Integrating RFID and GIS to Support Urban Transportation Management and Planning of Hajj

Nabeel Koshak[1] and Akram Nour[1, 2, 3]

[1] KACST GIS Innovation Center, Saudi Arabia
[2] Center of Research Excellence in Hajj and Umrah (Transportation & Crowd Management), Saudi Arabia
[3] Transportation System Research Group, University of Waterloo, Canada
nakoshak@uqu.edu.sa; anour@uwaterloo.ca

Abstract

Hajj is one of the greatest logistics challenges in the world. Each year, more than three million pilgrims arrive in Makkah, Saudi Arabia to perform Hajj. The movement of pedestrians and vehicles during Hajj has unique spatial and temporal constraints. The movement between one stage to another within a specific time has to be carefully planned, monitored and managed.

This paper presents an interactive integrative framework of Radio Frequency Identification (RFID) technology and Geographic Information Systems (GIS) to monitor and provide real-time online information about the movement of pilgrims. The framework also captures and stores information for future use in transportation planning. The RFID system is composed of RFID tags embedded on the vehicles that transport the pilgrims and RFID readers installed at key locations. The data read by the RFID readers are sent wirelessly to a workstation for analysis and, then presented on interactive maps utilizing a GIS application. A prototype of this project was successfully implemented during Hajj.

The system developed through this research is essential to support urban transportation planning and management of Hajj. Decision makers and urban transportation planners can use this system to monitor and control the pilgrims' movements and then archive the data for future urban transportation planning and management.

1. Introduction

RFID technology is an automatic identification system that uses radio waves to identify and track groups or individual objects at distance using an electromagnetic charge and response exchange. RFID has been implemented in sectors such as retail, health care, and transportation [7]. It has found rapid acceptance as an efficient and economical system for identifying and tracking objects. Conceptually, RFID technology is similar to bar-code identification systems. However, one difference between RFID and bar-code technology is that RFID does not rely on the line-of-sight reading, which is required by bar-code scanning. It is capable of transmitting data by a portable device (*i.e.* a tag) that is remotely detected by a reader. In addition, unlike bar-code, RFID can read multiple tags simultaneously. The capacity of tags can be expanded to carry more information than a bar-code. Moreover, RFID technology and systems still work despite bright sunlight and extreme heat.

The reading range and the speed of data transfer of RFID technology have been enhanced by sophisticated RFID components. Consequently, the capabilities of RFID have been investigated and used to improve operational efficiencies. This can be achieved by providing spatial referenced information about the tracked objects. Hence, there have been many opportunities to integrate the collected RFID data with other systems such as GIS. GIS integrates different methods to establish a decision support system associated with spatial problems.

Hajj is one of the five pillars of Islam. It is a set of worships to be performed in and around Makkah (Mecca), Saudi Arabia, at least once in a lifetime. Today's Hajj requires substantial planning and efforts. The Hajj is also one of the world's largest mass events. Over three million pilgrims come to Makkah for six days each year to perform their religious duty. This number increases every year, making it one of the world's largest temporary gatherings. The Hajj has unique spatial and temporal constraints. These constraints post challenges to Hajj authorities. Planning, monitoring, controlling, and managing the pilgrims as they move from one stage to another is one of the critical challenges during Hajj. This research project therefore proposes an integrated RFID-based monitoring system and GIS framework.

This application was integrated with the spatial referenced data collected through RFID technology for the transportation system. The system provides real-time information to ensure that the pilgrims have been transported within the time constraints of the Hajj. Thus, RFID technology is deployed to track the vehicles at specific locations. This information is, then, integrated with a customized interactive GIS application. The integration process gives the managers and operators in Hajj authorities a decision support system that provides live spatial-temporal and statistical information about the pilgrims' transport. It also provides urban planners with valuable data to support future transportation planning.

2. Hajj Background

Hajj is held in Dhul-Hijjah (the last month of the Hijri calendar), and lasts for six days. On the first day of Hajj, pilgrims travel 1.5 miles from Makkah to the plain of Mina and camp there. The next morning, they travel 9 miles (14.4 km) to the plain of Arafat where they spend the entire day. That evening after sunset, the pilgrims move 6.5 miles (10 km) to camp at Muzdalifah, a zone between Mina and Arafat (Fig. 1). The transportation in this 5-hour time frame between sunset and midnight is one of the most serious traffic problems in Hajj. Pilgrims stay overnight and return to Mina the next day. After three days in Mina, they return to Makkah and depart for their home countries. The first three zones (Mina, Arafat, and Muzdalifah) are non-residential areas, except for the six days of Hajj.

The pilgrims' movement from Arafat to Muzdalifah is a critical stage during Hajj. All pilgrims need to leave Arafat simultaneously and arrive at Muzdalifah using the available transportation modes and infrastructure.

3. Case Study and Problem Definition

3.1. Study Area

Arafat is divided into small areas and the pilgrims are distributed by nationality. Every nationality or group of nationalities is organized by a private establishment under the supervision of Hajj authorities.

In this study, the upper part of pilgrims' camps in Arafat and the transportation system in the network between Arafat and Muzdalifah will be the focal points (Fig. 1). The chosen part of Arafat is assigned to the Pilgrims Establishment of Turkey, Europe, North America, and Australia (PETENA). In every group, pilgrims are divided into sub-groups, each with its own number (Table 1).

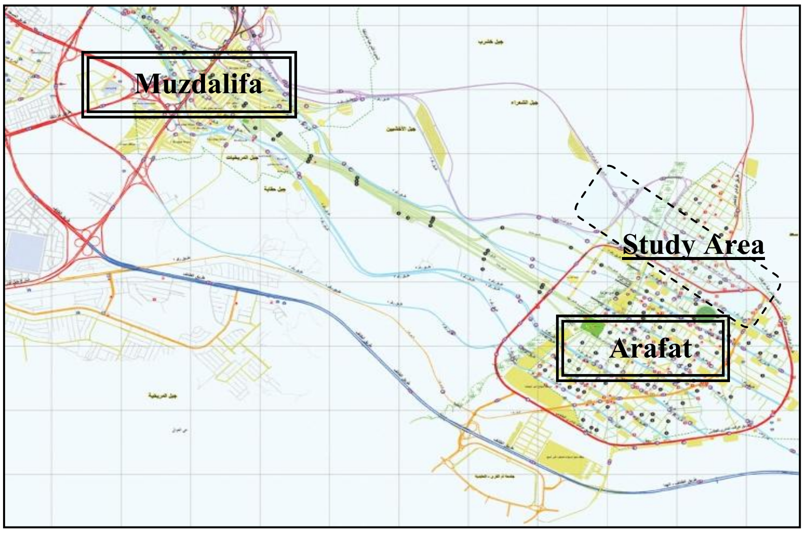

Fig. 1. The holy areas of Arafat and Muzdalifah, showing the study area.

Table 1. PETENA main groups' names, numbers, and sub-groups

Group Name	Group Number	Sub-Group Number
Turkey	1	1-24
East-Europe	2	31-36
West-Europe	3	41-46 and 51-58

3.2. Transportation System

The transportation network connecting the study area of Arafat to Muzdalifah consists of one 2-lane road with a capacity of 500 vehicles per hour per lane (vphpl).

The road is operated as right-of-way A for the transportation mode between Arafat and Muzdalifah. The only mode of transportation mode available to transfer the PETENA pilgrims from their camps in Arafat to

Muzdalifah is a shuttle service with a capacity of 67 passengers per bus. This shuttle service is a scheduled public transport system operates at frequent intervals on a short route between two or more stations. In Hajj, the pilgrims are transported only in one direction. In our case study the pilgrims need to be transported from their camp in Arafat to the camp in Muzdalifah.

Each bus in the service will be assigned to specific subgroup locations; the driver will be given the subgroup number. These locations represent the boarding station at Arafat and the alighting station at Muzdalifah. All locations are equipped with a big sign with the subgroup number and a gate to board or alight. The bus transfers the pilgrims between the two points until the last pilgrim in the assigned subgroup has been moved.

All the buses are stored in an area close to Arafat to depart at a scheduled time. Based on the number of pilgrims in each subgroup, a specific number of buses will be operated (Table 2). For example, the Turkey pilgrims need two buses to serve each of the twenty-four subgroups.

Table 2. Number of Buses needed by each sub-group

Group	Number of buses
Turkey	2 buses/ sub-group/ convoy
East-Europe	3 buses/ sub-group/ convoy
West-Europe	2 buses/ sub-group/ convoy

3.3. Problem Definition

Thirteen bus companies transport the pilgrims between the holy areas. The buses used in the shuttle services are not in the same shape and condition; some of them are old and likely to break down. In addition, the drivers of the buses are hired just for the Hajj and may not be familiar with the topography of the holy areas. Some of them might get lost after some shuttle rounds or at the beginning of the transporting process.

Hajj authorities have difficulties in planning, monitoring, managing, and controlling the buses. These difficulties and delays are caused by a lack of real-time information. Consequently, pilgrims might miss their hajj. In this stage, authorities need to observe and ascertain whether or not the pilgrims have been placed their assigned buses based on the schedule.

4. Methodology and Prototype

4.1. System Architecture

The reason for the introduction of an automatic RFID-based tracking system and GIS framework is to improve and expand the observation and traditional monitoring systems used in Hajj. The purpose of this research is to develop a reliable and efficient system of monitoring and planning. This system is capable of automatically tracking, visualizing, and analyzing spatial-temporal data for pilgrims over a specific period of time, as shown in Figure 2.

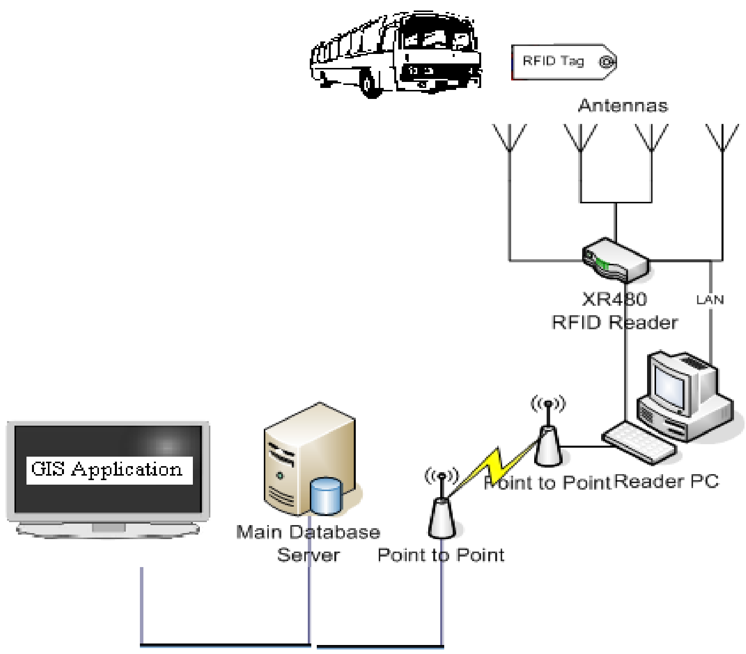

Fig. 2. The RFID-GIS System Architecture

4.2. Data Collection through RFID

RFID is a technology that uses small computer chips (tag) and radio waves to transmit the identity of an object wirelessly. The RFID tag is a small object that can be attached to or incorporated into an object. It contains an antenna with which it receives and responds to radio-frequency queries through a reader. A typical RFID reader has one or more antennae that emit radio waves to energize the tag and receive signals. The reader then wirelessly passes the information in digital form to a computer system. The system is depicted in Figure 3.

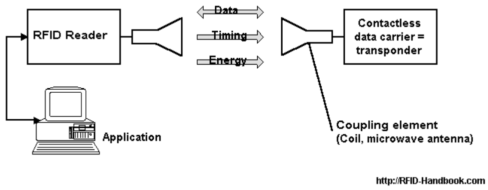

Fig. 3. The working mechanism of RFID technology (Source: RFID-Handbook)

The rationale for choosing RFID technology for this project is first to assess whether RFID technology is suited for monitoring and managing a transport system. Second, the relative low infrastructure and operational cost during Hajj compared to GPS. However, the largest portion of the total RFID technology implementation cost is associated with the RFID readers and their installation.

4.2.1. RFID Tags

An RFID tag consists of a micro-chip attached to a radio antenna mounted on an encapsulating material (Figure 4). The chip can be programmed with up to 2 kilobytes of data. RFID tags can be either active or passive. Passive tags are powered by the magnetic field sent by RFID readers. Active tags are powered with an internal battery that runs the tag's antenna. Active tags have a longer reading range than passive tags which have a maximum range of 10m. Consequently, the trade-off choosing passive tags over active tags is smaller size, lower cost, and longer operational life.

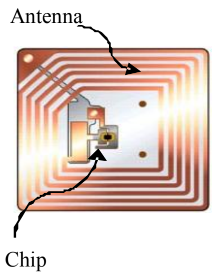

Fig. 4. Components of an RFID tag

Passive tags are sufficient for the goals of this research; hence, they have been used as the first part of the designed RFID technology.

In this project, RFID tags were mounted on top of all buses used for transportation between the camps of Arafat and Muzdalifah (Figure 5). Each tag was encoded with a unique ID to keep track of the bus.

Fig. 5. The team installing RFID tags **on** the buses

4.2.2. RFID Readers

An RFID reader, or interrogator, communicates with the RFID tag by broadcasting a radio signal to energize the RFID tag. The tag responds by sending its data to the reader. Readers can either be portable handheld terminals or stationary devices. The frequency of the RFID reader affects the reading range. High frequency RFID systems (850 MHz to 950 MHz and 2.4 GHz to 2.5 GHz) offer transmission ranges of more than 90 feet [1].

In this research, four RFID readers with a frequency 902-928 MHz have been installed to read RFID tags on the buses (Figure 6). The locations of the readers over the shuttle bus routes are as follows:

- Arafat Entry
- Arafat Exit
- Muzdalifah Entry
- Muzdalifah Exit

Fig. 6. The RFID readers installed at Arafat entry

Each RFID reader has been given a unique ID. Furthermore, the locations of the readers are geo-referenced to be integrated easily with the customized GIS application. The reader is used to energize the tags on each bus passing it and read the unique tag ID stored in each of them (Figure 7 and Figure 8). Hence, it is possible to record when each shuttle-bus enters or exits either of the two holy areas, Arafat and Muzdalifah. Through this project, a sophisticated computer application has been developed to analyze the raw data based on the requirements to help Hajj authorities to monitor and manage the pilgrims' transportation on the shuttle-bus system.

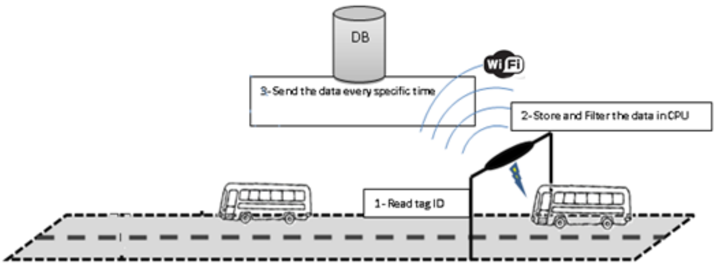

Fig. 7. Conceptual data collection mechanism for the system

Fig. 8. The buses passing the RFID readers at Arafat entry and Arafat Exit

The data will be collected instantaneously from the readers and processed in the CPU connected to each reader. In this step, each tag's data, once read will be stored as a record containing the following information after ensuring that no duplication has occurred in reading the tags:

1. RFID Reader ID
2. RFID Tag ID
3. Time that the record is stored

4.3. Data Processing

The algorithm designed for this process is shown in Figure 9. Subsequently, the processed data will be sent simultaneously through a point-to-point wireless network to the main server in the control room.

In the main server, the data will be stored in a database for real-time analysis. Each tag ID number is a primary key in the database that links to the vehicle information dynamic database.

Processed RFID data was provided as a Microsoft Access database. The database consists of six data tables, categorized in Table 3. The RFID database structure is illustrated in Figure 10**Fout! Bladwijzer niet gedefinieerd.**.

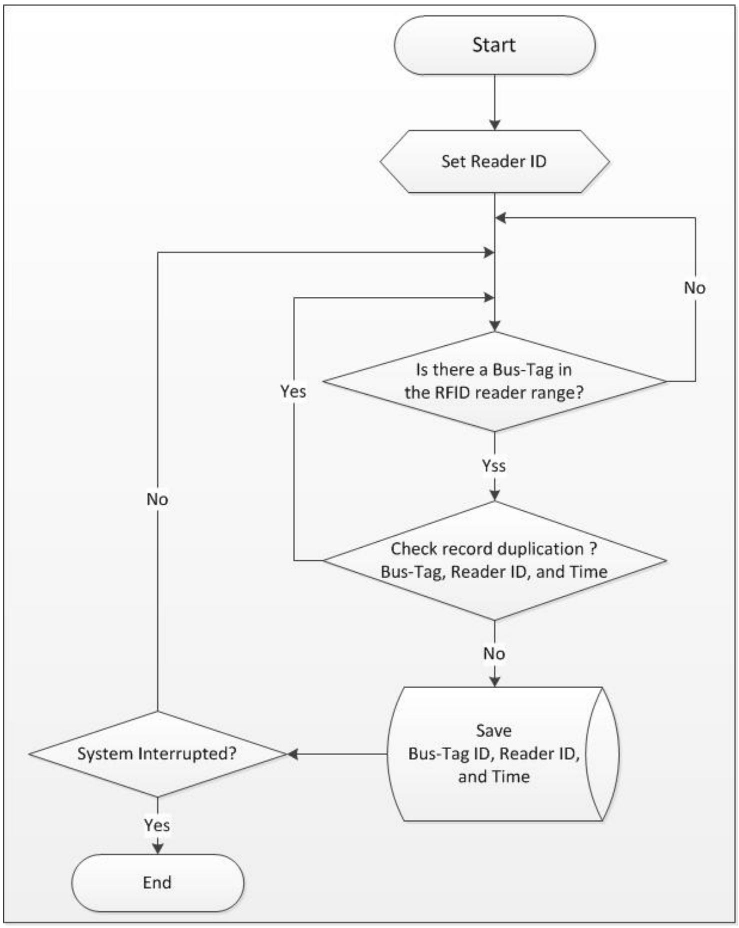

Fig. 9. Data collection algorithm flow-chart

Table 3. Categories of Data in RFID Database

Data Category	**Table Name(s)**
Information about Bus	tblVehicle
Information about RFID Observations	tblTransaction
Information about RFID Readers	tblLogical, tblDevice
Information about Bus ‘Group’	tblGroup, tblSubGroup

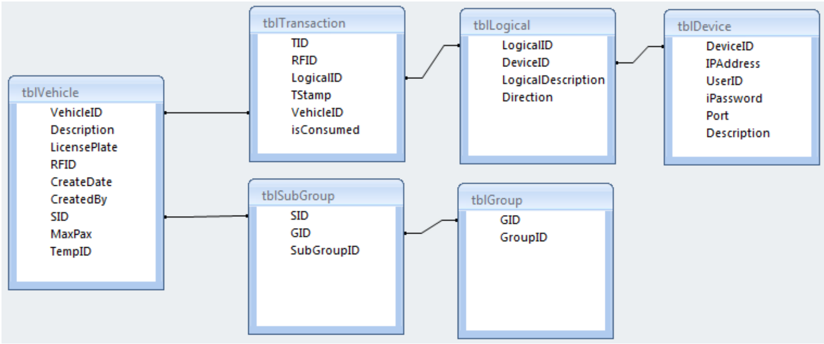

Fig. 10. RFID Database Structure

For the purpose of analyzing the RFID data, the most valuable fields are:

1. LogicalID (location of the detector)
2. VehicleID (unique identifier for each bus)
3. MaxPax (capacity of each bus)
4. TStamp (date and time of observation)
5. GID (major group that bus was assigned to)
6. SID (station where a bus picks up and drops off pilgrims during initial runs)

This database is programmed to be updated with every new record received in the main server through the number of shuttle round field. The number of shuttle round field is based on the number of records scanned by the RFID reader at the Arafat exit. Therefore, the initial value for all the buses for this field is 0, as the buses will depart for the first time from Arafat. As long as the bus is read by the reader at Arafat exit, the value will be updated in the database based on the equation shown in Equation (6.1).

$$NSR_{new} = NSR + 1 \qquad (6.1)$$

$$NSR = NSR_{new}$$

where
NSR_{new} = the new value of the number of shuttle round
NSR = the current value of the number of shuttle round

Moreover, the database is linked to a main dynamic databases includes three tables presents three levels associated with the pilgrims' camps in Arafat. The changes in the previous database will be reflected in all three tables though dynamic calculated fields.

The first table presents the level of the pilgrims' sub-groups camps in Arafat that includes the following information:

1. Sub-group number (Primary Key)
2. Group
3. Total number of pilgrims
4. Number of pilgrims transferred to Muzdalifah
5. Number of pilgrims remaining in Arafat

As mentioned before, each bus can hold a maximum of 67 pilgrims. Thus, whenever the RFID reader at Arafat exit reads a bus tag ID, 67 pilgrims are boarded from the designated sub-group to alight at Muzdalifah. Consequently, the “Number of pilgrims transferred to Muzdalifah” field has an initial value of 0. Afterward, it is estimated as the sum of the number of round for each bus multiplied by the capacity of the bus over all the buses assigned to each subgroup, Equation (6.2). Subsequently, the “Number of Pilgrims remaining in Arafat” field is updated from its initial value, which is the total number of pilgrims in the sub-group, as shown in Equation (6.3).

$$NPM_k = \sum_{ID} NSR_{ID}^{k} \times C_b \tag{6.2}$$

$$NPA = TNP_k - NPM_k \tag{6.3}$$

where

NPM_k = number of pilgrims in sub-group k transferred to Muzdalifah

k= sub-group number

ID= tag ID associated with the bus

C_b = bus capacity (67 passengers)

NSR_{ID}^{k} = number of shuttle round performed by specific bus associated with a tag ID serving subgroup k

NPA= number of pilgrims remains in Arafat

TNP_k= total number of pilgrims in subgroup k

The second table presents the pilgrims’ main group camps in Arafat, including the following information:

1. Group (primary key)
2. Total number of pilgrims
3. Number of pilgrims who transferred to Muzdalifah
4. Number of pilgrims remaining in Arafat

Similar to the first table, the last two fields are estimated as shown in Equations (6.4) and (6.5).

$$NPM_l = \sum_k NPM_k^l \tag{6.4}$$

$$NPA_l = TNP_l - NPM_l \tag{6.5}$$

where

NPM_l = number of pilgrims in group *l* transferred to Muzdalifah

l= group number

NPM_k^l = number of pilgrims in sub-group *k* in group *l*

NPA_l =number of pilgrims remains in Arafat in group *l*

The third table presents the all-camp of Arafat belonging to PETENA which includes the following information:

1. Total number of pilgrims
2. Number of pilgrims who transferred to Muzdalifah
3. Number of pilgrims remaining in Arafat

Once more, the dynamic calculated fields will be estimated as the sum of the number of pilgrims transferred to Muzdalifah from all groups and subtracted from the total number of all pilgrims in PETENA.

In addition, the system is designed to detect and report the buses that are running behind schedule as broken-down or lost. The received data will undergo parallel analysis to ensure that each sub-group is fully serviced as scheduled. As mentioned before, the convoy of buses will launch based on a pre-set schedule starting with convey 1 and going through 7. The order will be kept for the entire operational period. Thus, the system can detect the buses that belong to each convoy at the four RFID readers' locations in the following order:

1. Arafat Exit
2. Muzdalifah Entrance
3. Muzdalifah Exit
4. Arafat Entrance

If a bus in convoy number (i+1) read before a bus in convoy (i) in serving a specific sub-group by a particular RFID reader, the system will report a problem. In this case, we will be facing four possibilities:

1. If the tag ID is last read by the RFID reader at Arafat exit, the bus will be in the road between Arafat and Muzdalifah and reported as broken-down.

2. If the tag ID is last read by the RFID reader at Muzdalifah entrance, the bus will be reported as lost or broken-down in the area of Muzdalifah.
3. If the tag ID is last read by the RFID reader at Muzdalifah exit, the bus will be allocated in the road between Muzdalifah and Arafat and reported as broken-down.
4. If the tag ID is last read by the RFID reader at Arafat entrance, the bus will be reported as broken down in the area of Arafat.

All of these possibilities need a quick response by the operators and managers in Hajj authorities to avoid causing delays for pilgrims.

4.4. Data Visualization (GIS Interactive Application)

GIS is an integrated system of computer hardware, software, geographic data and trained people designed to store, manipulate, retrieve, analyze, display and report all forms of geographically referenced information towards a particular set of purposes [4, 9]. GIS is a spatial and statistical method of analyzing attribute and geographic information. The result of the analysis can be presented in formats such as reports and charts.

In this research, the GIS vector spatial system is used to present the camps distribution in Arafat for the study area. The main geo-database created includes three polygons feature classes:

1. All tent camps of Arafat.
2. Groups' camps distribution.
3. Sub-groups' camps distribution.

These three feature classes in the database will be linked via primary keys (Establishment ID, Group Number, and Sub-group Number) to the dynamic database. Hence, the pilgrims' transport will be monitored through a real-time customized interactive GIS application. The application can convey real-time statistical information about the number and percentage of pilgrims that have moved and those remaining in Arafat at the establishment, group, and sub-groups levels. Figure 11 shows a screenshot from the developed GIS application showing the map with the percentages of the pilgrims remaining in each tent camp in Arafat in each subgroup in addition to a bar-chart presentation on the left.

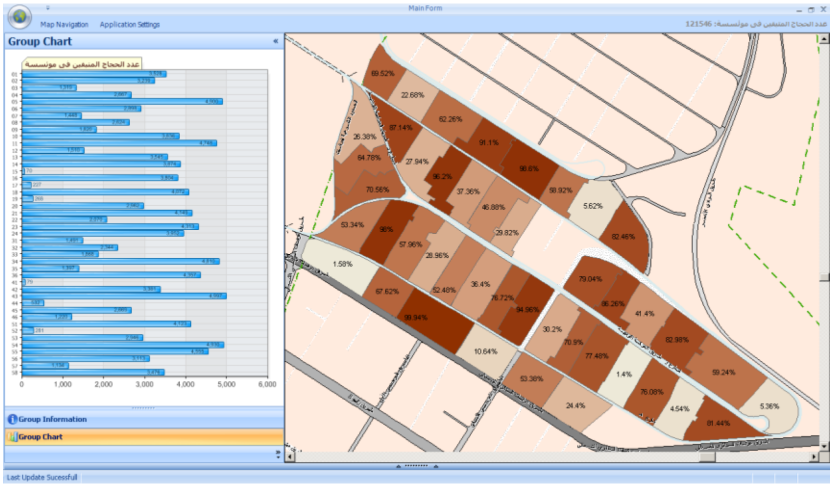

Fig. 11. A screenshot showing the percentages of the pilgrims remaining in each tent camp in Arafat.

Fig. 12 shows another screenshot from the GIS application showing the map with the percentages of the pilgrims in each subgroup remaining in each tent camp in Arafat. On the lower part, three gauges give the number of pilgrims remaining at the level of all establishment, East-Europe group (group 2), and subgroup number 33 (right to left).

Fig. 12. A dynamic map and three gauges representing the percentages of the pilgrims remaining in tent camps.

5. Concluding Remarks and Future Plans

In this research, an interactive integrative framework of RFID and GIS solution is developed and applied during Hajj. The system helped in managing the pilgrims' movements from Arafat to Muzdalifah. Moreover, the system provided the managers and operators with accurate information. The framework presented here is essential to supporting urban transportation planning and management during Hajj. Decision makers and urban transportation planners can use this framework to monitor and control the pilgrims' movements.

The system can generate performance evaluation reports for transportation companies. Furthermore, it will be extended to provide traffic information for the traffic network between Arafat and Muzdalifah, such as average speed and travel time. Such information can be used to support future redesign of the road network and urban planning in order to enhance performance and efficiency.

The system developed through this research is essential to support urban transportation planning and management of Hajj. The system enables Hajj authorities to track and control pilgrims' movements, and to archive essential data for future urban transport planning and management.

Acknowledgment

This project is generously sponsored by the Center of Research Excellence in Hajj and Umrah and KACST GIS Technology Innovation Center at Umm Al-Qura University, Saudi Arabia. The authors express their sincere appreciation to their support.

References

1. Albar O (2005) Evaluating the roads and the services between the holy areas in Makkah. Makkah: Hajj committee.
2. Badwi A (1996) Using the Shuttle bus in Hajj for Turkish pilgrims. Makkah: Hajj Research Institute.
3. Badwi A (2003) Evaluating the vehicles and pedestrians movement between the holy areas in Makkah. Makkah: Hajj Research Institute.
4. Burrough P, (1986) Principles of Geographic Information Systems, 1st ed. Oxford University Press, New York 336.

5. Casello J, Nour A, Hellinga B (2009) Quantifying the Impacts of Transit Reliability on User Costs. Journal of the Transportation Research Board No. 2112, Transportation Research Board of the National Academies, Washington, D.C., pp. 136–141.
6. Catherine M (2007) Turkish Municipality Using RFID to Track Its Vehicles, RFID Journal.
7. Finkenzeller K (2003) RFID Handbook: Fundamentals and Applications in Contactless Smart Cards and Identification, 2nd Edition. USA. Wiley
8. Huang W, Shen Q (2005) GIS and related question summary", Journal of Northwest University for Nationalities (Natural Science) China, vol.26, no. 4, pp.64-69.
9. Kapetsky J, Travaglia C (1995) Geographical information systems and remote sensing: an overview of their present and potential applications in aquaculture. In: Nambiar, K.P.P., Singh, T. (Eds.), AquaTech '94: Aquaculture Towards the 21st Century. INFOFISH, Kuala Lumpur, pp. 187–208.
10. Koshak N, Fouda A (2008) Analyzing Pedestrian Movement in Mataf Using GPS and GIS to Support Space Redesign.Proceedings of DDSS 2008 (The 9th International Conference on Design and Decision Support Systems in Architecture and Urban Planning). July 7-10, 2008. The Netherlands.
11. Koshak N (2005) A GIS-Based Spatial-Temporal Visualization of Pedestrian Groups Movement to and from Jamart Area. Proceedings of CUPUM (International Conference on Computers in Urban Planning and Urban Management), June 29 - July 1, 2005, London, United Kingdom.
12. Koshak N (2006) Developing a Web-Based Geographic Information System for Hajj Traffic Plan. Journal of Urban Planning Research, Volume 6, Issue 6, May 2006.
13. Liu Y, Li Y, Zhou H (2007) Mine shaft traffic control system research and development based on radio frequency technology, Mining machinery China, vol. 35, no. 11, pp.53-55.
14. Manish B, Shahram M (2005) RFID Field Guide: Deploying Radio Frequency Identification Systems, Prentice Hall PTR.
15. Nath S, Bolte J, Ross L, Aguilar-Manjarrez J. (2000). Applications of geographical information systems (GIS) for spatial decision support in aquaculture. Aquacultural Engineering 23:233-278.
16. Nour A, Casello J, Hellinga B (2010) An Anxiety-Based Formulation to Estimate the Generalized Cost of Transit Travel Time. The Journal of the Transportation Research Board No. 2143, Transportation Research Board of the National Academies, Washington, D.C., pp. 108–116.

17. Swedberg C (2008) Land Rover Finds ROI in Tracking New Cars, RFID Journal.
18. Tuttle John R (1997) Traditional and Emerging Technologies and Applications in the Radio Frequency Identification (RFID) Industry, IEEE Radio Frequency Integrated Circuits Symposium
19. Wang A, Sheng X (2007) RFID technology and application, Beijing: Chinese Commodity Publishing house.
20. Wang J, Zhang Y, Wang J (2007) Query method in real time based on GIS for underground personnel safety monitoring", Journal of Liaoning Technical University China, vol.26, no.4, pp.505-508.
21. You Z, Li S (2004) Wireless radio frequency recognition technology (RFID) theory and application, Beijing: Electronics industry publishing house.
22. Zhang S, Yuan F (2006) RFID technique and its application in safety management system for people and vehicle in mine shafts", Southern metals China, sum.148, no.1, pp.12-14.