RFID-based decision support within maintenance management of urban tunnel systems

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ABSTRACT
Efficiently, tracking information related to components, materials and equipment from the production/construction phase to operation and maintenance is a challenge in the industries. The industry environment is a natural fit for generating and utilizing instance-level data for decision support. Advanced electronic identification and data storage technologies e.g. radio frequency identification (RFID), are used to identify equipment automatically and to integrate related information with equipment in various industries. The purpose of this paper is to explore and describe the impact of RFID-based decision support on maintenance management performance of urban tunnel systems. An RFID-based decision support–maintenance management model is theorized and tested with data collected from a sample of maintenance organizations using a structural equation methodology. This paper contributes to the RFID community by providing empirical insights into the impact of RFID-based decision support on maintenance management performance. This technology can potentially reduce the time for handling data in process of maintenance management. Timely and relevant information enables informed decision-making and causes to improvement for maintenance management performance.

Keywords
Radio frequency identification, maintenance management, structural equation methodology

1. Introduction
The success of an enterprise is largely determined by its ability and flexibility to react to changes and its business process stability and safeness. Innovative technologies help to improve the execution and management of business processes and ensure that a competitive position can be achieved or enhanced. One possible enabler to optimize Maintenance Management is the adoption of emerging technologies. Automatic identification systems (auto-ID) such as barcode, radio frequency identification (RFID) and sensor technique are such emerging technologies (figure1). They are able to automatically identify objects, collect data about these objects and provide this data to computer systems. One of the most significant auto-ID systems is RFID (Donath, 2010). Inaccurate or poor data may influence the decision incorrectly, especially if the system using the data is not able to verify the quality (Tretten and Karim, 2014). Recently, radio frequency identification (RFID) technology has gained considerable attention from business executives because of its potential to change the way commerce is conducted. It has the potential to transform all areas of business: manufacturing, transportation, distribution, warehousing, inventory, sales, marketing, and customer service. The major purposes of deploying RFID are identification, authentication, location, and automatic data acquisition (ADA).There are many challenges to making effective decisions rapidly, particularly when the decision involves a complex issue involving multiple stakeholders, unanticipated events, adhoc structures or groups, and uncertain or unstable environments, cross-cultural contexts-whether technological organizational, or ethnic-also complicate the conditions for making effective decisions rapidly. (Institute for the future, 2005). The industry environment is a natural fit for generating and utilizing instance-level data for decision support. RFID technology, with its relatively small foot print and reasonable enough memory and processing power, is an ideal candidate in such applications (Miller et al., 2011).The advanced data capture capabilities of RFID technology coupled with unique product identification and real-time digital information coming from different data sources, such as environmental sensors, define a new and rich information environment that opens up new horizons for efficient decision-making activities.RFID technology is

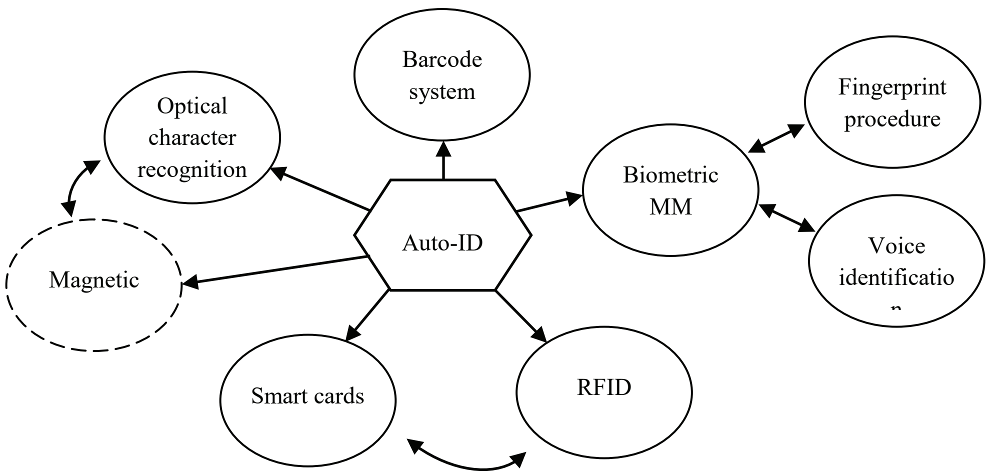


Figure1. Overview of automatic identification and data capture (AIDC)[31].

one of the supporting tools for automating processes and improving maintenance management. The reality is that it can bring more power to the decision making team by providing real time information.The increased availability of data makes it possible for accurate and precise decision-making in maintenance, given that the collected data are relevant, used correctly and maintain the expected level of quality. It is necessary to have a high quality of data since correct information is essential in assisting the decision-making process (Aljumaili et al., 2012).Indeed, the RFID technology can be used to identify an entity, such as a maintenance operator, physical asset, tool or spare part, and store information. The RFID tag is attached to the entity and enables the exchange of data locally with a RFID reader. This leads to the following functional features of the RFID system: capability of identifying the tagged entity; capability of storing, reading and writing the entity's data; the connection to a back-office system for further data processing (e.g. a CMMS for storing more data about the entity (Crespo Marquez el al., 2014).We show that the RFID-based decision support has a positive impact on maintenance management performance, and discuss how radio-frequency identification (RFID)-based can be employed to provide the necessary information for decision making within maintenance management. The paper also investigates how decisions based on RFID can be modeled present the impact this kind of decision on maintenance management.

2. Case description

TTCC as a subsidiary of the municipality of Tehran, is responsible for designing, implementing and developing of tunnel intelligent systems in Tehran. This responsibility has initiated since 2006 with opening the Resalat tunnel as a first tunnel that has equipped with intelligent systems in Iran. Considering the municipality plans and policies to develop this kind of projects and increasing the equipment, maintenance management of tunnel systems are being complicated and because of populated city and heavy traffic, most of equipment must be active full time, there is a need to present the solution in order to optimize the maintenance management of them.

3. RFID technology

Radio frequency identification (RFID) technology, which is defined as "a wireless automatic identification and data capture (AIDC) technology" (FossoWamba et al., 2008, p. 615), is increasingly viewed by many practitioners (e.g. SAP, HP, IBM, etc.) and scholars (Curtin et al., 2007; FossoWamba and Chatfield, 2009; Loebbecke and Huyskens, 2008; Ngai et al., 2007a) as a means to achieve a high level of intra and inter-organizational operational efficiency (Wamba, 2012).Radio frequency identification (RFID) is a fascinating, fast developing and multidisciplinary domain with emerging technologies and applications. It is characterized by a variety of research

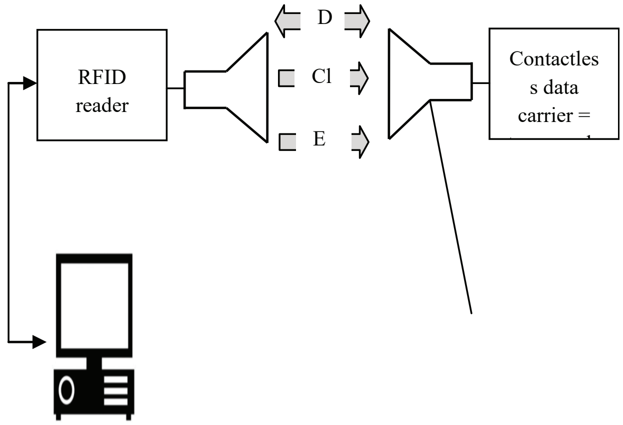


Figure2. The reader and transponder are the main components of every RFID system [13]

topics, analytical methods, models, protocols, design principles and processing software. With a relatively large range of applications, RFID enjoys extensive investor confidence and is poised for growth. To put it differently, significant technological advances and falling RFID tag and readers prices enable more and more organizations to adopt RFID solutions. RFID has been successfully applied in manufacturing, retail, supply chain, livestock, asset and people tracking, etc. (Turcu, 2010).The major components of an RFID system are tags or transponders that are affixed to objects of interest and readers or interrogators that communicate remotely with the tags to enable identification (figure2).RFID systems exist in various flavors that can be classified based on the frequency of operation, power source of the tag and the method of communication between the reader and the tags (Bolic et al., 2010). For a successful deployment of RFID, it is important to have a set of widely accepted standards and regulations, similar to the path of the progression of barcode standards. Their movement from proprietary to globally accepted open standards has played a pivotal role in a worldwide acceptance of the technology (Michael and McCathie, 2005). Viehland and Wong (2007) recognize seven issues important for RFID adoption; these include standardization, system cost, business process reengineering, integration, privacy, lack of RFID-skilled professionals, and warehousing. They conclude that standardization is the most important issue of all (So et al., 2010)

RFID tags can be classified by their size and functionalities such as power source, operating frequency, data storage capacity and capability, operational life, and cost. For example, active tags have an embedded tiny battery as power source, whereas passive tags do not contain any power source, and semi-passive tags work as a passive tag. But semi-passive tags have a power source that allow them

to use an aboard sensor to monitor their environment (e.g. temperature, vibrations, and shocks).With regard to operating frequency, the low-frequency tags use frequencies ranging from 125 to 134 kHz; the high-frequency (HF) tags use the 13.56 MHz frequency, and the ultra-high-frequency (UHF) tags use from 866 to 960 MHz frequency. Whereas the microwave tags work with frequencies ranging from 2.4 to 5.8 GHz. When dealing with data storage capacity and capability, RFID tags may either be read-only or read/write. In addition, the data transmission rates of the active tags are higher than that of the passive tags, and likewise, the data-storage capacity of the passive tags is smaller than that of the active tags. With
regard to operational life, the active tags' operational life is usually shorter than that of the passive tags. Finally, as it should be obvious, because passive tags do not require a power source, they are less expensive than active or semi-active tags.

3.1. RFID vs Barcode

RFID is a technology which allows remote interrogation of objects using radio waves to read data from RFID tags which are at some distance from an RFID reader. This has several advantages over manual scanning using optical barcodes, since many tagged items (or embedded subcomponents of a composite product) could be simultaneously identified in an automated manner, very quickly and without the need for line-of-sight to each item (Parlikad and McFarlane, 2006).The immense commercial potential of RFID is mainly due to the numerous advantages that the technology possesses over traditional identification mechanisms such as barcodes. We show some difference between RFID and barcode in table1

Main benefits of RFID can be categorized as follows:

Table1.Differences between RFID and barcode technology [30].

Characteristic	RFID tag	Rate	Barcode	Rate
Traceability	The combination of unique identification code (UIC), user data, serial number and on-board memory makes it possible to track, recall or document the life span of a single item	5	Bar code is limited to an entire class of products. It is not feasible to recall track or document a single item	3
Dynamic updating	Tags may be written to and offer on board memory to retain information. This feature may be used to store a product calibration history, preventive maintenance, etc. Updates may be made automatically without human intervention	5	Once a bar code is printed it remains constant. The code and the process of attaching the bar code are not supportive of real time updates	1
Lifespan	Tags have no moving parts and are embedded in protective material for an indestructible case and multi-year lifespan	5	Bar codes have unlimited shelf life but are subject to degradation with handling	2
Counterfeinting	Tags are produced with a UIC or serial number from the manufacturer. This is embedded digitally on the microchip and may not be changed, therefore, making them extremely resistant to counterfeiting	5	Bar codes may easily be duplicated and attached to products and are, therefore, easily counterfeited	1
Scanning	Offers a range from inches to hundreds of feet and does not require line of sight	5	Offers a range over inches and requires line of sight to read the code	4
Cost	High volume tags are currently about 50 cents	1	This is a clear advantage for bar code since they cost about 1 cent	5
Reusability	Yes	5	No	1
Application in harsh environments	Tags may be placed in extreme environments and perform to specification. They are very robust to handling	5	Barcodes cannot be read if they become dirty or damaged (during handling)	3
Sum		36		20

- Improving the speed and accuracy for tracking pallets, cartons and containers.
- Helping to reduce stock levels.
- Helping to reduce operating costs.
- Improving the management of inventory.
- Improving efficiencies in WIP reporting.
- Improving inventory visibility to feed JIT systems.

4. Maintenance Management

Maintenance management refers to the activities of management that determine maintenance objectives, priorities, strategies and responsibilities, and implement them by maintenance planning, maintenance control and supervision, as well as several improvement methods

including the technical and economic aspects of the organization. Therefore, maintenance management is clearly a multi-disciplinary area consisting of a wide set of different interrelated approaches (Soderholm et al., 2007). Interesting integrated maintenance management models have been reported in the literature as reviewed by Lopez Campos and Crespo Marquez (2009)and Barber et al. (2012). Each proposal usually identifies a list of processes, activities, actions or steps, which are part of an integrated and comprehensive management system. For instance, Crespo Marquez (2007) suggested eight sequential managerial steps to ensure efficiency, effectiveness and continuous improvement of the maintenance management system:

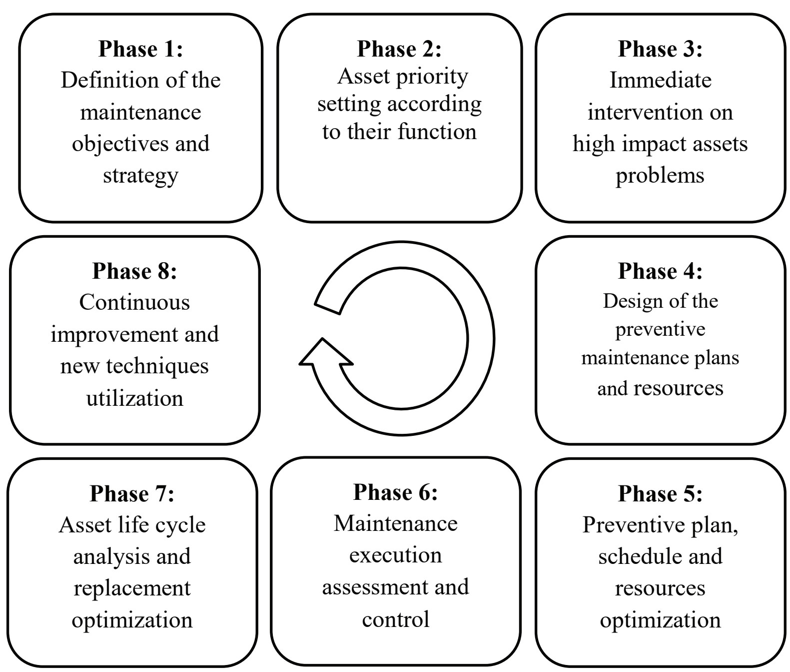
(1) Definition of the objectives, strategies and maintenance responsibilities;
(2) Ranking of the equipment;
(3) Analysis of weak points in high-impact equipment;
(4) Design of maintenance and resources plans;
(5) Maintenance scheduling and resource assignment;
(6) Control, evaluation and data analysis;
(7) Life cycle analysis; and
(8) Continuous improvement;

A generic process for maintenance management, integrating ideas found in the literature for built and in-use assets, could consist of the following sequential management steps (Marquez, 2007):

- Asset maintenance planning
  - Identify the asset;
  - Prioritize the asset according to maintenance strategy;
  - Identify its performance requirements according to strategy;
  - Evaluate the asset's current performance;
  - Plan for its maintenance;
- Scheduling maintenance operation;
- Manage maintenance actions execution (including data gathering and processing);
- Assess maintenance;
- Ensure continuous improvement;
- Consider the possibility of equipment re-design (Marquez, 2007).

Asset management is a fundamental business process. It determines corporate value and has a direct impact on profitability. The maintenance management model from marquez (2007) is depicted in figure 3.

4.1.E-maintenance



Technologies, methodologies, and tools aimed for maintenance are continuously being developed and improved, i.e. CMMS. In particular, the CMMS is seen as the main information system to which an E-maintenance platform could be linked. Technology is evolving not only to support communication with machines but also for better management of the information exchanged among maintenance personnel. Hence, PDAs, smart-phones, and mobile devices play an important role, as confirmed by Campos et al. (2009) and Emmanouilidis et al. (2009).

It is endowed with a number of functional features to support maintenance planning/scheduling, work order management, performance monitoring, budgeting/cost controlling and spare parts management. Finally, the information retrieved by using such devices and information systems can then be properly analyzed by reliability and maintenance engineering software in order to improve maintenance plans (Tucci and Bettini, 2006; Stegmaier et al., 2011; Crespo Marquez el al., 2014).

As the tools and technologies become more advanced, the need for information processing solutions, which can communicate between different systems, such as, operation systems and maintenance systems is increasing (Karim, 2009).From a general perspective,eMaintenance concerns the use of new information communication technologies (ICT) solutions in the field of maintenance (Levrat et al., 2008). Today, ICT-based maintenance solutions, i.e. eMaintenance solutions, are designed to support enterprises with effective and efficient decision making by enabling just-in-time access to maintenance information (Karim et al., 2009; Wandt et al., 2012). In Figure 4, the difference between e-Maintenance and conventional maintenance is depicted.

5.RFID in maintenance management

Companies across a broad spectrum of industries rely on critical assets to drive their business. Manufacturing companies rely on equipment availability and uptime to keep production lines moving and meet production goals. And while the asset types across industries may be varied, there is still a common need for effective management. Any item that is a part of the work process but does not leave as part of a finished product is a candidate for intelligent asset management with RFID. This technology can help enterprises automatically track and secure these assets with very little human intervention. RFID technology can potentially reduce the time for handling data in process of maintenance management. It is possible to improve data quality and richness due to the automated identification equipment. RFID allows to obtain a huge amount ofinformation regarding equipment usage and moves inside the project environments (Lopez, et al, 2010).

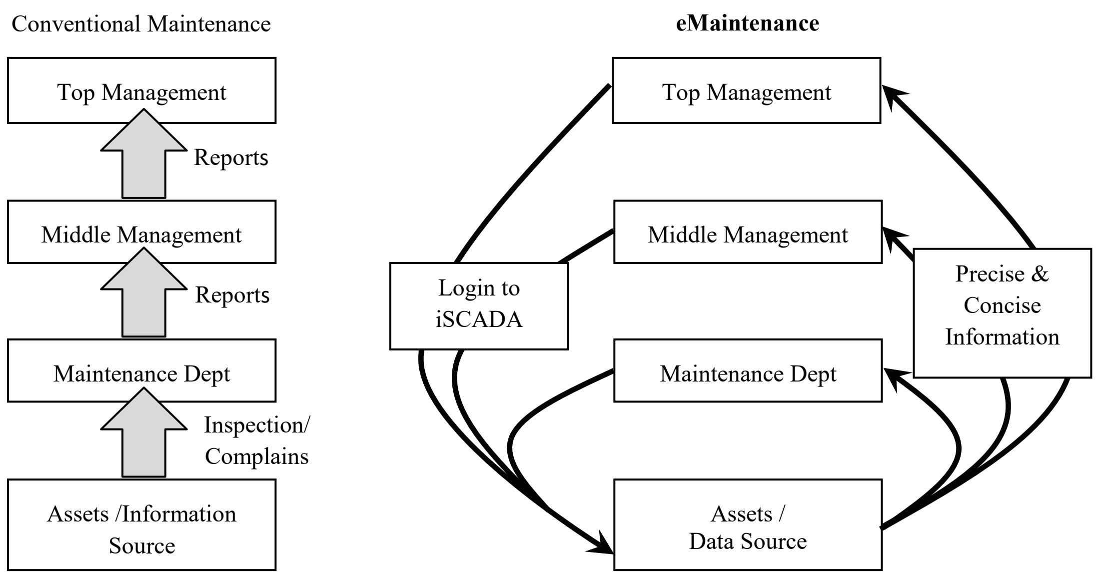


Figure 4. Reporting concept: eMaintenance vs conventional maintenance (Devicesworld, 2015)

During maintenance, tags information can be retrieved and providing all the information required for online querying of CMMS. Certainly, it can also reduce data entry mistakes thus saving time. However, it is not a perfect because RFID contains a deficiency that it will not function in difficult environments such as high electromagnetic interference, high/low temperature and presence of liquids and metal surfaces. Under these environmental conditions, the performance of the RFID is influenced, in a serious case, it will cause malfunction. Thus, recently there are some new hybrid RFID and multi-standard operable devices can befound with the aim to combine usage of different standards, active or passive tags together appropriately in order to allow RFID working effectively in poor environmental conditions. On the other hands, RFID can be combined with GPS technology to provide auto global position tracking application that achieves the idea of anywhere, anytime monitoring. Since the memory size of RFID tags is continually increasing (in line with many other hardware devices) the ability to store information such as the maintenance history of a particular machine is now a

realistic possibility. A briefly outline a selection of potential data templates which could be applied to such scenarios as found in the maintenance domain (Adgar et al., 2009). Table 2 outlines the functionalities of RFID, associated technologies and their application in maintenance.

Table 2. Variants of RFID use in maintenance [25]

Description	Technology	Example in Maintenance	Central system/ Database
a) Pure identification			
An asset has only one distinct identification number	1-D barcode or RO/ WORM transponder (passive)	Identification of a measuring or diagnostic point or a spare part	Central system contains all relevant data on an asset
b) Storage of static information on asset			
An asset has one distinct identifier (e.g. machine type and serial number) and other static data	2-D barcode or WORM/RW transponder (passive)	Electronic nameplate for motors, spare part identification	Central system contains all relevant data on an asset
c) Storage of dynamic information on asset			
Like b) but any other data may be stored or edited	RW transponder (passive)	Asset transponder containing all master and current motion data on an asset; synchronization of data over mobile terminals; mobile order management	Part of the data is redundant on the transponder and in the central system
d) Localization			
Tracking of mobile asset (people, equipment, tools, etc.) through space and time	WORM/RW transponder (passive) and gates or active transponder (MW)	Localization of ground conveyors, containers and people on the plant premises	Internal middleware and interface to central system
a) Condition monitoring			
Monitoring of assets' motion and condition (temperature, shock pulse, vibration, humidity, etc.)	RW transponder (passive) with sensors; active transponder (MW) with sensors	Operating conditions on assets without internal monitoring control; determination of data for condition-based monitoring	Internal middleware and interfaces to central system

6. Urban tunnel systems

If tunnels are longer than a few hundred meters, specific equipment is required to enhance safety to the users, both in normal situations and in case of accidents. To reduce the risks of accidents and limit the possible consequences, but also to keep an adequate level of comfort to the users, a large variety of equipment can be installed (PIARC, 2011).Tunnels are normally provided with technically advanced and expensive equipment that, for operation and maintenance, demands a high degree of competence and considerable resource. Professional and structured planning of operation and maintenance activities is necessary if the following demands are to be met:

- The safety of road-users;
- Ensuring free traffic flow
- Operational economy

If the available amount of money for maintenance is not sufficient, there will be an adverse influence on both service levels and safety (PIARC, 2011).

6.1. Tunnel equipment and systems:

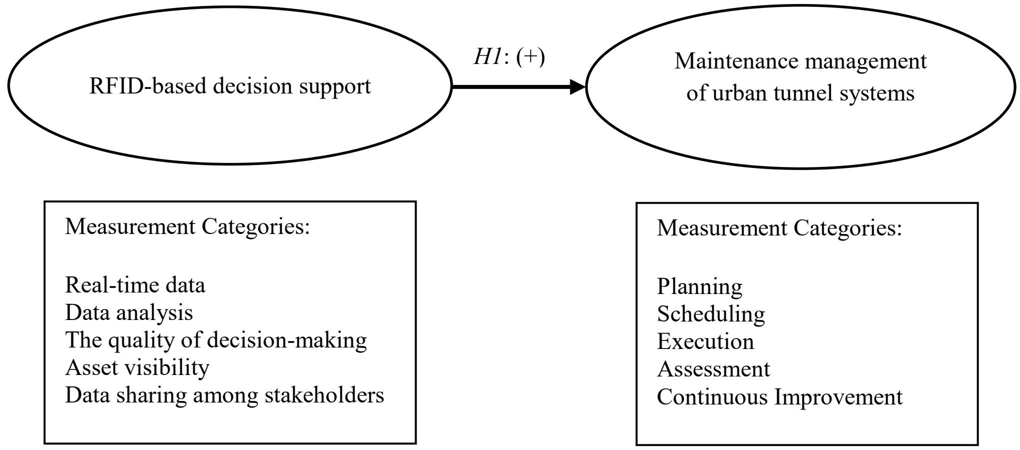
- Electrical power supply
- Supervisory control and data acquisition systems (SCADA)
- Communication and alert systems
  - Emergency telephone
  - Alarm push buttons
  - Automatic alarm when emergency systems meant for users are used
  - Automatic incident detection
  - Fire/Smoke detection
  - Radio-retransmission of public FM broadcasts, frequencies of operators and emergency services
  - Load speakers
- Lighting
- Ventilation
- Fire-fighting equipment
  - Objectives
  - Water supply
  - Fire Hydrants
  - Portable fire extinguishers
  - Fire house
- Fixed Fire Fighting systems
- Systems for surveillance and control of traffic
- Signposting
- Barrier

7. Methodology

We propose RFID-based decision support and maintenance management of urban tunnel systems as the focal constructs. The theoretical model is shown in figure 5. The model includes one main hypothesis. The context of a structural model as depicted in figure 5 allows assessment of the model as a whole as opposed to investigation of the hypothesized relationships individually. The model supports an investigation of the capability of decision support based on RFID technology to enhance maintenance management. Thus, clarifying the role that RFID-based decision support can play within maintenance management. Systems theory suggests that changes in one aspects of a system will reveal as changes to other parts of the system. Systems theory is incorporated in the theorized model to the extent that the using RFID-based decision support for the purpose of enhancing maintenance management leads to improve planning, scheduling, execution, assessment and continuous improvement of maintenance operation.

H1. RFID-based decision support positively impacts on maintenance managementof urban tunnel system

The theorized model and constructs included in the model are defined and described with a focus on maintenance management. It was our intent to gather data from maintenance managers with expertise related to the RFID and maintenance capabilities of their organization. Approximately 150 individuals working in tunnel projects were invited to participate in the survey. In total, 12.5 percent hold in technician positions, 51.8 percent hold in technical expert positions, 30.4 percent hold in managerial positions and 5.3 percent hold in executive manager positions. We use the PLS structural equation model to assess the model fit and hypothesis with t-values and path analysis. At the first level, we assess the unidimensionality, reliability and validity of measurement models then assessment of structural model fit and finally GoF of whole model. During these steps, we discard measurement scale with poor quality. The structural model is displayed in figure 6. The model fits the data relatively well with relative chi-square of 0.57. The path from RFID-based decision support to maintenance management performance of urban tunnel systems (H1) is significant at the 0.01 level with a standardized coefficient of 0.59 and associated t-value of 5.66 is supported. RFID-based decision support directly impacts maintenance management performance.



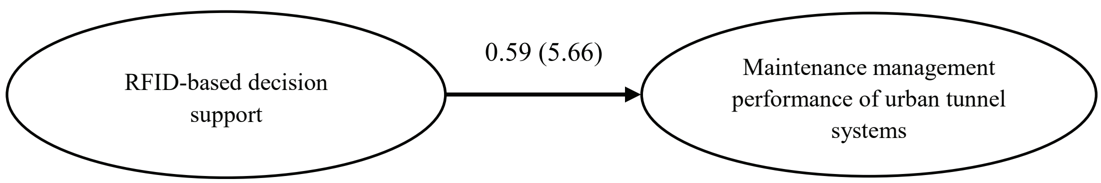


Figure 6. RFID-based decision support and maintenance management performance of urban tunnel systems with standardized coefficient and t-value

8. Conclusions

With a brief discussion in this paper, we attempted to highlight that RFID-based decision support leads to improve the maintenance management performance of urban tunnel systems. Considering the aim of this research and the results show that RFID technology enables maintenance managers to better scheduling of maintenance operation. This technology significantly facilitates data acquisition, gathering (centralized data from host and decentralized data through attached tags), access to technical information, reporting and tests accurately.

Maintenance managers can accurately assess the quality of maintenance operation through the better access to failure and repair times of equipment. By cooperating with RFID technology, data analysis and receiving real-time data can be performed appropriately also applying this technology leads to control inventory automatically, nearing a JIT system and consequently the quality and speed of decision making are improved in inventory management scope. Finally, the decision support based on RFID technology, enhances maintenance management performance.

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