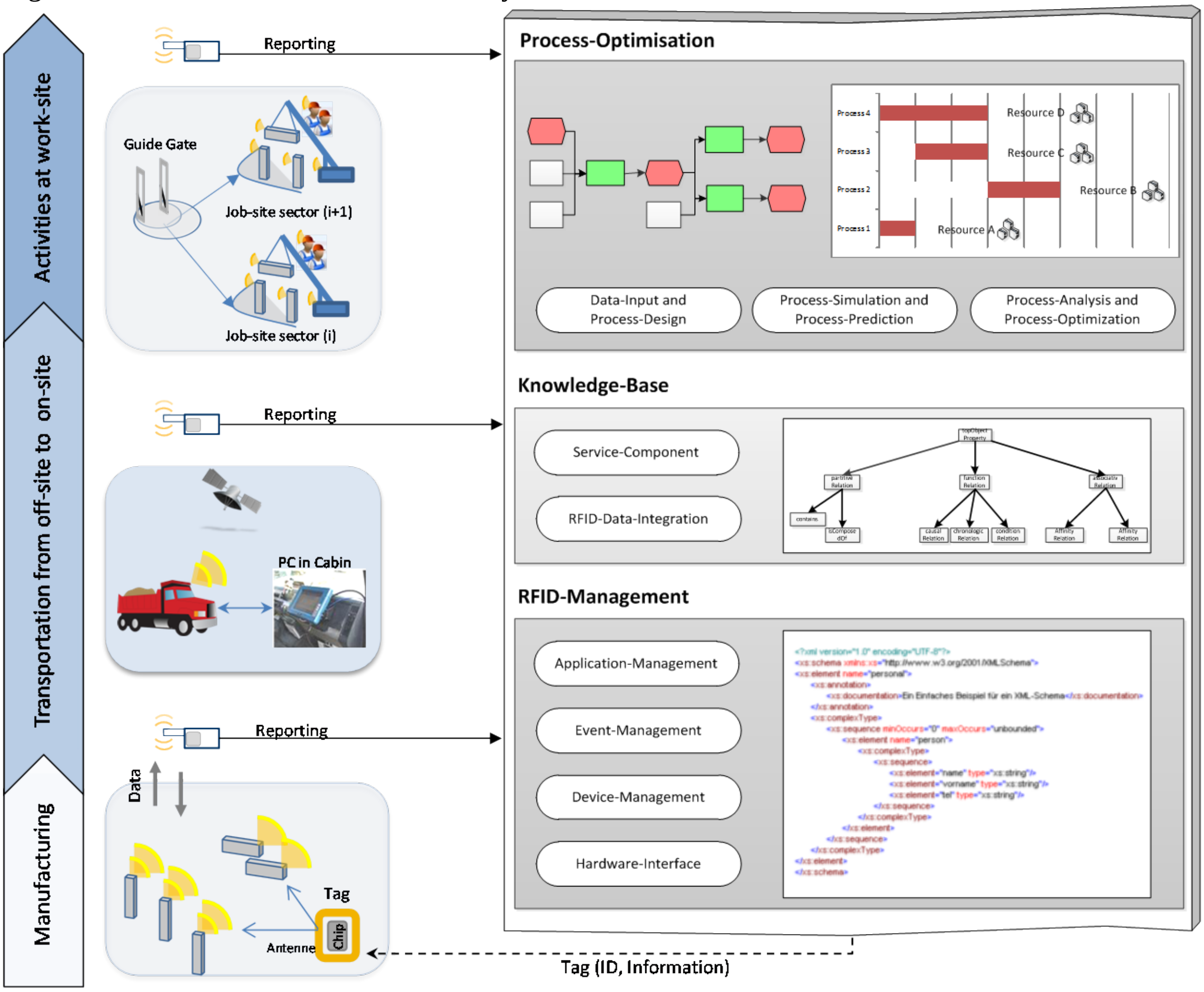

Figure 2: Architecture of RFID information system.

1 RFID-Management-Components

The RFID-Management-Component function is to connect the knowledge base with the RFID readers. This component enables the direct control of several different readers and the real-time processing of bulk data produced by the large number of read procedures. It follows modern solutions of RFID-Middleware implementations running on local servers and is divided into four sub-components: Hardware interface, device management, event management and application management.

The hardware interface is a common interface for RFID-communication hardware. It recognizes and supports different heterogeneous standards like EPC (Electronic Product Code) and ISO RFID standards, so that readers and transponders can be added simply without regard to specific read and communication standards.

The device management is responsible for all tasks relating to the connection and management of the devices. This includes the configuration of the devices, in order to add, remove or to quick adapt the devices to the new conditions, the monitoring and the technical diagnosis of the reader in real-time operation, in order to capture functional disturbances and the utilization rate of readers and the visualization of selected reader properties.

It is the task of the event management to convert the incoming raw data (events) into a homogeneous format, to filter them and to route them to advanced applications. Therefore, the filtering comprises the sorting out of unauthorized, invalid and redundant events.

The application management realizes a common interface for the connection of third-party applications like the knowledge base. This component is organized as a service orientated architecture

(SOA), which provides concrete service implementations to operate readers and to exchange event data directly from the application. Furthermore, there are standardized and the wide-spread formats like JMS, XML, HTTP and SOAP as access protocols available.

2 Knowledge Based Integration

The idea of the knowledge base (figure 3) is to combine semantically subject-specific contents with RFID-based technology and applications at the ontological level with the aim of horizontal analyses of all information in real-time.

Although more comprehensive middleware solutions contain methods to transfer the RFID-raw-data into business processes and to annotate them with corresponding logic, the semantics, which are used, are not homogenous but varies depending on the producer. The advantage in the choice of an ontological model is that it provides constructs like concepts, relations and rules enabling the formalization of relationships between events and specific concepts and of reasoning rules based on these dependencies on a fast and intuitive way. This allows an uncomplicated homogenization of the different heterogeneous forms of descriptions used in several middleware solutions and process applications.

The developed knowledge based integration approach here is very generic and not only suitable for application in the field of construction site management. Thereby the core component of this approach is represented by the RFID-integration-ontology consisting of ontology-entities and inference rules. Apart from the typical service components of a knowledge base the integration component integrating RFID-technology in terms of content operates on this ontology.

The user circle is made up of knowledge engineers, planers and ordinary users. The responsibilities of knowledge engineers comprise the design and the implementation of the core-ontology. It means, the development of the ontology-schema including the concept and property structures and the development of a set of core-rules. The planer focuses on issues in the area of modeling concrete facts. His work is restricted by the specifications of the core-ontology. The ordinary user can only operate on the given structures of the ontology. Therefore search- and reasoning methods are offered.

The most important tasks of the RFID-supported knowledge base include the modeling and the updating of knowledge. Below, we will briefly introduce how these tasks will be managed by the described architecture.

Modeling of knowledge:

> The integration of RFID-technology during the modeling phase is depicted exemplarily from the point of view of the ontology-engineer. At the beginning he conceptualizes and implements via schema-editor and core-rule-editor the ontology-schema and the core-rules, which remain unchanged in their further applications. The development of ontology includes the definition of concepts and the restrictions of concepts, which correspond to RFID-reader and reader-commands or transponder and tag-data. After the successful checking for consistency by means of schema-reasoning-engine sets of mapping-rules has to be specified connecting the ontology with the presented RFID-Management-Component or other middleware-software.

Updating of knowledge:

> The automatic updating of the ontology with RFID-data is the most essential feature of the knowledge base. The updating process starts with the receipt of tag-events or reader commands. But before these data will be integrated in the ontology, the correct set of mapping rules is identified. In addition, the events with an outdated time stamp are sorted out. After successful integration, further update steps derived from the transmitted data can be executed by the updating-module and the reasoning-engine interpreting the corresponding rules. Basically, new process and component states as well as new relations describing the location of a tag are identified and modeled during the update procedure. Finally the ontology is getting checked for defined conditions. Such a condition check could, for instance, contain the controlling of the correct process sequence. If the condition check failed a corresponding warning message will be generated and sent.

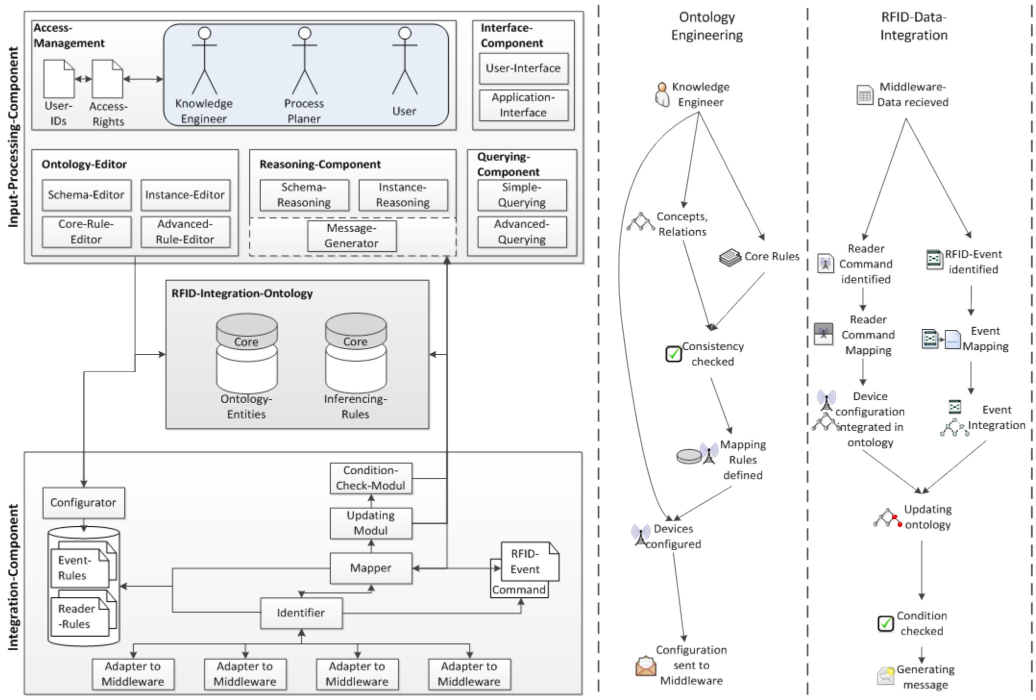

Figure 3: The knowledge base architecture, ontology engineering and RFID data integration

3 Process Optimization

Whereas the knowledge base essentially serves to provide a homogeneous and consistent structure with up-to-date content for an interoperable use, the simulation software is a suitable software for analyzing processes and process variants and finding an optimum process. As application software for the knowledge base it uses the stored information for generating the necessary simulation model.
The result of the following simulation is a listing of possible processes, which are evaluated on selected criteria (process duration, resource utilization, etc.) and sorted by them. At the end, the planer selects a process from the list, which is optimal from his own point of view, and updates the ontological model of the knowledge base. In particular the RFID-data, supporting the process planning, will improve the quality of optimization measures.
The simulation process starting with the generation of the model and ending with the sorted listing of processes is very complex and will not be discussed here. The focus of this paper lays on the ontological Integration, which is detailed in the following section.

5. RFID-INTEGRATION ONTOLOGY FOR JOB-SITE-PROCESSES

The ontological model of RFID-based job-site processes describes the assembly of prefabricated components. Because of the identification of the individual process stages all contents are required addressing the lifecycles of prefabricated components from leaving the factory to the final assembly stage. Figure 4 shows a graphic representation of the underlying lifecycle relevant for the ontology development in this approach. The presented lifecycle focuses the core processes: component loading, transporting, storing and assembling. These processes are assumed as idealized, so process disturbances and technical disturbances do not find consideration. The lifecycle begins with the “component loading”-process at the factory. As shown in the Figure 4, a component is registered as “loaded” if the RFID-tag mounted on the component is in the range of the truck reader and the GPS position of the truck is near the factory at the same time. If the component tag is detected by the RFID-gate at the main-entrance of the factory the state changes to “Transportation to job site”. Alternatively, this state can be determined by combining the information of the truck reader and the GPS signal. The GPS signal indicates the position of the truck outside of the factory and the reader identifies the loaded component, which can be associated to this position.

The other processes can be identified in a similar way. But finally, the proper assembly process should be mentioned, because in this case the system state “Component assembled” is indicated with a delay relative to the real state. So a component has the system state “Begin assembly” as long as the crane picks up a new component and the dependency between both components is identified as predecessor-successor-relation.

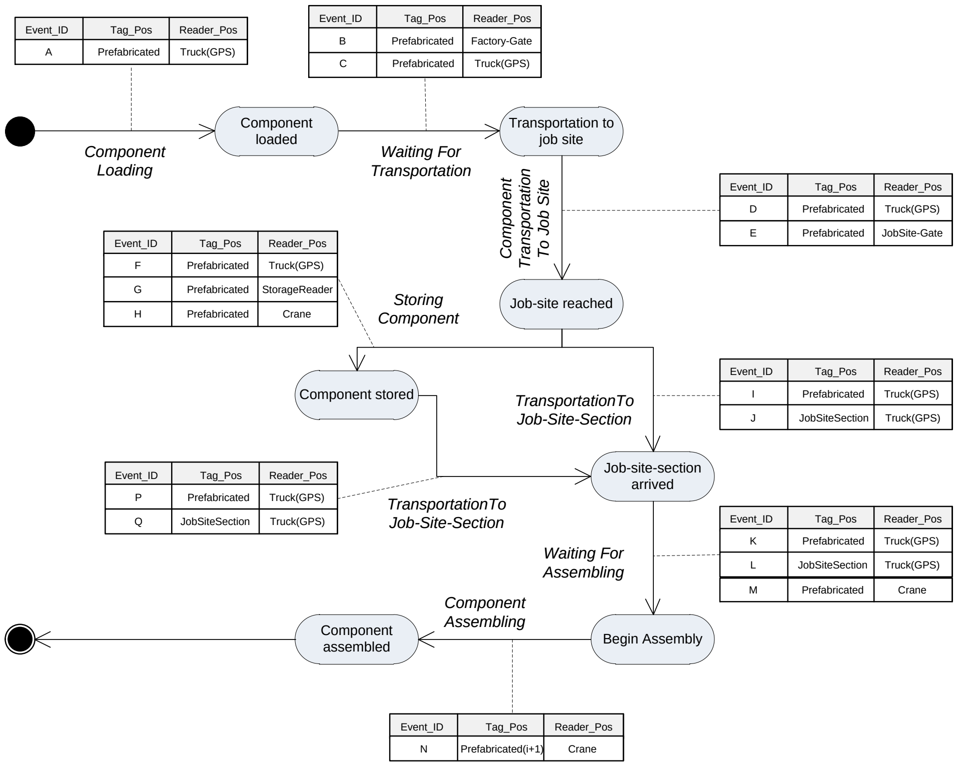

Figure 4: A graphic representation of the lifecycle of a prefabricated component

Our solution for an ontology resulting from the presented lifecycle and the involved processes is illustrated in figure 5.

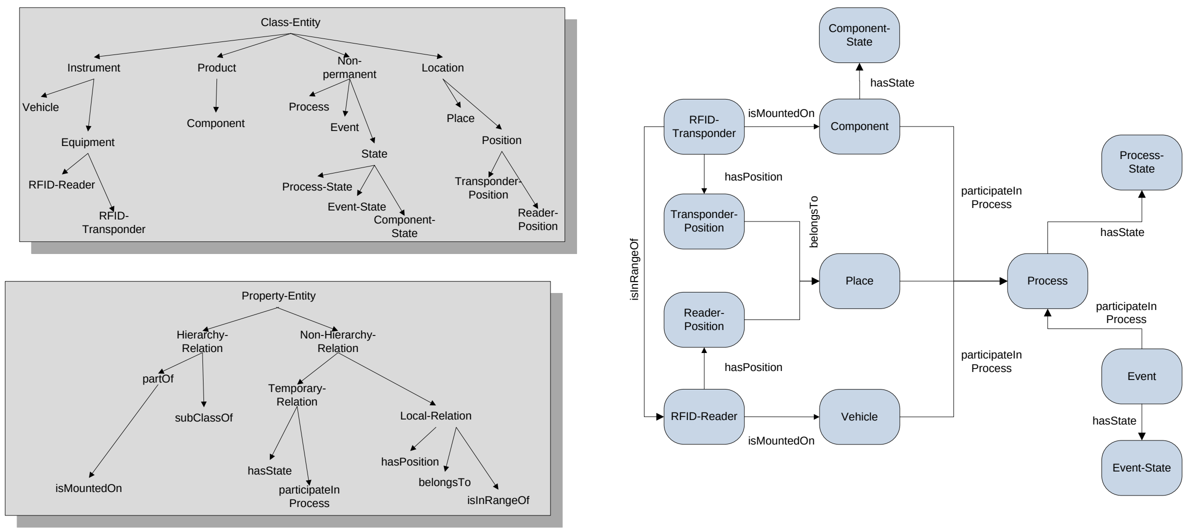

Figure 5: Ontology for on-site processes

The core element of the ontology is the concept of process connecting the concepts of component, event, place and vehicle and establishing a relationship between each other. In addition, the dynamic aspect is introduced by RFID-technologies, their representations (RFID-Reader/Transponder, Reader/Transponder-Position) and their interactions (isInRangeOf).

To identify a process and the corresponding process state the information of the involved events is required. So a process has started, if all start-events have occurred; the process is completed, if all end-events took place. When a triggering event exists, the corresponding process can be derived from the location of a component-tag and the location of a reader associated to a vehicle or a place. Furthermore, process dependencies provide information about the event state. So if the start event of a process has occurred and the process has been started the direct ancestor processes has to be completed, as already mentioned above.

The updating-module and the reasoning-component described in the preceding section interpret rules including such aspects in a formal language and derive the current states for the components, the events and the processes. Thus, for the given lifecycle and the seven component states the inference rules can be represented in the language SWRL (Semantic Web Rule Language). Exemplarily for the process "Component loading" corresponding to the component state "Component loaded" an inference rule will be formulated in SWRL:

$$\begin{aligned}
&\bigwedge\Big(Process\big(LoadingProcess\big), Event\big(LoadingEvent\big), Place\big(Factory\big), Process-State\big(LoadingProcessState\big),\\
&Event-State(LoadingEventState), Component-State(ComponentLoadingState),\\
&participateInProcess(LoadingProcess, LoadingEvent, Component, Vehicle, Factory),\\
&hasState(Component, ComponentLoadingState), hasState(LoadingEvent, LoadingEventState),\\
&\qquad hasState(LoadingProcess, LoadingProcessState),\\
&isMountedOn(RFID-Reader, Vehicle), isMountedOn(RFID-Transponder, Component),\\
&\qquad isInRangeOf(RFID-Transponder, RFID-Reader),\\
&hasPosition(RFID-Reader, Reader-Position), hasPosition(RFID-Transponder, Transponder-Position),\\
&\qquad belongsTo(Reader-Position, Factory)\Big)
\end{aligned}$$

$$\begin{aligned}
&\Rightarrow ComponentLoadingState.Loaded\\
&\Rightarrow LoadingEventState.EeventTriggered\\
&\Rightarrow LoadingProcessState.ProcessStarted
\end{aligned}$$

The SWRL-rule describes the relationship between the concepts of the ontology as shown in figure 5 via logical conjunctions. To substantiate the selected process the relevant instances of the classes and their relations are specified. In this context the "isInRangeOf"-relation plays a special role. The loading process started when the RFID-tag is detected by the truck reader, so this relation is the triggering entity.

If all terms of the conjunction have been fulfilled the state of the component is updated and set to "Loaded". This implies that the loading-event is triggered and the loading-process is indicated as "started".

6. CONCLUSION

The overall goal of the research is to optimize the construction processes on-site. For this purpose, methods are identified that may improve the detecting and monitoring of components and equipment and the analyzing of the gathered information. To bridge the information gap, the planers are confronted with on construction site, RFID-technology is the preferred solution for ensuring a continuous information stream. In this paper RFID-technology has an important role in optimizing on-site processes. It is used for tracking and recording building components status in all production phases: shipping, storing, and on-site assembling. Furthermore, this technology is provided for the identification of processes and their states. To convert, filter, manage and analyze the incoming data of RFID-technology a knowledge management system is proposed comprising three components: RFID data component, knowledge base and optimization component. The focus in this approach lays on the development of this knowledge base especially on the underlying ontology. The ontology describes in a formal matter the contents and relations relevant for modeling on-site processes. It creates the possibility to connect RFID-technology and its information with the aspects of construction site managing. The advantage of this kind of modeling is to keep the process information up to date by interpreting the contents. The ontology presented in this paper shows a prototype model for on-site processes. However, not all on-site scenarios are considered in this approach, for instance, the process disturbing resulting from the technical problems (i.e. tags missing or tags breakdown, etc). In addition, other open questions that may be subject of further research still exist. One aspect is considering complex structures (i.e. component systems) resulting from partitive relations in a dynamic environment.

ACKNOWLEDGMENTS

The presented research is partially funded by the FP7 European Project Trans-IND. This support is gratefully acknowledged.

REFERENCES

Bolic, M. et al. Eds (2010) “RFID Systems: Research Trends and Challenges.” *John Wiley and Sons*.

Dziadak, Krystyna; Sommerville, James; Kumar, Bimal (2008) “RFID based 3D buried assets location system.” *ITcon Vol. 13, Special Issue Sensors in Construction and Infrastructure Management*, pp. 155-165

Erabuild (2006) “RFID in construction; review of the current state of Radio Frequency Identification (RFID) technology, its use and potential future use in construction”, *ERABUILD final report*

Goodrum, P.M., McLaren, M.A., Durfee, A. (2006) “The application of active radio frequency identification technology for tool tracking on construction job sites.” *In Automation in Construction*, Vol. 15 Iss: 3, pp 292-302.

Kauko Tulla, Pentti Vähä, Tapio Matinmikko, Anne Tolman, Veli Möttönen (2009) "RFID technology changes FM services deliveries", *Facilities*, Vol. 27 Iss: 11/12, pp.457-468

Kim, Y; Yoo, J. and Park, N. (2006) “RFID Based Business Process Automation for Harbor Operations in Container Depot.” *In Proceedings of Industrial & Manufacturing Engineering Graduate Research Symposium at Wayne State University*, pp. 213-226, Detroit, USA.

Klaubert, C.; Schorr, M.; Günthner, W. (2010) “Real time construction progress control using NFC.” *In proceeding of the Systech 2010*; Ciudad Real, Spain.

Li, Zang; Chu, Chao-Hsien; Yao, Wen (2008) “SIP-RLTS: An RFID Location Tracking System Based on SIP.” *In: RFID, 2008 IEEE International Conference*, pp.173-182.

Mylyy, Oleksandr (2006) “RFID Data Management, Aggregation and Filtering.” Hasso lattner Institute at the university of Potsdam, Germany.

RFID Inc. (n.d) “Extend-a-Read Next Generation Release of Active Tag RTF Systems for Asset Applications”.

Song, J., Haas, C., and Caldas, C. (2006) “Tracking the location of materials on construction job sites.” *Journal of Construction Engineering and Management*, Vol. 132 Iss: 9, pp. 911-918.

Srewil Y. (2010) “Application of business process modelling approach for FRP bridge management.” *In proceeding of 22. Forum Bauinformatik* 29 Sept. - 1 Oct. 2010, Berlin, Germany.

Torrent, D. and Caldas, C. H. (2009) “Methodology for Automating the Identification and Localization of Construction Components on Industrial Projects.” *Journal of Computing in Civil Engineering*, Vol. 23 Iss: 1, pp. 3-13.

Wolf-Rüdiger, Hansen and Gillert, Frank (2008) “RFID for the Optimization of Business Processes.” *John Wiley & Sons Ltd*, England

Won-Suk, Jang and Mirosław J. Skibniewski (2009) "Embedded System for Construction Asset Tracking Combining Radio and Ultrasound Signals." *Journal of Computing in Civil Engineering* Vol. 23. Iss: 4, pp. 221-229