Industrial Management & Data Systems

A cost-effective decision-making algorithm for an RFID-enabled HMSC network design: A multi-objective approach

Ahmed Mohammed, Qian Wang, Xiaodong Li,

Received 21 February 2016
Revised 31 July 2016
3 October 2016
16 October 2016
Accepted 17 October 2016

A cost-effective decision-making algorithm for an RFID-enabled HMSC network design

A multi-objective approach

Ahmed Mohammed and Qian Wang
School of Engineering, University of Portsmouth, Portsmouth, UK, and
Xiaodong Li
Department of Mathematics, University of Portsmouth, Portsmouth, UK

Abstract

Purpose – The purpose of this paper is to investigate the economic feasibility of a three-echelon Halal Meat Supply Chain (HMSC) network that is monitored by a proposed radio frequency identification (RFID)-based management system for enhancing the integrity traceability of Halal meat products and to maximize the average integrity number of Halal meat products, maximize the return of investment (ROI), maximize the capacity utilization of facilities and minimize the total investment cost of the proposed RFID-monitoring system. The location-allocation problem of facilities needs also to be resolved in conjunction with the quantity flow of Halal meat products from farms to abattoirs and from abattoirs to retailers.

Design/methodology/approach – First, a deterministic multi-objective mixed integer linear programming model was developed and used for optimizing the proposed RFID-based HMSC network toward a comprised solution based on four conflicting objectives as described above. Second, a stochastic programming model was developed and used for examining the impact on the number of Halal meat products by altering the value of integrity percentage. The ε-constraint approach and the modified weighted sum approach were proposed for acquisition of non-inferior solutions obtained from the developed models. Furthermore, the Max-Min approach was used for selecting the best solution among them.

Findings – The research outcome shows the applicability of the developed models using a real case study. Based on the computational results, a reasonable ROI can be achievable by implementing RFID into the HMSC network.

Research limitations/implications – This work addresses interesting avenues for further research on exploring the HMSC network design under different types of uncertainties and transportation means. Also, environmentalism has been becoming increasingly a significant global problem in the present century. Thus, the presented model could be extended to include the environmental aspects as an objective function.

Practical implications – The model can be utilized for food supply chain designers. Also, it could be applied to realistic problems in the field of supply chain management.

Originality/value – Although there were a few studies focusing on the configuration of a number of HMSC networks, this area is overlooked by researchers. The study shows the developed methodology can be a useful tool for designers to determine a cost-effective design of food supply chain networks.

Keywords Multi-objective optimization, RFID, Halal, Supply chain design, Facility location-allocation problem, Stochastic programming

Paper type Research paper

The authors would like to express the authors' gratitude to the Higher Committee for Education Development (HCED) in Iraq for the financial support in this study. Also, the authors would like to thank the anonymous referees whose thorough reviews and insightful comments made a valuable contribution to this paper.

Industrial Management & Data Systems
Vol. 117 No. 9, 2017
pp. 1782-1799
Emerald Publishing Limited
0263-5577
DOI 10.1108/IMDS-02-2016-0074

Nomenclature

Deterministic model

Sets

I	set of farms $i\in I$
J	set of abattoirs $j\in J$
K	set of retailers $k\in K$

Given parameters

$C_i^{E,\alpha}$	RFID equipment (E) cost required for farm i
$C_j^{E,\beta}$	RFID equipment (E) cost required for abattoir j
$C_i^{I,\alpha}$	RFID implementation (I) cost required for farm i
$C_j^{I,\beta}$	RFID implementation (I) cost required for abattoir j
C_i^t	RFID tag cost per item at farm i
C_j^t	RFID tag cost per item at abattoir j
$C_{ij}^{T,u}$	unit transportation (T) cost per mile from farm i to abattoir j
$C_{jk}^{T,v}$	unit transportation (T) cost per mile from abattoir j to retailer k
$C_i^{h,\alpha}$	handling cost per item at farm i
$C_j^{h,\beta}$	handling cost per item at abattoir j
d_{ij}^u	travel distance of livestock from farm i to abattoir j
d_{jk}^v	travel distance of Halal meat products from abattoir j to retailer k
W	transportation capacity per vehicle
S_i^α	maximum supply capacity of farm i
S_j^β	maximum supply capacity of abattoir j
D_j^β	minimum demand of abattoir j
D_k^γ	minimum demand of retailer k
P_{ij}^u	integrity percentage of livestock through first transportation link u from farm i to abattoir j
P_{jk}^v	integrity percentage of meat products through second transportation link v from abattoir j to retailer k
R_i^α	return of investment for farm i
R_j^β	return of investment per item for abattoir j

Decision variables

x_{ij}^u	quantity of units transported through the first transportation link u from farm i to abattoir j
x_{jk}^v	quantity of units transported through second transportation link v from abattoir j to retailer k
y_i^α	{1: if farm i is open, 0: otherwise
y_j^β	{1: if abattoir j is open, 0: otherwise

Stochastic model

Sets

Ω	set of scenarios $\xi\in\Omega$

Given parameters

$P_{ij\xi}^u$	integrity percentage of livestock through the first transportation link u from farm i to abattoir j in scenario ξ
$P_{jk\xi}^v$	integrity percentage of meat products through the second transportation link v from abattoir j to retailer k in scenario ξ
Prob ξ	Probability of scenario ξ

Decision variables

$x_{ij\xi}^u$	quantity of units transported through the first transportation link u from farm i to abattoir j in scenario ξ
$x_{jk\xi}^v$	quantity of units transported through the second transportation link v from abattoir j to retailer k in scenario ξ
$y_{i\xi}^\alpha$	{1: if farm i in scenario ξ is open, 0: otherwise
$y_{j\xi}^\beta$	{1: if abattoir j in scenario ξ is open, 0: otherwise

1. Introduction

Today, a cost-effective design of efficient food supply chain networks is crucial for retailers to maintain a share in the increasingly competitive market. The design of a food supply chain network, however, often involves a trade-off decision-making process by minimizing its total cost and transportation time, whilst maintaining quality of food to be delivered to customers. In practice, such a trade-off decision may also vary over time due to the consistent change in conditions of the unpredictable market. Thus, the performance of a supply chain network needs also to be evaluated consistently providing a timely and right decision based on alternative solutions (Shen, 2007; Shankar *et al.*, 2013).

In recent years, safety and quality of food has been the major issue on which consumers require more transparent information relating to food they purchase at supermarkets. For Muslim communities in the UK, integrity of Halal food is essential. The Islamic term Halal means “allowed” or “permitted” in its English translation and it is often used to describe food products that are permissible for Muslims to eat or drink under the Islamic Shari’ah (laws). Production of Halal meat products, for instance, needs to comply with the Islamic Shari’ah in each process of livestock feeding, slaughtering, packing, storing and transporting before being sold at supermarkets. If a specific process of the Halal Meat Supply Chain (HMSC) is not handled, accordingly, retailers and consumers at the end of the chain may treat these meat products as non-Halal. Today, consumption of Halal meat products is a well-known diet not merely among Muslim but also many non-Muslim people and Halal meat production and distribution is one of fast-growing sectors in the world. However, the HMSC concept is a challenge and often confusing for supply chain designers because of the specific rules that need be followed. A radio frequency identification (RFID)-based monitoring system was proposed to monitor the process in production throughout the HMSC and distribution through the transportation (Mohammed and Wang, 2015). The implementation of RFID is subject to extra costs that may break-down the chain in presenting an unfeasible supply chain network in terms of economical costs. Consequently, it is important to optimize the HMSC network design to balance the extra costs and merchandize quality. The optimization of an RFID-enabled HMSC is a typical multi-objective problem since it is associated with several variables and imprecise parameters. Nevertheless, this field is overlooked by researchers, although there were a few studies focusing on various configurations rather than optimizations of HMSC networks (Lodhi, 2009; Zulfakar *et al.*, 2012).

This paper contributes to the knowledge in investigating the economic feasibility of a three-echelon HMSC network that is monitored by implementing an RFID-based system to improve the integrity traceability of Halal meat products. To help design a cost-effective RFID-based HMSC network, first, a deterministic four-objective mixed integer linear programming model was developed and used for investigating the proposed RFID-based HMSC network in terms of number of facilities to open to the HMSC network and optimal quantity flow of Halal meat products towards a compromised solution based on four conflicting objectives: minimizing the total investment cost of the HMSC network, maximizing the average integrity number of Halal meat products, maximizing the return of investment (ROI) and maximizing the capacity utilization (percent) of facilities (i.e. farms and abattoirs) and a comparison in the total investment cost using the RFID-based HMSC and the non-RFID-based HMSC. Second, a stochastic programming model was developed and used for examining the effect on the HMSC network design by altering the integrity percentage of Halal meat products. To obtain non-inferior solutions based on the developed multi-objective model, two methods were used. This includes the ε-constraint approach and the modified weighted sum (MWS) approach that aim at obtaining accurate non-inferior solutions values. Subsequently one of these solutions can be selected using the Max-Min approach. The study shows that the proposed models can be a useful tool as a decision maker for HMSC supply chains network design.

2. Literature review

Related research is reviewed under two categories: RFID-enabled applications in supply chain management and multi-objective approaches in solving supply chain problems.

In the context of food supply chains, many studies using RFID techniques for improving tracecibility in ensuring safety and/or originality of food products provided in food supply chain sectors (Manos and Manikas, 2010; Zailani *et al.*, 2010). Kelepouris *et al.* (2007) studied the main requirements of traceability and examined how the technology of RFID can address these requirements. Expósito *et al.* (2013) proposed an RFID-based monitoring system used for tracing a wine supply chain. Barge *et al.* (2014) described an item-level traceability system for cheese products in a dairy factory as each piece of cheese is attached with an RFID tag containing cheese identifications such as cheese type, production date and expiry date. Chen *et al.* (2014) proposed a new type of RFID application, namely, 2G-RFID-Sys using the Internet of Things technology with RFID sensor tags (semi-passive tags integrated with sensors) that can monitor food temperatures in a refined smart cold supply chain.

Furthermore, the implementation of RFID technology has been gaining an ever-increasing popularity in different applications in logistics and supply chain management (Nath *et al.*, 2006; Hou and Huang, 2006; So Park *et al.*, 2010). Rafique *et al.* (2016) presented a literature study that shows how RFID-based lean manufacturing is helpful for handling barriers affecting lean manufacturing. Lu *et al.* (2006) presented a framework and five-step deployment process aimed at developing a holistic approach for implementing RFID-enabled manufacturing in manufacturing enterprises. Wang *et al.* (2010) discussed the trend of RFID-based supply chains and logistics sectors in a future prospective view. Giadaa *et al.* (2016) developed a smart logistic unit based on radio frequency technology to support the management of the food supply chain, in order to guarantee the shelf life of products in agreement with logistic efficiency and system sustainability. Zhong *et al.* (2013) proposed a RFID-enabled real-time manufacturing execution system for mass-customization production shop-floor management including real-time data collection, real-time scheduling as well as real-time work in progress tracing and tracking.

Multi-objective optimization refers to an optimization of multiple decision-making objectives concurrently. These objectives are possibly conflicting. The multi-objective mathematical model can be useful for solving the facility location-allocation problem of a supply chain design based on conflicting objectives (Gen and Cheng, 1997; Deb, 2001; Barros *et al.*, 1998; Jayaraman *et al.*, 1999; Krikke *et al.*, 1999; Mohammed and Wang, 2017). These objectives may be involved in such as minimization of costs of investing and running a supply chain network, maximization of its incomes and customer satisfaction and minimization of the environmental impacts (Ding *et al.*, 2006; Villegas *et al.*, 2006; Bhattacharya and Bandyopadhyay, 2010; Cheshmehgaz *et al.*, 2013; Hiremath *et al.*, 2013). Nozick and Turnquist (2001) proposed a mathematical model used for optimization of locations of distribution centers based on costs of facility, inventory, transportation and service coverage. Cakravastia *et al.* (2002) provided a mixed integer multi-objective model for determining a selection of suppliers of a supply chain. Chen and Lee (2004) introduced a multi-product, multi-stage and multi-period scheduling model used for seeking a fair profit distribution, a safe inventory level and a maximum customer service level. Guilléna *et al.* (2005) formulated a mixed integer multi-objective mathematical model used for optimizing a supply chain design by achieving a maximization of the total profit under uncertainty of financial risk and demand. The similar studies were conducted by Shen (2006), Bojarski *et al.* (2009) and Chibeles-Martins *et al.* (2012). Tzeng *et al.* (2006) offered a production and distribution model using a multi-objective programming method for maximizing profits of the enterprise and quality of customer services. For the research work of multi-objective approaches, it can refer to a study by Shen *et al.* (2003). Sabri and Beamon (2000) developed a two-objective programming model aiming to minimize the total cost and maximize the volume flexibility of plants of a supply chain. Lee and Dong (2009) proposed a mathematical model for optimizing the design of a closed-loop supply chain network using the scenario-based programming method. Vahdani *et al.* (2012) developed a fuzzy bi-objective optimization model in assisting the design of a closed-loop supply chain by minimizing costs of facilities and transportation as objectives. In other studies, Kannan *et al.* (2012) developed an integrated, multi echelon, multi-period, multi-product mixed integer linear programming model used for optimizing the distribution and inventory level of a closed-loop supply chain network using a genetic algorithm. Niknamfar (2015) presented a multi-objective non-linear model using a non-dominated sorting genetic algorithm and a non-dominated ranking genetic algorithm for solving a production-distribution planning problem of a three-level supply chain. Zhang *et al.* (2015) proposed a dynamical optimization method for shop-floor material handling based on real-time and multi-source manufacturing data. It integrates three important features including a new allocation strategy for move tasks, intelligent trolleys with the capability of active sensing and self-decision and the combination optimization method of move tasks to reduce the transport cost and energy. Teimoury *et al.* (2013) developed a multi-objective model for a supply chain of perishable fruits and vegetables. The model used for identifying the best import quota policy of fruits and vegetables. Harris *et al.* (2014) proposed a multi-objective optimization approach for solving a facility location-allocation problem for a supply chain network where financial costs and CO_2 emissions are considered as objectives. Talaei *et al.* (2015) presented a bi-objective facility location-allocation model for a closed-loop supply chain network design. Robust and fuzzy programming approaches were used to investigate the effects of uncertainties of the variable costs, as well as the demand rate on the network design. Bortolini *et al.* (2016) developed a three-objective distribution planner to tackle the tactical optimization issue of a fresh food distribution network. The optimization objectives were to minimize operating cost, carbon footprint and delivery time; the work, however, did not consider other costs and the effect of uncertainty that may occur.

The main contributions of this paper are:

(1) investigate the feasibility of a proposed RFID-based HMSC in terms of economic costs;

(2) design the HMSC network with respect to the additional costs in investment;

(3) present a trade-off among the considered objectives;

(4) examine the impacts of integrity uncertainty on the HMSC network design;

(5) develop a modified solution approach aiming to obtain accurate solutions values; and

(6) evaluate the potential benefits of the RFID-based HMSC in terms of costs by comparing it with the HMSC without using the RFID technology.

3. The HMSC network model

Figure 1 illustrates a three-echelon HMSC network, which consists of farms, abattoirs and retailers. To ensure the integrity of Halal meat products, an RFID-based monitoring system was proposed to monitor the process in production at farms and abattoirs and distribution through the transportation (Mohammed and Wang, 2015). In order to help designers determine a cost-effective HMSC design, a multi-objective mathematical model was developed as an aid for quantifying the investment cost, the ROI, the integrity number of Halal meat products and capacity utilization (percent) of the HMSC-related facilities.

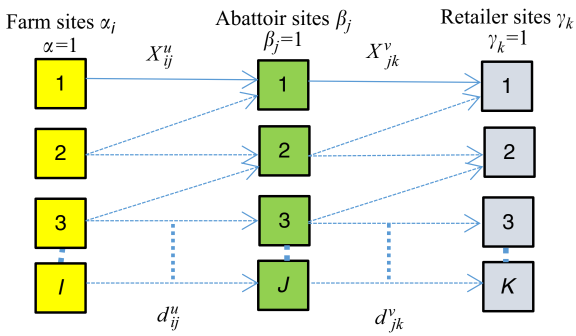


Figure 1.
The three-echelon HMSC

3.1 *The deterministic model*

Thus, the RFID-based HMSC multi-objective model can be formulated as follows:

$$\begin{aligned}\text{Min } OF_1 = &\sum_{i\in I}\left(C_i^{E,\alpha}+C_i^{I,\alpha}\right)y_i^\alpha+\sum_{j\in J}\left(C_j^{E,\beta}+C_j^{I,\beta}\right)y_j^\beta+\sum_{i\in I}\sum_{j\in J}C_i^t x_{ij}^u\\ &+\sum_{j\in J}\sum_{k\in K}C_j^t x_{jk}^v+\sum_{i\in I}\sum_{j\in J}C_i^{h,\alpha}x_{ij}^u+\sum_{j\in J}\sum_{k\in K}C_j^{h,\beta}x_{jk}^v+\sum_{i\in I}\sum_{j\in J}C_{ij}^{T,u}\left\lceil\frac{x_{ij}^u}{W}\right\rceil d_{ij}^u\\ &+\sum_{j\in J}\sum_{k\in K}C_{jk}^{T,v}\left\lceil\frac{x_{jk}^v}{W}\right\rceil d_{jk}^v-\sum_{i\in I}C_i^{h,\alpha}x_{ij}^u+\sum_{j\in I}C_j^{h,\beta}x_{jk}^v\end{aligned}\tag{1}$$

where OF_1 refers to the minimization of the total cost:

$$\text{Max } OF_2 = \sum_{i\varepsilon J}\sum_{j\varepsilon J}P_{ij}^u x_{ij}^u+\sum_{j\varepsilon J}\sum_{k\varepsilon K}P_{jk}^v x_{jk}^v\tag{2}$$

where OF_2 refers to the maximization of integrity number of Halal meat products:

$$\text{Max } OF_3 = \sum_{i\varepsilon I}\sum_{i\varepsilon J}R_i^\alpha x_{ij}^u+\sum_{j\in J}\sum_{k\in K}R_j^\beta x_{jk}^v\tag{3}$$

where OF_3 refers to the maximization of the ROI:

$$\text{Max } OF_4 = \sum_{i\in I}\sum_{j\in J}\frac{x_{ij}^u}{S^\alpha}+\sum_{j\in J}\sum_{k\in K}\frac{x_{jk}^v}{S^\beta}\tag{4}$$

where OF_4 refers to the maximization of capacity utilization (percent) of HMSC facilities.

By minimizing objective OF_1 based on the non-RFID-based HMSC model, it is given as follows:

$$\begin{aligned}\text{Min } OF_1^{\text{non}} = &\sum_{i\in I}\sum_{j\in J}C_{ij}^{T,u}\left|\frac{x_{ij}^u}{W}\right|d_{ij}^u+\sum_{j\in J}\sum_{k\in K}C_{jk}^{T,v}\left|\frac{x_{jk}^v}{W}\right|d_{jk}^v\\ &+\sum_{i\in I}C_i^{h,\alpha}x_{ij}^u+\sum_{j\in I}C_i^{h,\beta}x_{jk}^v\end{aligned}\tag{5}$$

Subject to the following constraints:

$$\sum_{i\in I}x_{ij}^u\leqslant S_i^\alpha y_i^\alpha\qquad\forall j\in J\tag{6}$$

$$\sum_{j \in J} x_{jk}^{v} \leqslant S_j^{\beta} y_j^{\beta} \qquad \forall k \in K \tag{7}$$

$$\sum_{i \in I} x_{ij}^{u} \geqslant D_j^{\beta} \qquad \forall j \in J \tag{8}$$

$$\sum_{j \in J} x_{jk}^{v} \geqslant D_k^{\gamma} \qquad \forall k \in K \tag{9}$$

$$D_j^{\beta} \geqslant \sum_{k \in K} x_{jk}^{v} \qquad \forall j \in J \tag{10}$$

$$x_{ij}^{u}, x_{jk}^{v} \geqslant 0, \quad \forall i, j, k; \tag{11}$$

$$y_i^{\alpha}, y_j^{\beta} \in \{0, 1\}, \quad \forall i, j \tag{12}$$

For Equation (1), it minimizes the total investment cost of the RFID-based HMSC. The total investment cost includes costs of RFID-related equipment and implementation, and transportation and material handling of Halal meat products. For Equation (2), it maximizes the integrity number of Halal meat products. For Equation (3), it maximizes the ROI. For Equation (4), it maximizes the capacity utilization (percent) of HMSC facilities. For Equation (5), it determines the minimum total cost for the non-RFID-based HMSC; the cost includes the transportation cost and the material handling cost. Equations (6) and (7) are capacity constraints of farms and abattoirs, respectively. For Equation (8)-(10), respectively, it ensures that all demands in product quantity are satisfied as requested by abattoirs and retailers. For Equation (11) and (12), respectively, it limits the decision variables to be binary and non-negative.

3.2 The stochastic model

The stochastic programming model is often used for dealing with uncertain parameters that may affect a scenario of a system or entity (Coello *et al.*, 2007; Birge and Louveaux, 1997; Al-Othman *et al.*, 2008). Considering a decision *y*, which is influenced by scenario *s* of element *r*, the result of decision *y* is defined by $z(y, r)$. Assuming a set of scenarios *S*, i.e. $\{r^s, s = 1, \ldots, S\}$ and P_s is the probability of r^s. By minimizing objective *OF*, it can be described as follows:

$$\text{Min } OF = \sum_{s=1}^{S} P_s z(y, r^s) \tag{13}$$

By minimizing objective OF_2 based on the stochastic objective function, it is given in the following formula:

$$\text{Max } OF_2 = \sum_{\xi \in \Omega} \sum_{i \varepsilon J} \sum_{j \varepsilon J} P_{ij_\xi}^{u} x_{ij_\xi}^{u} \text{Prob}_\xi + \sum_{\xi \in \Omega} \sum_{j \varepsilon J} \sum_{k \varepsilon K} P_{jk\xi}^{v} x_{jk\xi}^{v} \text{Prob}_\xi \tag{14}$$

where OF_2 refers to the maximization of integrity number of Halal meat products by altering the value of integrity percentage, subject to:

$$\sum_{i \in I} x_{ij\xi}^{u} \leqslant S_i^{\alpha} y_{i\xi}^{\alpha} \qquad \forall (j \in J; \xi \in \Omega) \tag{15}$$

$$\sum_{j \in J} x_{jk\xi}^{v} \leqslant S_j^{\beta} y_{j\xi}^{\beta} \qquad \forall (k \in K; \xi \in \Omega) \tag{16}$$

$$\sum_{i \in I} x^u_{ij\xi} \geqslant D^\beta_j \qquad \forall (j \in J; \xi \in \Omega) \tag{17}$$

$$\sum_{j \in J} x^v_{jk\xi} \geqslant D^\gamma_k \qquad \forall (k \in K; \xi \in \Omega) \tag{18}$$

$$D^\beta_j \geqslant \sum_{k \in K} x^v_{jk\xi} \qquad \forall (j \in J; \xi \in \Omega) \tag{19}$$

$$x^u_{ij\xi}, x^v_{jk\xi} \geqslant 0, \quad \forall i, j, k, \xi; \tag{20}$$

$$y^\alpha_{i\xi}, y^\beta_{j\xi} \in \{0, 1\}, \quad \forall i, j, \zeta \tag{21}$$

4. Solution approaches

In order to obtain non-inferior solutions based on a multi-objective model, a number of solution approaches were found through a literature review. In this work, the ε-constraint approach and the MWS approach were utilized as described below.

4.1 The epsilon-constraint approach

With this approach, the multi-objective model can be converted into a mono-objective model in which a single objective is optimized and other objectives are shifted to the constraints to be less than or equal to a given target value ε_n that gradually varies from a minimum value to a maximum value of the constrained objective (Ehrgott, 2005). By minimizing objective *OF*, the equivalent objective function can be formulated as follows:

$$\begin{aligned} \text{Min } OF = & \sum_{i \in I} \left(C^{E,\alpha}_i + C^{I,\alpha}_i \right) y^\alpha_i + \sum_{j \in J} \left(C^{E,\beta}_j + C^{I,\beta}_j \right) y^\beta_j + \sum_{i \in I} \sum_{j \in J} C^t_i x^u_{ij} \\ & + \sum_{j \in J} \sum_{k \in K} C^t_j x^v_{jk} + \sum_{i \in I} \sum_{j \in J} C^{h,\alpha}_i x^u_{ij} + \sum_{j \in J} \sum_{k \in K} C^{h,\beta}_j x^v_{jk} + \sum_{i \in I} \sum_{j \in J} C^{T,u}_{ij} \left\lceil \frac{x^u_{ij}}{W} \right\rceil d^u_{ij} \\ & + \sum_{j \in J} \sum_{k \in K} C^{T,v}_{jk} \left\lceil \frac{x^v_{jk}}{W} \right\rceil d^v_{jk} - \sum_{i \in I} C^{h,\alpha}_i x^u_{ij} + \sum_{j \in I} C^{h,\beta}_i x^v_{jk} \end{aligned} \tag{22}$$

Equation (22) is subject to the following constraints:

$$\left(\sum_{i \varepsilon J} \sum_{j \varepsilon J} P^u_{ij} x^u_{ij} + \sum_{j \varepsilon J} \sum_{k \varepsilon K} P^v_{jk} x^v_{jk} \right) \geqslant \varepsilon_1 \tag{23}$$

$$\left(\sum_{i \varepsilon J} \sum_{j \varepsilon J} P^u_{ij} x^u_{ij} + \sum_{j \varepsilon J} \sum_{k \varepsilon K} P^v_{jk} x^v_{jk} \right)^{\min} \leqslant \varepsilon_1 \leqslant \left(\sum_{i \varepsilon J} \sum_{j \varepsilon J} P^u_{ij} x^u_{ij} + \sum_{j \varepsilon J} \sum_{k \varepsilon K} P^v_{jk} x^v_{jk} \right)^{\max} \tag{24}$$

$$\left(\sum_{i \varepsilon I} \sum_{j \varepsilon J} R^\alpha_i x^u_{ij} + \sum_{j \in J} \sum_{k \in K} R^\beta_j x^v_{jk} \right) \geqslant \varepsilon_2 \tag{25}$$

$$\left(\sum_{i\varepsilon I}\sum_{j\varepsilon J}R_i^\alpha x_{ij}^u+\sum_{j\in J}\sum_{k\in K}R_j^\beta x_{jk}^v\right)^{\min}\leqslant\varepsilon_2\leqslant\left(\sum_{i\varepsilon I}\sum_{j\varepsilon J}R_i^\alpha x_{ij}^u+\sum_{j\in J}\sum_{k\in K}R_j^\beta x_{jk}^v\right)^{\max} \tag{26}$$

$$\left(\sum_{i\in I}\sum_{j\in J}\frac{x_{ij}^u}{S^\alpha}+\sum_{j\in J}\sum_{k\in K}\frac{x_{jk}^v}{S^\beta}\right)\geqslant\varepsilon_3 \tag{27}$$

$$\left(\sum_{i\in I}\sum_{j\in J}\frac{x_{ij}^u}{S^\alpha}+\sum_{j\in J}\sum_{k\in K}\frac{x_{jk}^v}{S^\beta}\right)^{\min}\leqslant\varepsilon_3\leqslant\left(\sum_{i\in I}\sum_{j\in J}\frac{x_{ij}^u}{S^\alpha}+\sum_{j\in J}\sum_{k\in K}\frac{x_{jk}^v}{S^\beta}\right)^{\max} \tag{28}$$

Additional constraints include Equations (6)-(12).

In the above model, the first objective is retained as an objective function in Equation (22), and objective functions 2-4 were considered as constraints; i.e. Equation (23) restricts the value of the second objective function to be greater than or equal to ε_1 that varies between a minimum value and a maximum value for objective 2 as Equation (24). Equation (25) restricts the value of the third objective function to be greater than or equal to ε_2 that varies between a minimum value and a maximum value for objective 3 in Equation (26). Equation (27) restricts the value of the fourth objective function to be greater than or equal to ε_3 that varies between a minimum value and a maximum value for objective 4 in Equation (28).

4.2 The MWS approach

With the MWS approach, Z can be minimized by the formula as follows:

$$\text{Min } Z = Z_s - Z_d \tag{29}$$

where Z refers to the solution function. We know:

$$Z_s = \left[(w_1\mu_1)-(w_2\mu_2)-(w_3\mu_3)-(w_4\mu_4)\right] \tag{30}$$

$$s.t.\begin{cases}\mu_1=\left[\frac{OF_1-OF_1^{\cdot}}{OF_1^{\cdot}}\right]\\ \mu_2=\left[\frac{OF_2-OF_2^{\cdot}}{OF_2^{\cdot}}\right]\\ \mu_3=\left[\frac{OF_3-OF_3^{\cdot}}{OF_3^{\cdot}}\right]\\ \mu_4=\left[\frac{OF_4-OF_4^{\cdot}}{OF_4^{\cdot}}\right]\\ 0\geqslant w_n\geqslant 1 \qquad n=(1,2,3,4)\\ \sum_{n=1}^{4}w_n=1\end{cases} \tag{31}$$

Set $w_n^* = \left(w_n OF_n^{\cdot}\right)/\left(OF_n^{\cdot}-OF_n\right)$, then:

$$\begin{aligned}Z_d &= w_1^*\,OF_1+w_2^*\,OF_2+w_3^*\,OF_3+w_4^*\,OF_4\\ &=\frac{w_1OF_1^{\cdot}}{OF_1^{\cdot}-OF_1}OF_1+\frac{w_2OF_2^{\cdot}}{OF_2^{\cdot}-OF_2}OF_2+\frac{w_3OF_3^{\cdot}}{OF_3^{\cdot}-OF_3}OF_3+\frac{w_4OF_4^{\cdot}}{OF_4^{\cdot}-OF_4}OF_4\end{aligned} \tag{32}$$

Thus, Z can be minimized using the following equation:

$$\text{Min } Z = \left(w_1\mu_1 - w_2\mu_2 - w_3\mu_3 - w_4\mu_4\right) - \left(\frac{w_1 OF_1^{\cdot}}{OF_1^{\cdot} - OF_1} OF_1 + \frac{w_2 OF_2^{\cdot}}{OF_2^{\cdot} - OF_2} OF_2 + \frac{w_3 OF_3^{\cdot}}{OF_3^{\cdot} - OF_3} OF_3 + \frac{w_4 OF_4^{\cdot}}{OF_4^{\cdot} - OF_4} OF_4\right) \quad (33)$$

The constraints contain Equations (6)-(12) and (31).

With this approach, a mono-objective function mixed integer linear programming model was established that can be optimized using LINGO or Xpress.

4.3 The Max-Min approach

In this case, the Max-Min approach was applied for selecting a trade-off solution among the non-inferior set of solutions obtained from the objective function *OF* based on a satisfaction value ϑ_{OF_x}. For the detail about this approach, it refers to the study Lai and Hwang (1992) and Basu (2004). The formula of using the Max-Min approach is given below:

$$\underset{x}{\text{Max}}\left\{\min\left\{\vartheta_{OF_x} - \vartheta_{OF_x}^{\text{ref}}\right\}\right\} = \underset{x}{\text{Max}}\left\{\min\left\{\left(\frac{OF_x^{\max} - OF(x)}{OF_x^{\max} - OF_x^{\min}}\right) - \vartheta_{OF_x}^{\text{ref}}\right\}\right\} \quad (34)$$

$$\text{s.t.}\left\{\vartheta_{OF_x} = \begin{cases} 1 & OF(x) \leqslant OF_x^{\min} \\ \left(\frac{OF_x^{\max} - OF(x)}{OF_x^{\max} - OF_x^{\min}}\right) & OF_x^{\min} \leqslant OF(x) \leqslant OF_x^{\max} \\ 0 & OF(x) \geqslant OF_x^{\max} \end{cases}\right. \quad (35)$$

where $OF_x^{\max}$ and $OF_x^{\min}$ are the maximum value and the minimum value of the objective function OF_x, respectively. Within the non-inferior set $\vartheta_{OF_x}^{\text{ref}}$ which is a minimal satisfaction value accepted for objective function OF_x. The minimal satisfaction is assigned by decision makers in consonance to their preferences.

5. Computational results and analysis

Table I shows a range of application data over a year period in London-South East area from the UK Halal Meat Committee (Halal Meat Committee (HMC) UK, 2014). For instance, the supply capacity of farms i (S_i^{α}) is given in a range GBP2,500-4,400. These data were used for generating the computational results as a case study, which comprises 5 farms, 11 retailers and 6 abattoirs. The travel distances between farms and abattoirs or between abattoirs and retailers were estimated using the Google map. The case study was investigated based on assumptions that there are no restrictions for sharing the HMSC network resources, i.e. any farm can supply the Halal meat products to any abattoir, and any abattoir can supply the Halal meat products to any retailer, and there is a steady demand from retailers.

$I = 5$	$C_j^{E,\beta} = $ 4K-7.5K (GBP)	$D_k^{\gamma} = $ 100-500	$d_{ij}^{u} = $ 23-400
$J = 6$	$C_j^{I,\beta} = $ 700-1.2K (GBP)	$P_{ij}^{u} = $ 0.90-0.95	$d_{jk}^{v} = $ 110-162
$K = 11$	$S_i^{\alpha} = $ 2.5K-4.4K	$P_{jk}^{v} = $ 0.91-95	$W = 100$
$C_i^{E,\alpha} = $ 4K-8K (GBP)	$S_j^{\beta} = $ 1.2K-1.8K	$R_i^{\alpha} = 60$	$C_i^{h,\alpha} = 4$ (GBP)
$C_i^{I,\alpha} = $ 400-800 (GBP)	$D_j^{\beta} = $ 800-1.3K	$R_j^{\beta} = 40$	$C_j^{h,\alpha} = 4$ (GBP)
$C_i^{t} = 0.15$ (GBP)	$C_j^{t} = 0.15$ (GBP)		

Table I. Parameters used for the case study

In this study, the deterministic model was coded using the LINGO[11] software and the stochastic programming model was coded using the Xpress IVE software on a personal laptop Corei5 2.5gigahertz with a 4gigbyte RAM.

5.1 Results of the deterministic model

To obtain the non-inferior solutions, two solution approaches were used as described in Section 4. Table II shows a list of results of 12 non-inferior solutions obtained using the ε-constraint approach by altering the incremental epsilon value of 1,124 between 6,771 and 19,137 for objective 2, of 67,672 between 397,600 and 1,141,992 for objective 3 and of 0.025 between 0.65 to 0.95 for objective 4, respectively. Table III shows the results of 11 non-inferior solutions obtained using the MWS approach where each objective was individually optimized as an optimal value of $OF_1^{\cdot}$, $OF_2^{\cdot}$, $OF_3^{\cdot}$, $OF_4^{\cdot}$, respectively, by altering the scalarization values (w_1, w_2, w_3, w_4) in Equation (33).

It can be seen in Table III that there is no feasible solution if the weights for the first objective are assigned less than 0.3. This implies that decision makers may not ignore the importance of this result for the HMSC network design. Also shown in Table III, the non-inferior solutions can be obtained by opening the less number of abattoirs, compared to the results shown in Table II. For instance, the result for solution 5 shown in Table II, it requires

	Assigned ε values			Objective function solutions				Facilities to open	
No.	ε_1	ε_2	ε_3	Cost (OF_1) (GBP)	Integrity (OF_2) (items)	ROI (OF_3) (GBP)	Capacity (OF_4) (%)	Farms	Abattoirs
1	6,771	397,600	0.65	131,051	6,876	397,600	0.65	1, 5	1, 4, 5
2	7,895	465,272	0.69	152,574	7,937	465,280	0.695	1, 5	1, 4, 5
3	9,019	532,944	0.715	185,735	9,019	532,960	0.72	1, 5	1, 4, 5
4	10,143	600,616	0.74	217,252	10,147	607,800	0.75	1, 4, 5	3, 4, 5
5	11,251	668,288	0.765	249,371	11,267	671,680	0.77	1, 4	1, 2, 5
6	12,391	735,960	0.79	294,938	12,638	735,960	0.8	1, 4, 5	1, 2, 3, 4, 5
7	13,515	803,632	0.815	348,498	13,868	803,640	0.815	1, 3, 4, 5	1, 2, 4, 5
8	14,639	871,304	0.84	401,008	14,939	871,340	0.85	1, 2, 4, 5	1, 2, 3, 4, 5
9	15,763	938,976	0.865	484,449	15,989	938,980	0.87	1, 2, 3, 4, 5	1, 2, 3, 4, 5
10	16,887	1,006,648	0.89	563,408	17,038	1,006,660	0.905	1, 2, 3, 4, 5	1, 2, 3, 4, 5
11	18,011	1,074,320	0.915	642,321	18,087	1,074,320	0.92	1, 2, 3, 4, 5	1, 2, 3, 4, 5
12	19,135	1,141,992	0.95	721,281	19,137	1,142,000	0.96	1, 2, 3, 4, 5	1, 2, 3, 4, 5

Table II.
Non-inferior solutions obtained using the ε-constraint approach

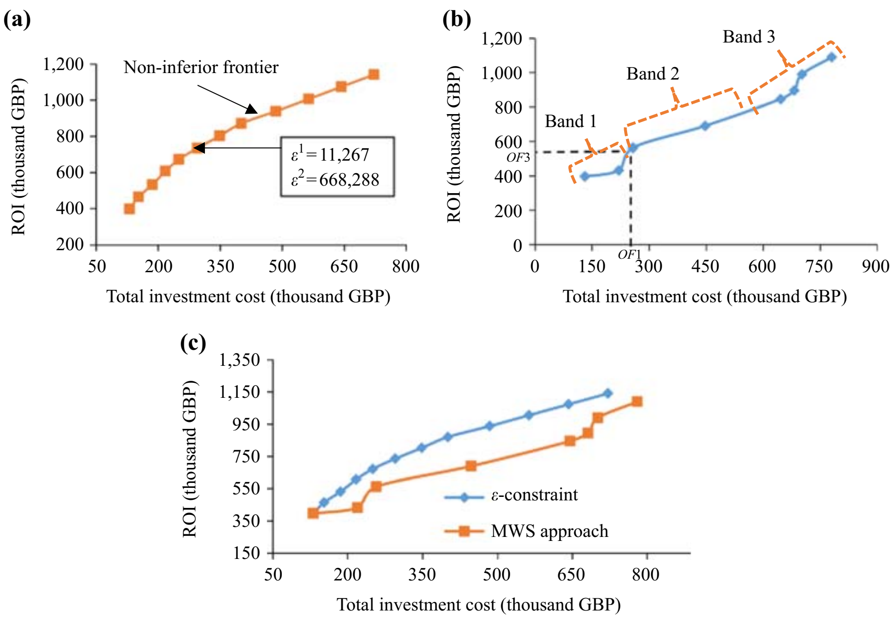
	Assigned weights	Objective function solutions				Facilities to open	
No.	w_1, w_2, w_3, w_4	Cost (OF_1) (GBP)	Integrity (OF_2) (items)	ROI (OF_3) (GBP)	Capacity (OF_4) (%)	Farms	Abattoirs
1	0.9, 0.025, 0.025, 0.05	131,051	6,876	397,600	0.65	1, 2	1, 4, 5
2	0.8, 0.1, 0.05, 0.05	131,051	6,876	397,600	0.695	1, 2	1, 4, 5
3	0.7, 0.1, 0.1, 0.1	131,251	6,974	398,000	0.72	1, 2	1, 4, 5
4	0.64, 0.2, 0.13, 0.13	219,704	8,079	433,680	0.75	1, 2, 4, 5	1, 2, 3, 4, 5
5	0.6, 0.13, 0.13, 0.14	257,170	9,911	563,600	0.77	1, 5	1, 5
6	0.5, 0.25, 0.125, 0.125	297,025	11,296	590,120	0.8	1, 3, 4, 5	2, 3, 4, 5
7	0.4, 0.2, 0.2, 0.2	645,100	14,654	845,480	0.815	1, 2, 3, 4, 5	1, 2, 3, 4, 5
8	0.34, 0.44, 0.11, 0.11	681,255	14,954	895,480	0.85	1, 2, 3, 4, 5	1, 2, 3, 4, 5
9	0.3, 0.4, 0.15, 0.15	701,255	15,038	990,860	0.89	1, 2, 3, 4, 5	1, 2, 3, 4, 5
10	0.2, 0.5, 0.15, 0.15	–	–	–	–	–	–
11	0, 1, 0.3, 0.3, 0.3	–	–	–	–	–	–

Table III.
Non-inferior solutions obtained using the MWS approach

three abattoirs, compared to the result for solution 5 shown in Table III that it requires two abattoirs at weights $w_1 = 0.6$, $w_2 = 0.13$, $w_3 = 0.13$ and $w_4 = 0.14$. With this solution, it leads to a maximal ROI of GBP563,600, a maximal integrity number of 9,911 items of Halal meat products and a maximal capacity utilization of 77 percent under the total investment cost of GBP257,170. The result shows that the MWS approach is more effective than the ε-constraint approach for gaining a better solution.

It is noteworthy that in Tables II and III, the value of maximum ROI for the all solutions is more than the total cost which proves the feasibility in terms of economic costs of the proposed RFID-enabled HMSC after one-year period for the RFID implementation.

Figure 2 explains the computational results of solutions in a relation between the total minimal investment cost and the maximal ROI. These solutions are divided into three bands shown in Figure 2(b) according to the assigned weight values. In band 1, by adjusting the varying weight values in a range at 0.9, 0.025, 0.025, 0.05 and 0.64, 0.12, 0.12, 0.12, respectively; it gives the value of OF_1 moderately increases from GBP131,051 to GBP220,000 and the value of OF_3 increases from GBP397,600 to GBP433,680, respectively. This implies that the HMSC may be configured with the lower cost investment. In contrast, by adjusting the weight values in a range at 0.64, 0.12, 0.12, 0.12 and 0.5, 0.25, 0.125, 0.125, respectively; it gives the value of OF_1 a moderate increase from GBP220,000 to GBP645,000 and the value of OF_3 increases from GBP433,680 to GBP845,480, respectively; this implies that the HMSC is configured with a compromised solution (i.e. solution 5 in Table III). Similarly, shown in band 3, the HMSC is configured with the higher ROI. A number of solutions were also identified and these results are placed in the middle of the non-inferior frontier shown in Figure 2(a). For instance, by giving an assigning of $\varepsilon_1 = 11{,}267$ and $\varepsilon_2 = 668{,}288$, it yields a total investment cost of GBP249,938 and a ROI of GBP735,930. Figure 2(c) shows comparative results obtained under



Notes: (a) The ε-constraint approach; (b) the MWS approach; (c) the ε-constraint and the MWS approaches

Figure 2.
ROI in relation to the total investment cost

the same constraints using the ε-constraint and the MWS approaches, respectively. It gives non-linear results of the ROI in response to the total investment cost. Figure 2(c) shows the total investment cost of GBP131,000 leading to the ROI of GBP397,600 using both approaches. After this point, the ROI increases over the increase of the total investment cost. Nevertheless, the ROI does not increase significantly if the total investment cost increases up to GBP220,000, but it increases sharply after the total investment cost increases more GBP220,000 using the MWS approach. By comparison, the ROI increases significantly over the increase of the total investment cost using the ε-constraint approach.

To design the HMSC network, decision makers often need to find a solution based on a number of alternative possibilities using a decision-making approach. To this aim, the Max-Min approach was applied. Based on this approach, solution 1 (shown in Table III) is determined as the best solution, where $\vartheta^{\text{ref}}_{OF_1} = 0.5$, $\vartheta^{\text{ref}}_{OF_2} = 0.5$, $\vartheta^{\text{ref}}_{OF_3} = 0$ and $\vartheta^{\text{ref}}_{OF_4} = 0$, i.e. in this case the decision maker seeks a compromised solution based on a cost/integrity-oriented HMSC network design. Figure 3 demonstrates an example of the established HMSC network design based on solution 1 which was obtained with $w_1 = 0.9$, $w_2 = 0.025$, $w_3 = 0.025$ and $w_4 = 0.05$. This network design includes an establishment of two farms which are located in Warwickshire and Leicestershire and three abattoirs which are located in Warwick, Birmingham and Norfolk, respectively. Figure 3 also illustrates the optimal quantity flow of Halal meat products from farms to abattoirs and from abattoirs to retailers. It shows that farm 1 is requested to supply 1,000 livestock to abattoir 5 which supplies 500 Halal meat products to retailer 7; 188 Halal meat products to retailer 8; 100 Halal meat products to retailer 9; and 10 Halal meat products to retailer 10, respectively.

5.2 Results of the stochastic model

Table IV shows a sample of varying integrity percentages and probability in response to each of integrity percentage by assigning a value from low to high levels associated with five farms based on 243 scenarios (3^5) as a case study. For instance, the integrity

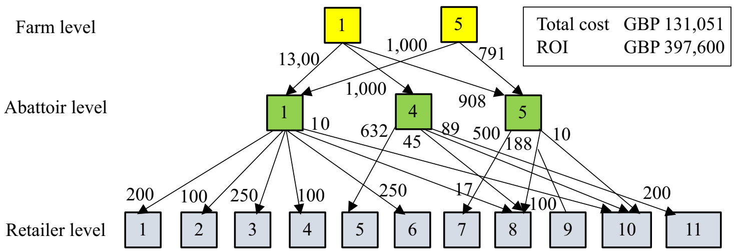


Figure 3.
An optimal HMSC network design

Table IV.
Integrity percentage and probability in integrity percentage for farms 1-5 in varying scenarios

Farm	Low	$P^{u}_{ij}(\%)$ Mid	High	Low	$\text{Pro}^{u}_{ij}(\%)$ Mid	High
1	85	92	95	0.25	0.50	0.25
2	90	93	99	0.25	0.50	0.25
3	88	95	98	0.25	0.50	0.25
4	86	90	96	0.30	0.40	0.30
5	90	93	98	0.30	0.40	0.30

percentages of the farm i in scenario 1 is (85, 90, 88, 86, 90). And the associated probability in scenario 1 is (0.25, 0.25, 0.25, 0.30, 0.30). Then, the scenario probability (Prob_ξ) is $0.25 \times 0.15 \times 0.15 \times 0.25 \times 0.25 = 0.0003515625$.

Table V shows the results of a set of non-inferior solutions based on the stochastic model using the ε-constraint approach. It shows that solution 1 has a maximal ROI of GBP397,611, a maximal integrity number of 7,634 Halal meat products, a maximal capacity utilization of 65 percent and a minimal total investment cost of GBP147,094; it gives two farms and three abattoirs that need to be opened for the specified HMSC network.

Figure 4 shows the values of objective function seeking for maximization of the integrity number of Halal meat products based on solution 5 which has the 12 selected scenarios. As shown in Figure 4, in scenario 12, it yields the highest value of $OF_2 = 12{,}698$ Halal meat products. By contrast, in scenario 1, it yields the lowest value of $OF_2 = 10{,}984$ Halal meat products. It is noted in Figure 4 that by altering the integrity percentage of Halal meat products, the capacity utilization (percent) varies. For instance, with a decrease of the average integrity percentage by 5 percent in scenario 1, the integrity number of Halal meat products decreases by 3.3 percent only. In scenario 12, with an increase of the average integrity percentage to 5 percent, it leads to 2.2 percent increase in the integrity number of Halal meat products. This is because the result was obtained by optimizing four conflicting objectives at a time as a compromised solution.

	Assigned ε values			Values of objective function				Facilities open	
No.	ε_1	ε_2	ε_3	Cost (OF_1) (GBP)	Integrity (OF_2) (items)	ROI (OF_3) (GBP)	Capacity (OF_4) (%)	Farm	Abattoir
1	6,771	397,600	0.65	147,094	7,634	397,611	0.65	1, 5	1, 4, 5
2	7,895	465,272	0.69	178,104	8,682	465,291	0.7	1, 4, 5	1, 4, 5
3	9,019	532,944	0.715	206,143	9,717	532,971	0.71	1, 4, 5	1, 4, 5
4	10,143	600,616	0.74	236,143	10,750	600,651	0.755	1, 4, 5	1, 4, 5
5	11,251	668,288	0.765	293,004	11,791	668,315	0.775	1, 3, 4, 5	1, 4, 5
6	12,391	735,960	0.79	356,042	12,914	735,961	0.855	1, 2, 3, 4, 5	1, 4, 5
7	13,515	803,632	0.815	356,042	12,914	735,961	0.815	1, 3, 4, 5	1, 3, 5
8	14,639	871,304	0.84	513,414	15,057	871,332	0.9	1, 2, 3, 4, 5	1, 3, 4
9	15,763	938,976	0.865	596,544	15,882	938,983	0.95	1, 2, 3, 4, 5	1, 2, 3

Table V. Results of a set of non-inferior solutions of the stochastic model

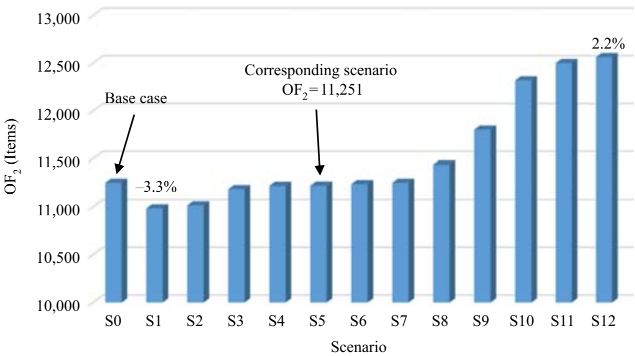


Figure 4. The value of OF_2 in response to each of the selected integrity scenarios

5.3 The HMSC network design with and without the RFID implementation: a comparison

Figure 5 shows the comparative result of the total investment cost of the HMSC network with or without the RFID implementation based on the eight non-inferior solutions obtained from the RFID-based HMSC multi-objective model and the non-RFID-based HMSC model. It can be seen in Figure 5 that it leads to a decrease in the total investment cost of an average GBP50,552 after a year period of the RFID implementation into the HMSC network, compared to the same HMSC network without the RFID implementation. This decrease is a result for the elimination of several manual operations. As shown in Figure 5, for solution 1, it yields a total investment cost of GBP158,555 of the non-RFID-based HMSC network compared to a total investment cost of GBP131,051 of the RFID-based HMSC network. For solution 5, it yields an average decrease in difference in the total investment cost of GBP45,068 after the RFID implementation. The result shows that the RFID implementation for the HMSC network is economically feasible.

6. Conclusions

In this paper, a deterministic model using the multi-objective approach was developed and used for examining the economic feasibility of a proposed RFID-based HMSC network with respect to minimizing the total investment cost, maximizing the average integrity of Halal meat products, maximizing the ROI and maximizing the capacity utilization of farms and abattoirs. Furthermore, a stochastic programming model was also developed for investigating the effect of varying integrity percentage that affects the number of Halal meat products of the HMSC network. Two solution approaches, which are the ε-constraint approach and the MWS approach, were applied and two sets of non-inferior solutions were generated and compared based on the developed multi-objective model. The Max-Min approach was proposed to select the best non-inferior solution. A case study was used for demonstrating the applicability of the developed models and a comparison of computational results based on the deterministic model and the stochastic model are presented in the paper. The conclusion shows that the proposed RFID-based HMSC is economically feasible and it leads to a decrease in the total investment cost of an average GBP50,552 after a year period. The developed models can also be useful for determining a cost-effective design of a HMSC network.

A number of other avenues are recommended to improve the developed multi-objective model such as exploring the HMSC network design considering different types of uncertainties (e.g. costs, demands and capacities of related facilities) and transportation means. Also, environmentalism has been becoming increasingly a significant global problem in the present century. Thus, the presented model could be extended to include the environmental aspects as an objective function.

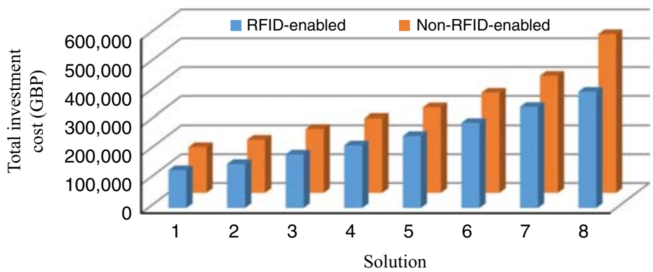


Figure 5. Comparative results of the total investment cost between the non-RFID-based HMSC and the RFID-based HMSC

References

Al-Othman, W.B.E., Lababidi, H.M.S., Alatiqi, I.M. and Al-Shayji, K. (2008), "Supply chain optimization of petroleum organization under uncertainty in market demands and prices", *European Journal of Operational Research*, Vol. 189 No. 3, pp. 822-840.

Barge, P., Gay, P., Merlino, V. and Tortia, C. (2014), "Item-level radio-frequency identification for the traceability of food products: application on a dairy product", *Journal of Food Engineering*, Vol. 125, pp. 119-130.

Barros, A.I., Dekker, R. and Scholten, V. (1998), "A two-level network for recycling sand: a case study", *European Journal of Operational Research*, Vol. 110 No. 2, pp. 199-214.

Basu, M. (2004), "An interactive fuzzy satisfying method based on evolutionary programming technique for multi-objective short-term hydrothermal scheduling", *Electric Power Systems Research*, Vol. 69 Nos 2-3, pp. 277-285.

Beamon, B.A. (2000), "A multi-objective approach to simultaneous strategic and operational planning in supply chain design", *Omega*, Vol. 28 No. 5, pp. 581-598.

Bhattacharya, R. and Bandyopadhyay, S. (2010), "Solving conflicting bi-objective facility location problem by NSGA II evolutionary algorithm", *International Journal of Advanced Manufacturing Technology*, Vol. 51 Nos 1-4, pp. 397-414.

Birge, J.R. and Louveaux, F. (1997), *Introduction to Stochastic Programming*, Springer Series in Operations Research, Springer-Verlag, New York, NY.

Bojarski, A., Laínez, J.M., Espuña, A. and Puigjaner, L. (2009), "Incorporating environmental impacts and regulations in a holistic supply chains modeling: an LCA approach", *Computers and Chemical Engineering*, Vol. 33 No. 10, pp. 1747-1759.

Bortolini, M., Faccio, M., Ferrari, M., Gamberi, M. and Pilati, F. (2016), "Fresh food sustainable distribution: cost, delivery time and carbon footprint three-objective optimization", *Journal of Food Engineering*, Vol. 174, pp. 56-67.

Cakravastia, A., Toha, I.S. and Nakamura., N. (2002), "A two-stage model for the design of supply chain networks", *International Journal of Production Economics*, Vol. 80 No. 3, pp. 231-248.

Chen, C.-L. and Lee, W.-C. (2004), "Multi-objective optimization of multi-echelon supply chain networks, with uncertain product demands and prices", *Computers and Chemical Engineering*, Vol. 28 Nos 6-7, pp. 1131-1144.

Chen, Y.-Y., Wang, Y.-J. and Jan, J.-K. (2014), "A novel deployment of smart cold chain system using 2G-RFID-Sys", *Journal of Food Engineering*, Vol. 141, pp. 113-121.

Cheshmehgaz, H.R., Desa, M.I. and Wibowo., A. (2013), "A flexible three-level logistic network design considering cost and time criteria with a multi-objective evolutionary algorithm", *Journal of Intelligent Manufacturing*, Vol. 24 No. 2, pp. 277-293.

Chibeles-Martins, N., Pinto-Varela, T., Barbósa-Póvoa, A.P. and Novais, A.Q. (2012), "A simulated annealing algorithm for the design and planning of supply chains with economic and environmental objectives", *Computer Aided Chemical Engineering*, Vol. 30, pp. 21-25.

Coello, C.A.C., Lamont, G.B. and Veldhuisen, D.A.V. (2007), *Evolutionary Algorithms for Solving Multi- Objective Problems*, Springer.

Deb, K. (2001), *Multi-Objective Optimization using Evolutionary Algorithms*, John Wiley & Sons, New York, NY.

Ding, H., Benyoucef, L. and Xie., X. (2006), "A simulation-based multi-objective genetic algorithm approach for networked enterprises optimization", *Engineering Applications of Artificial Intelligence*, Vol. 19 No. 6, pp. 609-623.

Ehrgott, M. (2005), *Multicriteria Optimization*, 2nd ed., Springer, New York, NY.

Expósito, I., Gay-Fernández, J.A. and Cuiñas, I. (2013), "A complete traceability system for a wine supply chain using radio-frequency identification and wireless sensor networks", *IEEE Antennas and Propagation Magazine*, Vol. 55 No. 2, pp. 255-267.

Gen, M. and Cheng, R. (1997), *Genetic Algorithms and Engineering Design*, John Wiley & Sons, New York, NY.

Giadaa, L.S., Lucab, S., Rosaa, M. and Marioa, E. (2016), "Predictive shelf life model based on RF technology for improving the management of food supply chain: a case study", *International Journal of RF Technologies*, Vol. 7 No. 1, pp. 31-42.

Guilléna, G., Melea, F.D., Bagajewiczb, M.J., Espuña, A. and Puigjanera, L. (2005), "Multiobjective supply chain design under uncertainty", *Chemical Engineering Science*, Vol. 60 No. 6, pp. 1535-1553.

Harris, I., Mumford, C.L. and Naim, M.M. (2014), "A hybrid multi-objective approach to capacitated facility location with flexible store allocation for green logistics modeling", *Transportation Research Part E*, Vol. 66, pp. 1-22.

Hiremath, N.C., Sahu, S. and Tiwari, M.K. (2013), "Multi objective outbound logistics network design for a manufacturing supply chain", *Journal of Intelligent Manufacturing*, Vol. 24 No. 6, pp. 1071-1084.

Halal Meat Committee (HMC) UK (2014), available at: www.halalhmc.org/; www.halalhmc.org/certified-outlets.htm/ (accessed October 26, 2014).

Hou, J.L. and Huang, C.H. (2006), "Quantitative performance evaluation of RFID applications in the supply chain of the printing industry", *Industrial Management & Data Systems*, Vol. 106 No. 1, pp. 96-120.

Jayaraman, V., Guige, V.D.R. and Srivastava, R. (1999), "A closed-loop logistics model for manufacturing", *Journal of the Operational Research Society*, Vol. 50 No. 2, pp. 497-508.

Kannan, G., Sasikumar, P. and Devika, K. (2012), "A genetic algorithm approach for solving a closed loop supply chain model: a case of battery recycling", *Applied Mathematical Modelling*, Vol. 34 No. 3, pp. 655-670.

Kelepouris, T., Pramatari, K. and Doukidis, G. (2007), "RFID-enabled traceability in the food supply chain", *Industrial Management & Data Systems*, Vol. 107 No. 2, pp. 183-200.

Krikke, H., Van Harten, R. and Schuur, P.C. (1999), "Reverse logistic network re-design for copiers", *OR Spektrum*, Vol. 21, pp. 381-409.

Lai, Y.L. and Hwang, C.L. (1992), *Fuzzy Mathematical Programming*, 1st ed., Springer, Berlin.

Lee, D. and Dong, M. (2009), "Dynamic network design for reverse logistics operations under uncertainty", *Transportation Research Part E*, Vol. 451 No. 1, pp. 61-71.

Lodhi, A. (2009), *Understanding Halal Food Supply Chain*, 1st ed., HFRC UK, London.

Lu, B.H., Bateman, R.J. and Cheng, K. (2006), "RFID enabled manufacturing: fundamentals, methodology and application perspectives", *International Journal of Agile Systems and Management*, Vol. 1 No. 1, pp. 73-92.

Manos, B. and Manikas, I. (2010), "Traceability in the Greek fresh produce sector: drivers and constraints", *British Food Journal*, Vol. 112 No. 6, pp. 640-652.

Mohammed, A. and Wang, Q. (2015), "Integrity of an RFID-enabled HMSC network", *Proceedings of the Third International Conference on Digital Enterprise and Information Systems, Shenzhen*, pp. 79-86.

Mohammed, A. and Wang, Q. (2017), "The fuzzy multi-objective distribution planner for a green meat supply chain", *International Journal of Production Economics*, Vol. 184, pp. 47-58.

Nath, B., Reynolds, F. and Want, R. (2006), "RFID technology and applications", *IEEE Pervasive Computing*, Vol. 5, pp. 22-24.

Niknamfar, A.H. (2015), "Multi-objective production-distribution planning based on vendor-managed inventory strategy in a supply chain", *Industrial Management & Data Systems*, Vol. 115 No. 6, pp. 1086-1112.

Nozick, L.K. and Turnquist, M.A. (2001), "A two-echelon inventory allocation and distribution center location analysis", *Transportation Research Part E*, Vol. 37 No. 6, pp. 425-441.

Rafique, M.Z., Ab Rahman, M.N., Saibani, N., Arsad, N. and Saadat, W. (2016), "RFID impacts on barriers affecting lean manufacturing", *Industrial Management & Data Systems*, Vol. 116 No. 8, pp. 1585-1616.

Shankar, B.L., Basavarajappa, S., Chen, J.C.H. and Kadadevaramath, R.S. (2013), "Location and allocation decisions for multi-echelon supply chain network – a multi objective evolutionary approach", *Expert Systems with Applications*, Vol. 40 No. 2, pp. 551-562.

Shen, Z.J. (2006), "A profit maximizing supply chain network design model with demand choice flexibility", *Operations Research Letters*, Vol. 34 No. 6, pp. 673-682.

Shen, Z.J., Coullard, C. and Daskin, M. (2003), "A joint location-inventory model", *Transportation Science*, Vol. 37 No. 1, pp. 40-55.

Shen, Z.-J.M. (2007), "Integrated supply chain design models: a survey and future research directions", *Journal of Industrial and Management Optimization*, Vol. 3 No. 1, pp. 1-27.

So Park, K., Koh, C.E. and "Ted" Nam, K. (2010), "Perceptions of RFID technology: a cross-national study", *Industrial Management & Data Systems*, Vol. 110 No. 5, pp. 682-700.

Talaei, M., Farhang, B., Pishvaee, M.S., Bozorgi-Amiri, A. and Gholamnejad, S. (2015), "A robust fuzzy optimization model for carbon-efficient closed-loop supply chain network design problem: a numerical illustration in electronics industry", *Journal of Cleaner Production*, Vol. 15 No. 1, pp. 959-6526.

Teimoury, E., Nedaei, H., Ansari, S. and Sabbaghi, M. (2013), "A multi-objective analysis for import quota policy making in a perishable fruit and vegetable supply chain: a system dynamics approach", *Computers and Electronics in Agriculture*, Vol. 93, pp. 37-45.

Tzeng, G.-T., Hung, Y.-M. and Chang, M.-L. (2006), "Multiple objective planning for production and distribution model of supply chain: case of bicycle manufacturer", *Journal of Scientific and Industrial Research*, Vol. 65, pp. 309-320.

Vahdani, B., Tavakkoli-Moghaddam, R., Modarres, M. and Baboli, A. (2012), "Reliable design of a forward/reverse logistics network under uncertainty: a robust-M/M/c queuing model", *Transportation Research Part E*, Vol. 48 No. 6, pp. 1152-1168.

Villegas, J.G., Palacios, F. and Medaglia, A.L. (2006), "Solution methods for the bi-objective (cost-coverage) unconstrained facility location problem with an illustrative example", *Annals of Operations Research*, Vol. 147 No. 1, pp. 109-141.

Wang, Q., McIntosh, R. and Brain, B. (2010), "A new-generation automated warehousing capability", *International Journal of Computer Integrated Manufacturing*, Vol. 23 No. 6, pp. 565-573.

Zailani, S., Arrifin, Z., Abd Wahid, N., Othman, R. and Fernando, Y. (2010), "Halal traceability and halal tracking systems in strengthening halal food supply chains for food industry in Malaysia (a review)", *Journal of Food Technology*, Vol. 8 No. 3, pp. 74-81.

Zhang, Y., Zhang, G., Du, W., Wang, J., Ali, E. and Sun, S. (2015), "An optimization method for shopfloor material handling based on real-time and multi-source manufacturing data", *International Journal of Production Economics*, Vol. 165, pp. 282-292.

Zhong, R.Y., Dai, Q.Y., Qu, T., Hu, G.J. and Huang, G.Q. (2013), "RFID-enabled real-time manufacturing execution system for mass-customization production", *Robotics and Computer-Integrated Manufacturing*, Vol. 29 No. 2, pp. 283-292.

Zulfakar, M.H., Jie, F. and Chan, C. (2012), "Halal food supply chain integrity: from a literature review to a conceptual framework", *Proceeding of the 10th ANZAM Operations Supply Chain and Service Management*, *Melbourne*, pp. 1-23.

Corresponding author
Ahmed Mohammed can be contacted at: ahmed.mohammed@port.ac.uk

This article has been cited by:

1. ZhongDr Ray Y., Dr Ray Y. Zhong, TanProfessor Kim, Professor Kim Tan, BhaskaranProfessor Gopalakrishnan, Professor Gopalakrishnan Bhaskaran. 2017. Data-driven food supply chain management and systems. *Industrial Management & Data Systems* **117**:9, 1779-1781. [Citation] [Full Text] [PDF]