Assessing the Need for Storing Data on Radio Frequency Identification (RFID) Tags

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ABSTRACT: Radio Frequency Identification (RFID) technology has been used within multiple research projects for identification and tracking of components in the construction industry. Although RFID has on-board data storage capacity, not all the studies used this capacity to store some object-related data directly in the tag. In some of the case studies performed, RFID tag was used only as an identifier for tracking various objects or for matching the related object with the additional information that is stored in a remote database. In this paper, the goal is to determine under which conditions an RFID tag needs to be used as a local data storage unit. To identify these conditions, previous research studies that were performed in the construction industry were investigated. The characteristics of cases that were described in the studies were identified and data storage needs were determined. Also, types of information items that were stored in the tags were identified. The results show in which types of cases RFID was used to store additional data. In addition, the advantages and disadvantages of storing data on the tag and on a remote database were discussed.

1 INTRODUCTION

Radio Frequency Identification (RFID) technology is used for identification of objects and for storing related information on the components. Large on-board data storage capacity of some tags allows for additional data storage on a tag attached to a component and enables direct data access from the object. On-board memory can also be integrated with on-board environmental sensors for automatic recording of a history of events to a tag (Karygiannis et al. 2007).

In construction industry, the RFID technology has been used within multiple research studies for identification and tracking of components and related information. As these RFID applications are examined, it is observed that there is an ongoing debate as to whether the necessary data should be stored on tags or on a network. In some studies, despite the on-board data storage capacity, RFID was only used to replace barcode technology by storing a unique identification code on the tag (ref ver). If there were additional data that was needed to be stored in relation to the object, this data was kept in a remote database and the unique ID on the tag was used to associate this object with the data. On the other hand, in some of the studies object-related data was stored directly on the tag that is attached to the object itself and data was accessed from the object (Goodrum et al. 2006, Ergen et al. 2007a). In this data storage approach, the object-related data is accessible without the need for a connection to the database.

Both approaches have advantages and disadvantages and require different types of RFID technologies. In some cases, network accessibility, might not be always provided throughout the lifecycle of a component within the construction phases. For example, wireless internet signal integrity lacks in basements (Ko 2008)). In addition, an existent network may not work efficiently due to a failure or disaster such as an earthquake and hence making the data on network inaccessible (Yabuki et al. 2002). Moreover, users that have privacy concerns would want to control when private data is shared. Therefore they might prefer that it remains on the tag and not in a database if the risk of storing data on tags is less than the risk of opening their networks to external entities (Karygiannis et al. 2007). On the other hand, storing all related data on tags can be disadvantageous in terms of cost, since it requires relatively expensive active RFID systems due to their higher memory capacities.

The aim of this paper is to determine under which conditions storing data on the tag is more appropriate for the construction industry and what types of data is stored in different cases. To determine these conditions, both research studies and industry applications that were performed were investigated for the construction industry. The characteristics of each case and their data storage needs were identified. Moreover, the types of information groups that were both stored in databases and on tags were identified for construction industry.

2 DATA STORAGE APPROACHES IN RFID SYSTEMS

Several types of RFID systems are available for different data storage needs. In the following section, three main data storage approaches and the types of RFID systems that were used in those approaches are described.

2.1 Storing data in a remote database

In this approach, RFID tags basically replace barcode labels and only a unique object ID is stored on the tag. Object ID is used to associate the object with the related data that is kept on a remote database. EPCglobal Network is a commonly used example of this approach in retail sector (Diekmann et al. 2007). The EPCglobal, formerly the MIT Auto-ID Center, is a non-profit organization that achieved standardization of Electronic Product Code (EPC) technology. EPC is a serial number created by the Auto-ID Center, which has digits to identify the manufacturer, product category and the individual item. Each RFID tag is equipped with a unique EPC. The EPC functions as a pointer and it references object-related data that is kept in the network within the supply chain.

In this approach, ID that is stored in the tag is permanent and therefore, updating is not needed. Consequently, usually WORM (write once read many) tags are used and a unique ID is prewritten on them. Since only a small memory is needed to store an ID, passive tags, which have limited memory, are usually selected in this approach unless longer read distances are needed. Passive tags do not have batteries and are smaller and less costly compared to active tags.

2.2 Storing data on a tag

The “data-on-tag” approach is based on the idea of integration of the object with related data. In this approach data is decentralized and made available with the object itself. The storage of additional data on the tag serves four main functions: (1) Information function (2) Documentational function (3) Temporary storage function (4) decentralized control function (Melski et al. 2007). Each function is explained in the following paragraphs.

Informational function: Data is stored in the tag to deliver additional information about the object such as dimensions, materials that were used, handling instructions. This approach guarantees immediate access to object-related information at all times and at all locations, even if there is no access to a network. Since informational data usually describes the characteristics of the object, it is typically static, thus it does not need to be modified or extended once it is stored. Therefore, read-only (WORM) tags are preferred for this type of functionality.

Documentational function: Additional data is stored on the tag to document history of the object, including object-related activities (e.g. quality measures and inspections). If the tag is used to record historical information, the data in the tag becomes dynamic since it needs to be updated or extended as the object goes through different phases (e.g. production, storage, delivery). To store dynamic information, the tag needs to be re-writable. Moreover, the storage capacity must be sufficient enough to document all the activities during the lifetime of the object. As active tags have larger memories compared to passive tags, usually active tags are preferred for having documentational function.

Temporary storage function: In this function, data stored in the tag: (1) is captured at the point of action, and (2) is temporarily stored, because of unavailability of a network to transfer data (e.g. during transportation). For example, sensors integrated to an RFID tag measure environmental parameters as the tag moves with the object throughout its supply chain and this data is temporarily stored in RFID tags until the next possible fixed reading point is reached. This function also requires active re-writable tags since data is updated.

Decentralized control function: RFID tags can be equipped with microprocessors and thus given the ability to make their own calculations (Collins 2006). As a result, objects themselves are authorized to make decisions and control systems are relieved since they can (1) pre-process data, and (2) carry out actions (e.g. activating alarms). They can even make independent decisions on the basis of their data (e.g. routing information). This function requires an active tag since it would perform some actions without receiving any power from a reader.

2.3 Integrated approach

In some cases only an integrated approach can guarantee the availability of the relevant information at all times. For example, an RFID tag memory may not be sufficient to store all the object-related data within an application. Thus, some of the data needs to be stored in a remote database. In another case, a seamless connection to a remote database may not be available in all phases that an object goes through. Therefore, all the object-related data that is needed when the object is outside the range of the network can be stored on the tag and the rest of the data can be kept in a remote database. This integrated approach enables data availability under different conditions. Another example for the integrated approach is a case where the tag data (e.g. temperature) needs to be transferred to a computer system to perform some necessary calculations (e.g. concrete maturity calculations) or to trigger some alerts.

There are some cases where the data that is stored on tags may also be transferred and stored on remote databases to create data redundancy. These kinds of applications are considered as data-on-tag cases within this paper, since the goal is to make data available on the tags.

A comparison of data storage approaches is given in Table 1. This table gives an overview of the differences and the similarities of the three data storage approaches in terms of various factors.

Table 1: Comparison of the data storage approaches (adapted from Diekmann et al. 2007)

	Data-on-remote DB	Data-on-tag	Integrated approach
Needs for data access	Necessary infrastructure (I)	Presence of object (II)	Both (I) and (II)
Storage of object data	Centralized (database) (III)	Decentralized (object) (IV)	Both (III) and (IV)
Content of data on tag	ID number (e.g. EPC)	All object-related data (e.g. history information)	Some part of the object-related data (e.g. Environment conditions)
Nature of data on tag	Static (mostly)	Dynamic (mostly)	Dynamic (mostly)
Storage capacity on tag & type of tags	Low (mostly passive tags)	High (mostly active tags)	Low or high-depends on application characteristics
Storage capabilities of tags	Mostly Read-Only (WORM)	Mostly Read-Write tags	Mostly Read-Write tags
Cost of tags	Low	High	Depends
Data security	Access mechanism in DBs (V)	Coding on the tag (VI)	Both (V) and (VI)

However, to understand the specific conditions that require different data storage approaches, the contexts of specific cases need to be known. Therefore, different cases which leveraged RFID technology in construction industry were investigated to identify under which specific conditions each data storage approach was selected.

3 RFID CASE STUDIES

The case studies that were examined were both conducted by academia and industry to utilize RFID within the construction/maintenance processes. Among thirty six case studies that were investigated, half of them were academic research studies and they were retrieved mostly from journal papers. A few of the academic case studies were described in conference papers. Real-world applications of RFID technology in construction industry were obtained through RFID-related web sites (e.g. www.rfidjournal.com).

The investigated cases were classified under five categories according to the application areas and purpose of utilization of the technology (Table 2). When a case fell under more than one category (e.g. object tracking and object localization), the primary purpose in using RFID was considered and the case was classified under that category.

Table 2: Categorization of the investigated cases

Category	# of cases	Purpose
Material tracking	9	Identifying and tracking components (e.g. pipe spools, steel members), tools (e.g. hammer drill, band saw), workers, etc. on the jobsite.
Equip. tracking	3	
People tracking	1	
Lifecycle information tracking	5	Tracking data that is related to the components throughout their lifecycles (e.g. manufacturer name, installation instructions, maintenance records, etc.).
Mobile object localization	2	Determining the exact location of objects (e.g. buried assets, materials at the jobsite).
Stationary object localization	5	
Construction/ progress management	6	Status information of components (e.g. manufactured, delivered, installed, etc.) at different phases during construction.
Quality management/ control	5	Tracking quality control test results and inspection results (e.g. concrete tests).

The largest group of cases belongs to the category of tracking objects at the jobsite. It includes applications that identify materials (e.g. pipe spools, steel members), tools and workers only when they pass by specific locations at job site (e.g. gates). This category is followed by the localization category which includes cases where RFID is used to pinpoint the exact location of objects, such as buried assets and materials at the jobsite. In six cases, status information of components (e.g. manufactured, delivered) were tracked by scanning RFID tags when specific tasks were completed. In a group of five cases, RFID was used for tracking life cycle/historical information of various components. In quality management and control category, RFID is utilized for keeping a record of quality control tests and inspections.

In each category, data storage approaches were investigated for each case. The goal was to determine under which conditions storing data on the tag is more appropriate for the construction industry by identifying the characteristics and data storage needs of the available cases.

3.1 Object tracking applications

Three types of objects were tracked at construction site: (1) materials (e.g. pipe spools, steel members, timber components) (2) people (3) equipment or tools (e.g. e.g. hammer drill, band saw). Object tracking cases mostly focused on material tracking (i.e. nine out of thirteen cases).

All types of data storage approaches that were identified in Section 2 were used for material tracking cases. Data-on-tag approach was more frequently used within this context (i.e. four out of nine). For example, when automating current tracking process of pipe spools, Song et al. (2006a) stored relevant data, such as the piece marked number, spool number, sketch number and purchase order number, on active tags that are attached to pipe spools. Jaselskis & Misalami (2003) also stored pipe supports' and hangers' procurement data (e.g. purchase order number, client number, job number, item number) on passive tags. In addition, their location in the lay down area and existence of any damage is also written to tags to make a permanent record for others to access at a later time (Jaselskis & Misalami, 2003).

Three material tracking cases followed an integrated approach for data storage. For instance, Yin et al. (2009) proposed a system where the data about quality control inspection results, inventory, transportation and delivery statuses of precast concrete components are stored in active RFID tags. More detailed information is sent to the main office or to a site worker via PDA and wireless Internet. This detailed information includes (e.g. inspection items, project forms, delivery date and time of the precast component, production and materials quantity, quality control inspection and inventory and transportation management information. Cheng et al. (2008) also used an integrated approach and the tags stored information about how to restore timber components. This information was modified and updated according to the needs of a specific restoration phase. In addition to the data stored on tags, other information such as restoration sequence, restoration contractors, supervisors, evaluated strength capacity data and drawings was available via a GIS application which was accessible online through a handheld PDA reader-writer used onsite (Cheng et al. 2008). Similarly, Ren et al. (2007) developed an RFID facilitated construction material management system to obtain up-to-date production and installation information about the pipes in a water supply project. PDAs were used to collect data from RFID tagged fittings and this data was transferred to a remote database everyday. Production and installation data related to the pipes such as their ID, manufacturer, drawing number, scheduled installation date, site to be installed, person in charge, etc. were stored in tags on the fittings. According to the data collected on site via RFID, comparison with the actual situation and the baseline schedule and analysis was made on usage of fittings and changes on site (Ren et al. 2007).

Within two material tracking cases the data-on-remote database approach is followed (Furlani & Pfeffer 2000, Swedberg 2009). For example, in one of these cases the tag ID is used for querying the graphical representation of steel components that are kept in databases (Furlani & Pfeffer 2000). It can be seen that, storing additional object-related data on tags is more preferable within material tracking applications.

There are three cases related to tracking of equipment (e.g. tools, crane parts). Data-on-remote database approach was used more often. Only Goodrum et al. (2006) followed a data-on-tag approach and tested a tool tracking system on a number of construction jobsites. In this case, active RFID was used to keep an inventory of small tools and to store pertinent operation and maintenance data on the tools. The two remaining cases stored equipment-related data on remote databases

(Swedberg 2005, Swedberg 2007, Swedberg 2009).

The only case where people were tracked, preferred an integrated data storage approach. The NEMO (Networked Embedded Models and Memories of Physical Work Activity) project utilized RFID technology to gauge the safety of construction employees at risk for hand/arm vibration syndrome, which is caused as a result of overexposure to heavily vibrating equipment (Swedberg 2008). Active RFID tags with built-in accelerometer sensors, were attached to tools to measure the level of vibration, as well as duration of operation for a particular tool. The tag transmits accelerometer's data to an RF reader in the employee's badge. The badge contains a chip, battery and display, and computes and stores the time and level of vibration that the worker is exposed to. A Wi-Fi access point installed in a project truck downloads the badge's data when the worker approaches the truck and transmits that information to a back-end server via a GPRS signal (Swedberg 2008).

3.2 Applications for lifecycle information tracking

In this category, the main goal is to track component-related data through different phases within component's lifecycle. In the existing studies, it is mostly suggested to store additional object-related data on the RFID tags (i.e. four out of five). Ergen et al. (2007a, 2007b) and Motamedi & Hammad (2009) preferred storing all object-related data on tags. For example, in a study data such as the ID number, manufacturer and owner information, handling, storage and installation instructions and maintenance information of engineered-to-order components were stored on active RFID tags (Ergen et al. 2007b). Similarly, in another study, active RFID tags were used to store maintenance data (e.g. date, inspector name, inspection results) of fire valves in the facility maintenance phase (Ergen et al. 2007a).

Motamedi & Hammad (2009) stored crucial information on both active and passive tags attached to fire safety equipments (e.g. extinguishers and valves). The goal was to provide information about the history and the conditions of these components for inspectors and maintenance/repair personnel without accessing any central database. Another study suggested using an integrated data storage approach where sensors of temperature, humidity and vibration integrated with preferably active RFID tags will monitor environmental conditions during delivery of glasses and after their installation (Gil & Kahn 2004). At the same time, a central computer will be used to track which truck is distributing which stillage, with what glass, to which location. However, such system has not yet been developed or tested in practice (Gil & Kahn 2004).

On the contrary, Ko (2008), developed a web-based building maintenance system and examined its performance in a material test center in Taiwan. This center has valuable experimental equipments (e.g. electron microscope, e-beam, etc.) and laboratory facilities (e.g. rain and wind laboratories, wind tunnel laboratory, etc.) that require periodic maintenance. Within the developed system, maintenance information of specific maintenance objects (e.g. equipment or facility) is kept in a database which is accessed over the Internet.

3.3 Localization applications

Localization approaches focused on determining the location of mobile and stationary objects at the construction site. In this category, both data-on-tag and data-on-remote database approaches are used.

Workers are the mobile objects that were localized within two cases where active tags were used (Ekahau Inc. 2006, Friedlos 2008). Ekahau's emergency tracking system was used in the construction of an underground tunnel in Spain and Wi-Fi enabled active RFID tags were used for tracking workers. The movement and location of each tagged worker was tracked by the software that calculates each tagged workers' position from the signal strength measurements that were sent from worker's tags. The collected tracking data was stored in a database and shown on a visual map on a computer screen (Ekahau Inc. 2006). Similarly, a company in Australia was using a data-on-remote database approach to know the location of its 1,700 employees and its construction vehicles in one of the country's biggest road projects (Friedlos 2008). Active tags, which were attached to workers and vehicles, transmit signals to the readers that are deployed on every 250 meters inside a tunnel. Location data of workers and vehicles were stored in a remote database. One reason for using active tags in these two cases is the long reading range that is provided by active tags.

RFID was also used to determine the locations of stationary buried assets (Swedberg 2006, Dziadak et al. 2008) and steel components that were relocated at construction site (Grau & Caldas 2009). In two of these three cases data is stored in passive tags (Swedberg 2006 and Dziadak et al. 2008). In Atlanta Airport case RFID markers were used to track buried cables. The marker's serial number, the type of cable and its location, its owner and its material (e.g. copper, fiber, etc.) was stored on passive tags (Swedberg 2006). Dziadak et al. (2008) also tried to locate the position of non-metallic buried assets using passive RFID with other technologies such as Global Positioning System (GPS). The proposed concept is still in its development stage but RFID gave promising results in determining the depth of buried assets during initial tests. It was suggested that additional data such as the type of the buried pipe (metallic/non-metallic), its dimension, material in the pipe (gas, water, sewer, etc.) can be stored directly on the tags.

3.4 Construction/progress management applications

Applications within this category mostly stored data on remote databases (i.e. five out of six) and used RFID to identify tagged components at different phases. For instance, in three cases the tagged components (e.g. steel components, HVAC components) were scanned at different phases and the related status information (e.g. manufactured, received, installed, etc.) was collected from passive tags (Hammad & Motamedi 2007, Wang et al. 2007, Chin et al. 2008, Wenfa 2008). This information was then transferred to a remote database. Also a comparison between the baseline and actual conditions of components was made on the scheduling software (Hammad & Motamedi 2007, Chin et al. 2008, Wenfa 2008). On the other hand, Wenfa (2008) followed an integrated approach and stored additional data about the steel beams and columns on tags for additional verification during receiving process. This data includes order number, release number, requisition number, mark number, client number, job number, item number, and quantity ordered In another study a construction management approach was introduced where tagged component parts were read as they pass through gates. The product URL, a unique address, stored on the chip of each part was used to determine the type of part, its place and its state within the information network (Yagi et al. 2005).

3.5 Quality management/control applications

In the cases classified within this category, integrated data storage method is the most commonly used (i.e. three out of five). Yabuki et al. (2002) suggested a "hybrid method" by distributing data on tags, on PDAs and on Internet to make sure that quality inspection data is continuously accessible at necessary level. For example, if basic data about a facility or a member is needed at the field, data on RFID tags (ID, main feature or specification, inspection procedures, latest measured data, latest inspection notes, etc.) would be sufficient. When more detailed data is needed on that item, PDAs that is preloaded with related information such as measured data, digital photographs, digital sounds, information about inspection routes, etc. can be used. Finally, all the inspected data, document and drawing files were made available on a local server (Yabuki et al. 2002).

Two cases used the tag data to make relevant computations on remote computers (Peyret & Tasky 2004, O'Connor 2006). For example, a company used RFID to detect the concrete's temperature and estimate its strength without having to wait for the results of conventional testing methods. Therefore, active RFID tags integrated with temperature sensors were embedded in the test cylinders. Data such as the tag number, location, and its depth within the concrete was written on tags and temperature was stored periodically on tags. A software that runs on handheld computers used tag data to calculate the maturity of concrete (O'Connor 2006). On the other hand, rest of the two cases preferred storing data on a remote database. One of them was a case of a Hong Kong Company where they embedded RFID tags onto the top surface of the concrete test blocks while they were still wet. Tags were programmed with data pertinent to the origin of the concrete before the samples were sent for testing (On the Move 2004). This data was also uploaded to a server. Since each sample was uniquely identified by its serial number, creating reports and making statistical analysis was more accurate than the conventional way. (On the Move 2004).

4 ANALYSIS OF THE CASES

The results show that out of thirty six cases, the data-on-tag approach was followed and/or suggested in ten cases. These cases mainly include lifecycle information tracking and material tracking applications. In life cycle information tracking applications, mostly historical data (e.g. maintenance and inspection records) was stored on tags. In material tracking applications data stored on tags was mostly related to the identification and receiving process of the materials (e.g. purchase order number, release number, requisition number, client number, quantity ordered). These information items were stored directly on the component because this information is needed at multiple places (e.g. production plant, storage yard, construction site) by multiple parties (e.g. manufacturer, contractor, inspector) throughout the lifetime of the component. Network accessibility cannot always be provided in all stages of a construction component throughout its lifetime. Thus, it is necessary to store related data on the component itself to make sure the availability of data under such circumstances.

In nine cases, integrated data storage approach was followed, and information items were both stored on the tags and in central databases. In four of these cases, data that is stored on the tags was transferred to a central database because this data would be used in making further interpretations or computations about the objects on remote computers (Peyret & Tasky 2004, O'Connor 2006, Ren et al. 2007, Swedberg 2008). Another reason in following the integrated approach was making the most necessary information immediately available on the tag and the rest of the information is stored on a PDA or on a server.

On the other hand, storing related data on remote databases (e.g. company databases, portal) was preferred in fifteen cases, most of which are related to construction/progress management applications, localization of objects and equipment tracking. These cases utilized RFID tags for identification of objects and stored object-related data on remote databases, such as status of the object, GPS data of objects, history of object usage and maintenance records. In some cases, the current status of the components were updated in the 3D model as well. These information items were stored in a central database since they need to be made available to multiple parties working at different locations at the same time.. PDA integration was also observed in the applications that stored data on remote databases, since PDAs enable uploading up-to-date data immediately to the network to improve the decision-making processes (Wang et al. 2007, Chin et al. 2008). In two cases RFID was only used for positioning/locating the tagged components, thus no additional data was stored either on tags or on remote databases (J. Song et al. 2006b, J. H. Song et al. 2007).

In applications that stored additional data on tags, mostly active RFID technology was preferred because active tags have larger data storage capacities compared to passive tags (Table 3). Thus, among the cases where additional data was stored in the tags, only five applications used passive tags and nine cases used/suggested using active tags. Within two cases both passive and active tags are used in different parts of applications at the same time. For the remaining three cases, the type of tag that was used was not provided.

Table 3: Number of tag types used/suggested in different data storage approaches

	Active tag	Passive tag	Both active & passive	N/A
Data-on-tag approach	5	4	1	-
Integrated approach	4	1	1	3
Data-on remote database approach	4	6	-	5

Among all the cases, passive tags were preferred when only a small amount of data, such as the identifier data (e.g. description of components, type of material) was needed to be stored on tags. Due to the similar reasons, passive tags are more frequently used in data-on-remote database cases (i.e. six out of fifteen) than active tags (i.e. four out of fifteen), since only a little data storage capacity is needed for data-on-remote database approach. Another reason for using the passive RFID systems is to have a more affordable application, since it is less expensive than active tags (Wang et al. 2007, Wang 2008, Chin et al. 2008). Consequently, if cost is an important issue, passive tags are used and additional data on tags is usually not stored due to low data storage capacity of passive tags. For the remaining five cases that stored data on remote databases, information on the tag type was not available. If no other information is stored on active tags, the reasons for using active tags were the need for longer reading ranges or self-signaling tags that can only work on their own batteries.

5 DISCUSSIONS ON THE INFORMATION GROUPS

Types of information stored both in tags and in central databases could be classified into seven groups according to their characteristics: (1) Identifier information: the unique information about the object (e.g. ID, serial number, production number, manufacturer information, etc.). (2) Technical features: data related to technical features of components (e.g. handling instructions, the maximum load, warranty information, etc.) (3) Historical information: Information about the processes that the components go through and about the problems that were encountered (e.g. any damage to a component, operation and maintenance data). (4) Location data: Spatial information about where the object currently is (e.g. building, floor, room information). (5) Status data: Current status information (e.g. manufactured, installed, etc.). (6) Task-related information: Information about the object related tasks that are going to be performed by the field workers (e.g. installation details, lifting schedule). (7) Environmental conditions: Environmental data collected by sensors (e.g. temperature, humidity, etc). All types of information is stored both in tags and in other databases in different levels of detail except the data about the environmental conditions. Environmental conditions data is only stored on sensor integrated tags and within data-on-tag and/or integrated data storage applications.

When information items that is stored on tags are investigated for the categorized cases in terms of functions described in Section 2.2, it is observed that all of the related cases (nineteen cases) benefited from the "informational" function within all categories (Table 4). This function ensures delivering characteristic information on the object at all times and it mostly remains unchanged. Both the identifier and technical features information is stored within this context.

Table 4: Number of cases in terms of benefited functions

	Function 1*	Function 2**	Function 3***
Object tracking	9	3	1
Lifecycle information tracking	4	3	1
Object localization	2	-	-
Construction progress /management	1	-	-
Quality management/control	3	2	1
Total	19	8	3

* Informational Function
** Documentational Function
*** Temporary Function

Storing the object-related data with the object is also preferred when history of the component needs to be permanently available even after the construction phase. These kinds of applications are for keeping records of object-related activities, thus they take the advantage of the "documentational function" of the data-on-tag concept. Eight of the cases within lifecycle information tracking, object tracking and quality management applications that stored additional data on tags benefited from this function. RFID tags are used to permanently store historical data such as operation (Goodrum et al. 2006) and maintenance information (Ergen et al. 2007a, 2007b, Motemadi & Hammad 2009), date of last inspection (Motemadi & Hammad 2009) and recent quality control inspection data (Yin et al. 2009, Yabuki et al. 2002).

Data storage on a tag is also preferred when data about the environment is needed to be captured. For example sensors monitor and record environmental conditions data and store it to an RFID tag. In this case, RFID tags serve the "temporary storage function" and data captured by other devices/methods are temporarily stored on tags. Three cases suggested/used sensor integrated RFID tags as temporary storage units whit the purpose of storing environmental conditions data in lifecycle information tracking category (Gil & Kahn 2004), temperature data within quality control category (O'Connor 2006) and the amount of vibration within a people tracking application (Swedberg 2008).

On the other hand, none of the cases that preferred the data-on-tag approach took advantage of the RFID tags for "decentralized control" function. While it seems as a future work for the construction industry, other industries are already benefiting from this function. For example, BP is implementing RFID in sensor networks in a pilot project where various rules are deposited on the tags (Collins 2006). One of these rules is for preventing chemicals that could potentially react with each other to be stored too close to each other. If this rule is broken, an alarm is set off. A similar approach can be adapted to the construction industry as well.

6 CONCLUSIONS

In construction processes, network accessibility, might not be always provided throughout the lifecycle of a component and an existent network may not work efficiently due to dynamic and harsh conditions at construction site. Data being stored on network would easily become inaccessible in such circumstances. Thus, storing all of the case/object-related data in a network may result in interruptions in data flow when performing the construction work.

An analysis is performed based on the data storage concepts for studies conducted for construction industry to identify which approach is preferred under different circumstances. It was observed that, storing additional data on tags was preferred in more than the half of the examined cases (i.e. nineteen out of thirty six). Additionally active RFID tags were used/suggested in these cases more frequently instead of passive tags (i.e. nine cases). When data ıs stored on a tag, it mostly has an informational function, in other words, it includes characteristic information about the object (e.g. manufacturer information, handling instructions) which remains mostly unchanged. Data on tag can also have documentational and temporary storage functions but decentralized control function was not observed for construction cases.

The future work would be creating a flowchart diagram for helping practitioners in deciding which data storage concept should be utilized for their own needs. A cost-benefit analysis could also be performed for different data storage concepts. Cases that are performed in other industries will also be investigated and a comparison will be made between the construction industry and other industries based on the characteristics and data storage needs of each industry.

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