products through an examination of slaughtering processes at abattoirs [2], although many abattoirs and retailers do not have a HMC certificate. At present, there is no effective mechanism that allows retailers (or consumers) to monitor or check the Halal meat integrity throughout existing HMSC including farms, abattoirs, stores, transporters and retailers. A survey by authors indicates that there are a number of concerns about the Halal meat integrity; these include feeding and growing history of livestock at farms, slaughtering processes at abattoirs and Halal meat transportation from abattoirs to retailers. Nevertheless, this research topic is overlooked by researchers [3], [4]. Mohd et al proposed a method used for identifying slaughtered poultry simply based on meat colors to determine if the poultry is slaughtered properly according to the Halal way [5]. Siti et al proposed a tracking system for enhancing the traceability of Halal product integrity using the RFID technology [6]. Syahrul et al suggested a mobile Halal product verification method using the camera-phone barcode scanning technique [7]. Murizah et al synthesized a similar system that uses the mobile application allowing customers to check Halal product information directly through their mobile phones [8].

Food traceability plays a crucial role in monitoring safety and quality of foods at each phase of supply chains during production, storage, transportation and distribution [9], [10]. In the past decade, RFID techniques have been widely used as one of the most popular IT applications that are implemented particularly into logics and supply chain sectors. Zhang et al introduced an RFID-based system that was applied for improving traceability of frozen foods during storage and transportation in order to reduce the number of recalls. The system was built by combining RFID, GPS and mobile applications that monitors data of food temperatures and arrival times [11]. Expósito et al developed an RFID-based monitoring system used for tracing a wine supply chain in which the system was implemented using RFID tags and wireless sensor networks. The developed system collects data via a GPRS system that monitors quality of wine and the collected information data can also be accessed online by consumers [12]. Feng et al proposed a traceability system by integrating RFID applications into a personal digital assistant (PDA) system, which is a handheld PC used by operators at the segmentation section for collecting data of the segmented beef and it prints out information data in a form of barcode label [13] for each packed product.

In order to identify the origin of agricultural products, Sun et al developed an anti-counterfeit RFID-GPS system in which GPS data and encrypted Chinese-sensible codes were applied [14]. Barge et al described a so-called item-level traceability system by attaching RFID tags with products of cheese in a dairy factory [15]; similar studies were presented by Hsu et al [16], Abada et al [17] and Mira et al [18]. For maintaining the freshness of perishable foods during the period of storage, transportation and sale, Chen et al proposed a new type of RFID application named 2G-RFID-Sys using Internet of Things (IoT) technology with RFID sensor tags (semi-passive tags integrated with sensors) that monitors food temperatures in a refined smart cold supply chain [19]. Jedermanna et al developed a smart-container system that combines RFIDs with sensor networks and software agents that monitor the freshness of fruits during transportation [20]. Wang et al discussed a real-time monitoring online decision support system which was used for reducing losses of delivered perishable products. The system includes a forecast module that predicts the quality of perishable products providing drivers with suggestions as to how to cope with an abnormality when an alert was received during transportation [21].

This paper describes architecture of an RFID-enabled HMSC. The paper illustrates an RFID-

based monitoring process and an RIFD-based monitoring system that enhances traceability of Halal meat integrity throughout the HMSC. In order to investigate the proposed HMSC network, a multi-objectives mathematical model was developed to describe the proposed HMSC with a case study that was used for testing the applicability of the HMSC. A Petri-net model was also developed for examining the network performance of the proposed HMSC in order to gain initial outcomes based on the developed simulation model as part of the feasibility investigation.

2 THE RFID-ENABLED HMSC

To ensure the integrity of Halal meats sold in supermarkets, Figure 1 illustrates the architecture of the simplified RFID-enabled HMSC with GPS and mobile applications used for monitoring each process of Halal meat production and transportation. The proposed RFID-based Halal meat supply chain consists of farms, abattoirs, transporters, retailers and consumers as described below:

- In farms: Each livestock is attached with an embedded RFID-sensor tag in which each sensor is used for transmitting information data in the relevance to each livestock's health status in such as heart beats and body temperatures. Each RFID tag contains information data of the tagged livestock with a unique identification code. Information data are collected by wireless RFID readers that interrogate RFID-sensor tags by emitting radio signals and subsequently the RFID tag responds to the RFID reader by sending back information data. The gathered information data by RFID readers are sent to a host computer management system. Water supply for each livestock is monitored by a water sensor mounted on a water basin. When contaminated water is detected by a water sensor, it sends an alert to the computer management system and farmers ought to isolate those contaminated livestock immediately from others. Periodically, farmers should also take any medical record of livestock relating to illnesses, medical treatments and treatment results during the growing period. The record should include information of given growing enzymes that do not contain pork enzymes which make livestock as non-Halal. The growing history of each livestock needs to be input into the computer management system. The collected information data are analyzed and displayed as shown in Table 1 allowing consumers to check relevant information in terms of integrity of Halal meat products they purchase in supermarkets by either entering product codes online or scan them using their smart mobiles.
- In abattoirs: Because each livestock is attached with an RFID tag, once these transported livestock from farms enter into abattoirs through an RFID-reader mounted gate, information data of each livestock will be collected and stored automatically in database of an abattoir computer management system. To comply with the Halal slaughtering process [22], slaughtering places must be monitored by abattoir operators through installed cameras. If a livestock is not slaughtered according to the Hahal way, this livestock needs to be isolated and marked as non-Halal. At the end of the slaughtering process, each segmented meat is packed and tagged with a new RFID sensor tag that is used for monitoring its pH values on which a typical pH value for meats ranges from 4.8 to 5.8 [23]. The information data can be collected by an RFID handheld reader and the collected information data are subsequently sent back to the abattoir's computer management system.
- In transportation: During transportation of Halal meats from abattoirs to retailers, it is traced by a GPS system. The detail of this is illustrated in subsection 2.1.

- At retailers or supermarkets: Once packed meats from abattoirs arrive into retailers or supermarkets, each packed meat is scanned by a handheld RFID reader to collect information data that are subsequently uploaded into an inventory management system of a retailer or supermarket. Meats in each package may then be sliced and repacked in smaller sizes and each packed meat is tagged with a barcode label that contains relevant information of the packed meat product as shown in Table 2. Each barcode can be used for tracing in-store meat products and individual consumers can check relevant information on purchased products by entering barcodes online or using a mobile code scanner.

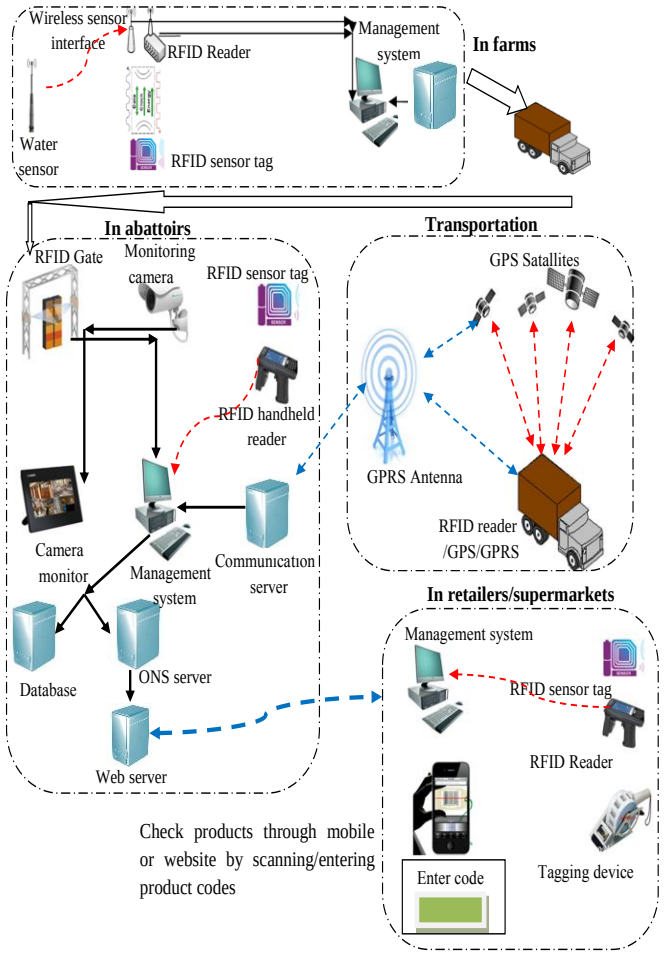

Figure 1. Architecture of the proposed RFID-enabled HMSC

Table 1. Growing history of a livestock in farms

Info category	Info details
Category	Beef
Feeding methods	Halal
Types of diseases /symptoms	Bovine Ephemeral Fever
Treatment duration	4 days
Treatment results	Healed
Growing History/Kg	10Kg/8mth
Enzyme History	None
Last Update of Info	11/02/15

Table 2. Information of a packed meat product in abattoirs to be sold at retailers or supermarkets

Info category	Info details
Meat type	Beef
Origin of meat	Scotland
Slaughtering date	12/08/14
Slaughterer Name	Omar
Arrival date to the shop	13/08/14

Figure 2 shows a flowchart that illustrates the complete monitoring process during Halal meat production (in farms and abattoirs) and transportation and in retailers. Table 3 shows the corresponding operations (or actions) that may be taken into account in order to maintain Halal meat integrity throughout the proposed HMSC network.

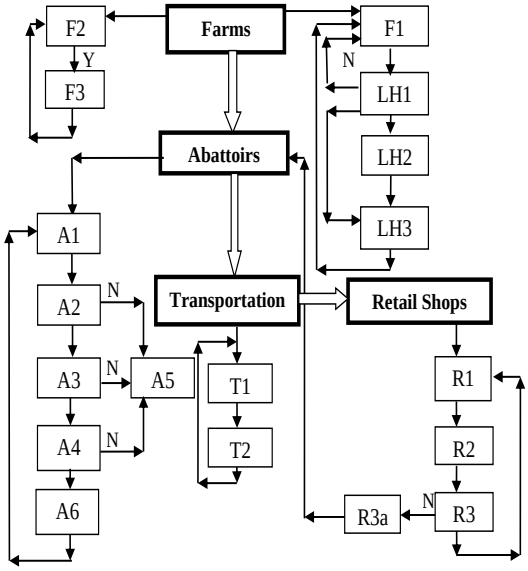

Figure 2. The Halal monitoring process of a HMSC

Table 3. The corresponding operations or actions of a HMSC monitoring process shown in Figure 2

Operations	Description
Fx	**Farms**
F1	Each livestock is attached with an RFID tag.
F2	A water sensor is installed at a water basin to detect water contamination; the water sensor sends an alert to the management system if water is contaminated at the water basin.
F3	Identify and separate the livestock watered by the contaminated water basin.
LHx	
LH1	Record any disease of a livestock by entering medical information data into the computer management system.
LH2	Identify and separate the infected livestock.
LH3	Update the management system by entering types of diseases and results of treatments of the infected livestock.
Ax	**Abattoirs**
A1	Receive inventory data of RFID-tagged livestock through an RFID-reader mounted gate at an abattoir.
A2	Monitor the Halal slaughtering process by operators through cameras to ensure that each livestock is slaughtered with absence of other livestock at a slaughtering station.
A3	Knife must be invisible to each slaughtered livestock.
A4	Each slaughtered livestock's head is held at a certain position for 25 seconds to allow draining contaminated blood.
A5	Separate and mark each slaughtered livestock as non-Halal if the slaughtering process does not follow steps A2-4.
A6	Attach each slaughtered livestock with an RFID sensor tag for monitoring meat quality during transportation; collect its information data by an RFID handheld reader.
Tx	**Transportation**
T1	Detect temperatures of each container by a sensor that sends an alert to notify drivers if the detected temperature reaches above the upper limit.
T2	Identify, separate and return any stale meat to the abattoir.
Rx	**Retailers**
R1	Operators unload arrived meats to stores of a retailer, scan RFID tags by a handheld RFID reader for acquisition of inventory data.
R2	Segment and repack meats in small packages tagged with barcode labels ready for sales.
R3	Consumers check information of Halal meat integrity by scanning the product barcode using a mobile scanner or enter the barcode online.
R3a	Retailers return non-Halal meat products to abattoirs.

2.1 The monitoring system during transportation of Halal meats

Figure 3 illustrates the architecture of the proposed monitoring system during transportation of Halal meats from abattoirs to retailers. Each container of a lorry is equipped with an RFID reader, a GPS, a temperature sensor and a GPRS transmitter. The GPS is used for tracking locations of the lorry providing an estimated arrival time to retailers. The information data collected by an RFID reader and a GPS are sent back to the abattoir management system via a GPRS transmitter through which all active transmissions between tags and readers can share available resources. Also, it uses a packet switch technique allowing an allocation of resources when needed.

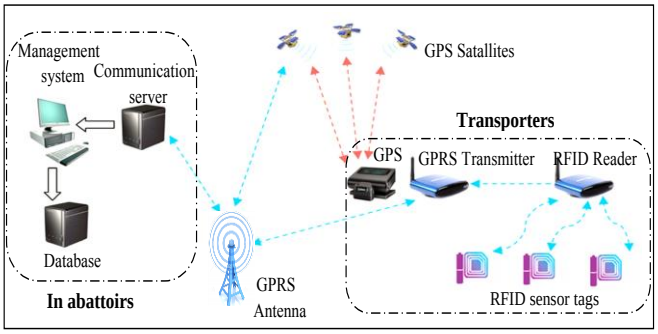

Figure 3. The transportation monitoring system

3 THE HMSC MATHEMATICAL MODEL

The following mathematical model describes the proposed HMSC focusing on three objectives. The first objective (Z1) is to minimize the total investment cost, the second

objective (Z_2) is to maximize the Halal integrity meats and the third objective (Z_3) is to maximize ROI (return of investments, i.e., profit). Sets, parameters and decision variables are as follows:

Sets

a_i set of farms where $i \in$ I

g_j set of abattoirs where $j \in$ I

e_k set of retailers where $k \in$ I

Parameters:

T_i^a cost of equipment for farm i

T_j^g cost of equipment for abattoir j

O_i^a cost of implementation for farm i

O_j^g cost of equipment for abattoir j

O_{ij}^{ag} cost of transportation per mile for farm i to abattoir j

O_{jk}^{ge} cost of transportation per mile for abattoir j to retailer k

d_{ij} travel distance from farm i to abattoir j

d_{jk} travel distance from abattoir j to retailer k

V transportation capacity per vehicle

S_i^a maximum supply capacity of farm i

S_j^g maximum supply capacity of farm j

D_j^g minimum demand of abattoir j

P_{ij}^{ag} integrity percentage from farm i to abattoir j

P_{jk}^{ge} integrity percentage from abattoir j to retailer k

R_i^a rate of return of investment per item for farm i

R_j^g rate of return of investment per item for abattoir j

Variables:

Z_i^a = 1, if farm i is open
0, if otherwise

Z_j^g = 1, if abattoir j is open
0, if otherwise

Y_{ij}^{ag} quantity of shipped meat from farm i to abattoir j

Y_{jk}^{ge} quantity of shipped meat from abattoir j to retailer k

The developed models are shown below:

$$MinZ1 = \sum_{i \in I}(T_i^a + O_i^a)Z_i^a + \sum_{j \in J} T_j^g + O_j^g)Z_j^g \quad (1)$$
$$+ \sum_{i \in I}\sum_{j \in J} Q^{ag}[Y_{ij}^{ag} / V \times d_{ij}] + \sum_{k \in K} Q^{ge}[Y_{jk}^{ge} / V \times d_{jk}]$$

$$MaxZ2 = \sum_{i \in I}\sum_{j \in J} P_{ij}^{ag} Y_{ij}^{ag} + \sum_{j \in J}\sum_{k \in K} P_{jk}^{ge} Y_j^{ge} \quad (2)$$

$$MaxZ3 = \sum_{i \in I} R_i^a \sum_{j \in J} Y_{ij}^{ag} + \sum_{j \in J} R_j^g \sum_{k \in K} Y_{jk}^{ge} \quad (3)$$

Where constraints are as follows:

$$\sum_{j \in J} Y_{ij}^{ag} \le S_i^a Z_i^a \qquad \forall i \in I \quad (4)$$

$$\sum_{k \in K} Y_{jk}^{ge} \le S_j^g Z_j^g \qquad \forall j \in J \quad (5)$$

$$\sum_{i \in I} Y_{ij}^{ab} \ge D_j^g \qquad \forall j \in J \quad (6)$$

$$\sum_{j \in J} Y_{jk}^{ge} \ge D_k^e \qquad \forall k \in K \quad (7)$$

$$\sum_{k \in K} Y_{jk}^{ge} \ge D_j^g \qquad \forall j \in J \quad (8)$$

$$Z_j^a, Z_j^g, Z_k^e \in \{0,1\} \quad \forall i, j, k \quad (9)$$

4 THE HMSC PETRI-NET MODEL

A Petri-net model was developed for examining the network performance of the proposed HMSC. The Petri-net model is a graphical simulation model that is often used for modeling a network and analyzing the network behavior or performance. Figure 4 shows a screenshot of the developed HMSC Petri-net

model in which a token represents information data that are transmitted between nodes. Each node stands for a device or the computer management system used for the proposed RFID-based HMSC network. Figure 5 shows initial simulation outcomes in terms of network performance of information flow between these devices within the proposed RFID-enabled HMSC network.

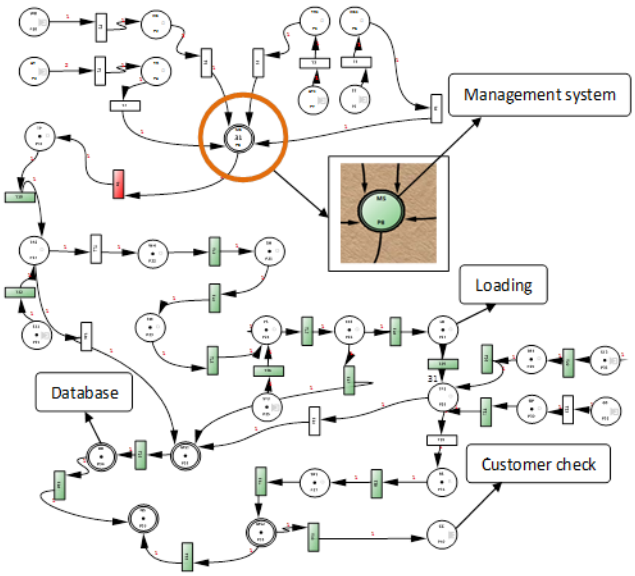

Figure 4. The Petri-net model of the HMSC network

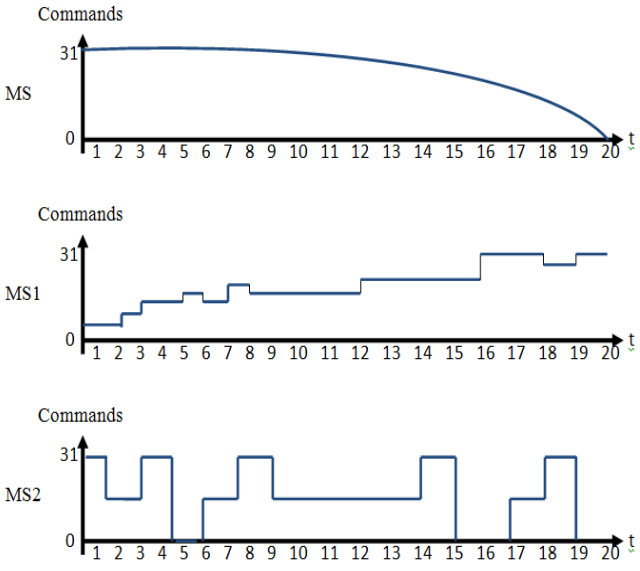

Figure 5. Results in network performance of the proposed HMSC information flow

4 CONCLUSIONS

This paper presents a feasibility study by examining and proposing an RFID-based monitoring process that enhances the integrity of Halal meat supply chains. This includes a framework of an RFID-based monitoring system to collect rather accurate and real-time information data to improve the traceability of Halal meat products at each stage in production and transportation sectors. Retailers and consumers can also check meat product information that relates to Halal meat integrity online or using mobile phones. A multi-objective mathematical model was developed for making a trade-off decision on the proposed RFID-enabled HMSC. Subsequently, a Petri-net model of the proposed HMSC network was also developed for obtaining some initial results to investigate the HMSC network performance.

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