An Optimization Approach for An RFID-enabled Passport Tracking System

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ABSTRACT

RFID is an automatic object identification technology that identifies objects within a given radio frequency range through radio waves without human intervention or data entry. In the industry, the implementation of RFID was rapidly developing into different sectors such logistics and supply chain management and object tracking. Even though, this implementation faces several hurdles from different perspectives such as the collision that may occur between RFID readers and economic challenge. This work investigates the design of a RFID-enabled passport tracking system in terms of numbers of related facilities that should be established. To this aim, a multi-objective optimization model was developed. The objectives are minimizing the implementation and operational costs and RFID reader interference. To reveal Pareto solutions, two solution methods namely the ε-constraint method and the LP-metrics method were applied. The best solution by comparing the obtained Pareto solutions was determined using the Max-Min method. The implementation of the developed model based on a case study has proved its applicability in presenting an optimal design for the RFID-enabled passport tracking system and trade-offs among the two objectives.

1. INTRODUCTION

Radio Frequency Identification (RFID) is an automatic identification technology via Radio Frequency (RF) signals. RFID is an automatic object identification technology that identifies objects within a given radio frequency range through radio waves without human intervention or data entry [1]. In the industry, the implementation of RFID was rapidly developing into different sectors such logistics and supply chain management [2, 3], and object tracking [4]. Even though, this implementation faces several hurdles from different perspectives such as the collision that may occur between RFID readers and economic challenge. Implementing a new traceability system is associated with extra costs in investment which considers as a barrier for decision makers particularly for small-size manufactures and low developed countries. The reducing costs and efficient performance is expected to encourage (i) decision makers to heavily contribute in the development and implementation of tracking systems and (ii) developed countries like China to implement tracking systems aiming to develop their competitiveness in the global industry [5]. This has led to constant interest in the optimization and the cost-effective design of RFID-enabled tracking systems. Design and optimization for such systems are a typical multi-objective problem associated with several variables and imprecise parameters.

There are relatively few historical studies in the area of the design and optimization of RFID-enabled systems. Where all the previous research focused on coverage requirements. Chen [6] proposed an optimization model used for allocating the locations of readers in a RFID-enabled network. The multi-swarm particle swarm approach was used for optimizing the model. Kardasa [7] investigated a RFID-enabled network planning problem via a development of a multi-objective artificial bee colony algorithm seeking a trade-off among optimal tag coverage, reader interference, economic efficiency and load balance. Mysore [8] proposed an algorithm for allocating the minimum number of readers required for an efficient coverage when the region is irregular shape. Ma [9] presented a multi-objective artificial colony algorithm for solving a RFID-enabled network planning problem.

This paper presents a development of a multi-objective model aims at presenting a cost-effective design for a proposed RFID-enabled passport tracking system in allocating the optimum number of related facilities that should be established. It also helps in obtaining a trade-off between minimizing the implementation and operational costs and minimizing the RFID reader interference.

2. THE MULTI-OBJECTIVE MOBEL

The structure of the passport system under investigation consists of three stages so-called office 1, office 2 and office 3. office 1 receives the request for new/or renew passports from clients. It also responsible of checking the required document are correct then sends it to Office 2. Office 2 is responsible for issuing the new passports and checking the relevant information are correct (in case of renewing a passport) then it sends them to office 3 to be filled and delivered to clients. The RFID was proposed to be implemented to improve the system performance in

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information accuracy, passport tracking for security purposes and easing the issuing and renewing process of passports for the clients. Notwithstanding, such a system is subject to extra costs in investment that need to be considered. The following sets, parameters and decision variables were used in the formulation of the model:

Sets:

I set of nominated office 1 $i \in I$

J set of nominated office 2 $j \in J$

K set of nominated office 3 $k \in K$

C set of clients $c \in C$

Given parameters:

C_{ij}^{g} RFID tag cost (GBP) per item transported from office 1 i to office 2 j

C_{i}^{r} RFID reader cost (GBP) required per office 1 i

C_{j}^{r} RFID reader cost (GBP) required per office 2 j

C_{k}^{r} RFID reader cost (GBP) required per office 3 k

C_{i}^{s} fixed cost (GBP) required for the RFID management system

C_{i}^{t} training cost (GBP) per labor at office 1 i

C_{j}^{t} training cost (GBP) per labor at office 2 j

C_{k}^{t} training cost (GBP) for labor (s) at office 3 k

C_{i}^{l} labor cost per hour (GBP) at office 1 i

C_{j}^{l} labor cost per hour (GBP) at office 2 j

C_{j}^{l} labor cost per hour (GBP) at office 3 k

C_{ij}^{l} cost (GBP) required for laborer transporting document from room 1 i to office 2 j

C_{jk}^{l} cost (GBP) required for laborer transporting document from room 2 j to office 3 k

R_{i} working rate (items) per laborer at office 1 i

R_{j} working rate (items) per laborer at office 2 j

R_{k} working rate (items) per laborer at office 3 k

R_{ij} working rate (items) per laborer required to transport document from office 1 i to office 2 j

R_{jk} working rate (items) per laborer required to transport document from office 2 j to office 3 k

H_{i} minimum required number of working hours (h) for laborer at office 1 i

H_{j} minimum required number of working hours (h) for laborer at office 2 j

H_{k} minimum required number of working hours (h) for laborer at office 3 k

H_{ij} minimum required number of working hours (h) for laborer transporting document from office 1 i to office 2 j

H_{jk} minimum required number of working hours (h) for laborer transporting document from office 2 j to office 3 k

C_{i} maximum handling capacity (items) of office 1 i

C_{j} maximum handling capacity (items) of office 2 j

C_{k} maximum handling capacity (items) of office 3 k

D_{j} demand (in units) of client j

D_{k} demand (in units) of client k

D_{c} demand (in units) of client c

Decision variables

q_{ij} quantity of units dispatched from office 1 i to office 2 j

q_{jk} quantity of units dispatched from office 2 j to office 3 k

q_{kc} quantity of units handed to client c from office 3 k

x_{i} required number of laborers at office 1 i

x_{j} required number of laborers at office 2 j

x_{k} required number of laborers at office 3 k

x_{ij} required number of laborers to transfer units from office 1 i to office 2 j

x_{jk} required number of laborers to transfer units from office 2 j to office 3 k

$\mathrm{y}_{\mathrm{i}} \begin{cases} 1\text{: if office 1 } i \text{ is opened} \\ 0\text{: otherwise} \end{cases}$

$\mathrm{y}_{\mathrm{j}} \begin{cases} 1\text{: if collection office 2 } j \text{ is opened} \\ 0\text{: otherwise} \end{cases}$

$\mathrm{y}_{k} \begin{cases} 1\text{: if collection office 3 } k \text{ is opened} \\ 0\text{: otherwise} \end{cases}$

The two objectives (e.g. minimization of implementation and operational costs and RFID reader interference) are formulated as follows:

Minimization of the implementation and operational costs F_2 for the RFID-enabled passport tracking system = RFID tag cost for each item + RFID reader cost required for office 1 *i*, office 2 *j* and office 3 *k* + labor costs at office 1 *i*, office 2 *j* and office 3 *k* + labor costs required to transport document from office 1 *i* to office 2 *j* and from office 2 *j* to office 3 *k* + training cost for labor (s) at office 1 *i*, office 2 *j* and office 3 *k*. Thus, minimum Z_1 is formulated as follows:

:

$$Min\ Z_1 = \sum_{i\in I}\sum_{j\in J} C^g_{ij} q_{ij} + \sum_{i\in I} C^r_i y_i + \sum_{j\in j} C^r_j y_j + \sum_{k\in K} C^r_k y_k \tag{1}$$

$$+ C^s_i + \sum_{i\in I} C^l_i x_i H_i + \sum_{j\in J} C^l_j x_j H_j + \sum_{k\in K} C^l_k x_k H_k + \sum_{i\in I}\sum_{j\in J} C^l_{ij} x_{ij} H_{ij}$$

$$+ \sum_{j\in J}\sum_{k\in K} C^l_{jk} x_{jk} H_{jk} + \sum_{i\in I} C^t_i x_i + \sum_{j\in J} C^t_j x_j + \sum_{k\in K} C^t_k x_k$$

Minimization of RFID reader interference Z_2 is formulated as follows:

:

$$Min\ Z_2 = \sum_{m_i\in RS_i}\sum_{n_i\in TS_{m_i}} \left(\delta - \left(P^{m_i}_{n_j} - \sum_{l_i\in RS}^{l_i\neq m_i} P^{l_i}_{m_i}\right)\right) \tag{2}$$

$$+ \sum_{m_j\in RS_j}\sum_{n_j\in TS_{mj}} \left(\delta - \left(P^{m_j}_{n_j} - \sum_{l_j\in RS}^{l_j\neq m_j} P^{l_j}_{m_j}\right)\right)$$

$$+ \sum_{m_k\in RS_k}\sum_{n_k\in TS_{m_k}} \left(\delta - \left(P^{m_k}_{n_k} - \sum_{l_k\in RS}^{l_k\neq m_k} P^{l_k}_{m_k}\right)\right)$$

Where, δ is the preferred power level; $P^{m_{i,jandk}}_{n_{i,jandk}}$ is the actual power level received by tag n in the interrogation area of reader m in office 1 i, office 2 j and office 3 k; $P^{l_{i,jandk}}_{n_{i,jandk}}$ is the received power by tag n in the interrogation area of reader l in office 1 i, office 2 j and office 3 k. It should be noted that the number of readers are equals to the number of offices that need to be established. Also, the number of tags are equals to the quantity of items transported from office 1 to office 2 where each document is attached with a tag. This objective aims at taking into account all the readers excluding the best one as interfering sources. s.t.

$$\sum_{i\in I} q_{ij} \le C_i\ y_i \qquad \forall j \in J \tag{3}$$

$$\sum_{j\in J} q_{jk} \le C_j\ y_j \qquad \forall k \in K \tag{4}$$

$$\sum_{k\in K} q_{kc} \le C_k\ y_k \qquad \forall c \in C \tag{5}$$

$$\sum_{i\in I} q_{ij} \ge D_j \qquad \forall j \in J \tag{6}$$

$$D_j \ge \sum_{k\in K} q_{jk} \qquad \forall j \in J \tag{7}$$

$$\sum_{k\in K} q_{kc} \ge D_c \qquad \forall j \in J \tag{8}$$

$$\sum_{c\in C} q_{kc} \le D_k \qquad \forall k \in K \tag{9}$$

$$\sum_{j\in J} q_{jk} \ge D_k \qquad \forall k \in K \tag{10}$$

$$\sum_{i\in I} q_{ij} \le x_i\ \mathrm{R}_i \qquad \forall\ \mathrm{j} \in J \tag{11}$$

$$\sum_{j\in J} q_{jk} \le x_j\ \mathrm{R}_j \qquad \forall\ \mathrm{k} \in K \tag{12}$$

$$\sum_{k\in K} q_{kc} \le x_k\ \mathrm{R}_k \qquad \forall\ \mathrm{c} \in C \tag{13}$$

$$\sum_{i\in I} q_{ij} \le x_{ij}\ \mathrm{R}_i \qquad \forall\ \mathrm{j} \in J \tag{14}$$

$$\sum_{j\in J} q_{jk} \le x_{jk}\ \mathrm{R}_j \qquad \forall\ \mathrm{k} \in K \tag{15}$$

$$q_{ij}, q_{jk}, q_{kc}, x_i, x_j, x_k, x_{ij}, x_{ij} \ \ge 0,\ \forall i,j,k; \tag{16}$$

$$y_i, y_j, y_k \ \in \{0,1\},\ \forall i,j,k; \tag{17}$$

Equations 3-4 ensure the flow balance of the document from office 1 to office 2 and from office 2 to office 3 with respect to their capacity. Equations 6-10 ensure that all demands are satisfied. Equations 11-15 determine the required number of laborers at office 1, office 2, office 3, between office 1 and office 2 and between office 2 and office 3. Equations 16 and 17 limit the decision variables to binary and non-negative.

3. SOLUTION APPROACHES

To obtain Pareto-solutions based on the developed multi-objective model, two solution approaches were applied as follows:

3.1ε-constraint

In the ε-constraint method, the multi-objective model turns into a single-objective model by keeping the most important function as an objective function, and considering other functions as the ε-based constraints [10]. Thus, the equivalent solution formula (Z) is given by:

$$Min\ Z = Min\ Z_1 \tag{18}$$

Subject to:

$$Z_2 \le \varepsilon_1 \tag{19}$$

$$[Z_2]^{\min} \le \varepsilon_1 \le [Z_2]^{\max} \tag{20}$$

And Eq. (3-17).

In this work, minimization of the implementation and operational costs is kept as the objective function (Eq.18) and minimization of reader interference is shifted to constraints (Eq.19). Pareto solutions can be obtained by varying the ε value (Eq.20).

3.2 LP-metrics

In the LP-metrics method, each objective function needs to be solved individually to obtain its ideal value ($Z_1^*, Z_2^*$and Z_3^*). Subsequently, the model is solved as a single objective model using the following formula [11]:

$$Min\ Z = \left[w_1 \frac{Z_1 - Z_1^*}{Z_1^*} + w_2 \frac{Z_2 - Z_2^*}{Z_2^*} \right] \tag{21}$$

4. APPLICATION AND EVALUATION

In this section, a case study was used for evaluating the applicability of the developed MOM and the performance of the proposed solution methods. Table I shows the relevant parameters and their values used for the case study. Date was collected from the ministry of interior in the Saudi Arabia. The demand reported in Table I is the total demand over a year horizon. The developed model was coded using the LINGO[11] optimization software to obtain the solution based on the developed MOM.

Table I. The values of parameters

Parameter	Value	Parameter	Value
C_{ij}^l	7.5-9.5	D_j	100K, 150K
C_{jk}^l	7.5-9.5	D_k	100K, 150K
C_{ij}^g	0.15, 0.18	R_i	20
C_i^t	30-55	R_j	15
C_i^r	800, 950	R_k	20
C_j^r	800, 950	R_{ij}	50
C_k^r	800, 950	R_{jk}	50
C_j^t	30, 55	H_i	7
C_k^t	30, 55	H_j	7
C_i^l	9.5, 13.5	H_k	7
C_j^l	9.5, 13.5	H_{ij}	7
C_k^l	9.5, 13.5	C_k	27
H_{jk}	7	C_i	27

The solution procedures of the model can be expressed as follows:

1) Optimize the MOM model employing two approaches as follows (i) for the ε-constraint method: the range between the maximum and minimum values for each objective was segmented into eight parts, the ε-points in between were assigned as ε values in Eq. 19. Then, Pareto solutions were obtained by implementing Eq. (18). The objective function related to the implementation and operational costs was minimized while the reader interference was considered as a constraint. Table II illustrates the results for eight ε-iterations; and (ii) for the LP-metrics method: each objective function was optimized independently under the problem constraints. The results are shown in Table III. For example, optimizing the second objective (Z_2) independently, the solutions of the two objective functions are determined as Z_1 = 508817, and Z_2 = 0.129. Illustrated in Table III, the ideal solutions for the two objectives are boldfaced which are: Z_1 = 488290, and Z_2 = 0.129.

Table III . Objectives values obtained by optimizing them individually

Objective functions	Min Z_1	Min Z_2
Z_1	**488290**	0.141
Z_2	508817	**0.129**

Then, different combinations of weights were assigned for the two objectives to obtain Pareto solutions of the MOM. Table IV illustrates the computation results obtained by determining eight different weights for the two objectives. These solutions are associated with the number of office 1, 2 and 3 that should be established.

2) Choose the final Pareto solution based on decision makers' preferences.

As previously mentioned, Table II and IV respectively, illustrate the results for simultaneously optimizing the two objective functions and the number of office 1, office 2 and office 3 that should be established. For example, solution#2 in Table II yields minimum implementation and operational costs equal 590011 GBP and minimum reader interference equals 0.176. This solution was obtained by an assignment of ε1 = 0.16. As shown in Table II, this solution an establishment three office 1, three office 2 and three office 3. It is noteworthy in these results that trade-offs among the three objectives (e.g. minimization of implementation and operational costs and minimization of reader interference) can be achieved.

To compare the two Pareto sets obtained by two different methods, Fig. 1 illustrates Pareto fronts corresponding to the optimization of the two objectives concurrently, using two solution methods. The two methods performed well in presenting the alternative Pareto solution. As shown in Fig. 1, the objectives (i.e. implementation and operational costs and reader interference) are conflicting as it is impossible to obtain an ideal value of each objective simultaneously. In other words, the Pareto solutions cannot get improved in one objective without deteriorating its performance in the other objectives. It is worth mentioning that all Pareto-optimal solutions are feasible. Nonetheless, after obtaining Pareto solutions, stakeholders should choose one solution to design their system. As shown in Fig. 1, the values of minimum implementation and operational costs and minimum reader interference are not considerably different for the two methods. Subsequently, solution#5 in Table II that is obtained by using the ε-constraint method is selected as the final solution. This solution is obtained by an assignment of ε_1 = .028. This solution requires 899001 GBP as a minimum

Table II. Pareto solutions obtained by the ε-constraint

#	ε_1	Min Z_1	Min Z_2	Open office 1	Open office 2	Open office 3
1	0.13	489110	0.132	2	3	3
2	0.16	590011	0.176	3	3	3
3	0.23	708800	0.198	4	4	3
4	0.24	833390	0.255	4	4	4
5	0.28	899001	0.283	5	6	5
6	0.34	1000310	0.322	6	7	5
7	0.39	1097771	0.387	6	8	6
8	0.49	1292100	0.487	6	8	7

Table IV. Pareto solutions obtained by the LP-metrics

#	w_1	w_2	Min Z_1	Min Z_2	Open Office 1	Open Office 2	Open Office 3
1	1	0	508817	0.134	2	3	3
2	0.9	0.1	600118	0.179	3	3	3
3	0.8	0.2	732990	0.229	4	5	3
4	0.7	0.3	859188	0.279	4	5	5
5	0.6	0.4	947771	0.311	6	7	4
6	0.5	0.5	1100110	0.332	6	7	5
7	0.4	0.6	1188100	0.382	6	8	8
8	0.3	0.7	1340010	0.501	6	8	8

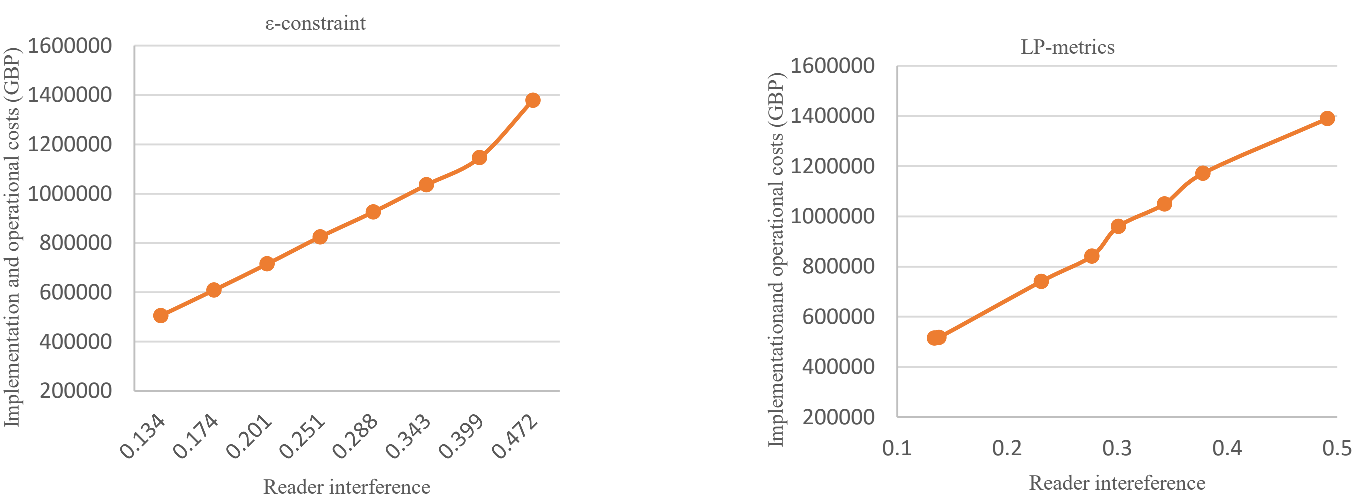

Fig. 1. Pareto fronts corresponding to the optimization of the two objectives concurrently.

implementation and operational costs in association to a reader interference equaling 0.283. It also needs an establishment of five office 1, six office 2 and five office 3.

5. CONCLUSION

This paper investigates a RFID-enabled passport location tracking system using a multi-objective approach. The systems consist three stages includes office 1, office 2 and office 3. The multi-objective model aimed at optimizing the proposed system in (i) allocating the optimal number of stages that should be opened; and (ii) obtaining compromised solutions between two objectives (e.g. maximization of the implementation and operational costs and RFID reader inference) of the proposed RFID-enabled passport location tracking system. To transform the multi-objective model into a mono-objective model, two solution approaches namely ε-constraint method and LP method were used and the results were compared. Subsequently, the final Pareto-solution was determined based on decision makers' preferences. Research results demonstrated the applicability of the developed model in presenting an optimal and cost-efficient design for the RFID-enabled passport tracking system that can be utilized as a reference for the designers of RFID-enabled networks. It also proved that the ε-constraint method outperformed the LP-metrics in this problem.

The ongoing research work is considering some parameters such demands, costs and capacity levels as imprecise parameters. This can be handled via the fuzzy programming approach.

REFERENCE

1. Muller-Seitz, G., Dautzenberg, K., Creusen, U. and Stromereder, C. (2009). Customer Acceptance Of RFID Technology: Evidence From The German Electronic Retail Sector. Journal of Retailing and Consumer Services, 16 (1), 31–39.

2. Mohammed, A and Wang, Q. (2016). A study in integrity of an RFID-monitoring HMSC. International Journal of Food Properties, DOI: 10.1080/10942912.2016.1203933

3. Mohammed, A and Wang, Q. (2017). The fuzzy multiobjective distribution planner for a green meat supply chain, Intern. Journal of Production Economics, 184, 47–58.

4. Nemmaluri, A., Corner, M. D. and Shenoy, P. (2008). Sherlock: Automatically Locating Objects For Humans. MobiSys, 187-198.

5. Karippacheril, T. G., Diaz Rios, L. and Srivastava, L. (2011). Global Markets, Global Challenges: Improving Food Safety And Traceability While Empowering Smallholders Through ICT, In book: ICT in Agriculture Sourcebook: Connecting Smallholders to Knowledge, Networks and Institutions, Ch 12, World Bank, 285-308.

6. H. Chen, Y. Zhu, K. Hu, and T. Ku, "RFID network planning using a multi-swarm optimizer," Journal of Network and Computer Applications, vol. 34, pp. 888–901, May 2011.

7. S. Kardasa, S. Celika, M. Yildiza, and A. Levib, "PUF-enhanced offline RFID security and privacy," Journal of Network and Computer Applications, vol. 35, pp. 2059–2067, November 2012.

8. Mysore, N., P. Nenavat, R. S. Unnithan, R. Mulukutla, and S. Rao. 2009. "An Efficient Algorithm for RFID Reader Positioning for Coverage of Irregularly-shaped Areas." Proceedings of IEEE International Conference on Automation Science and Engineering, Bangalore, 233–240.

9. Ma, L., K. Hu, Y. Zhu, and H. Chen. 2014. "Cooperative Artificial Bee Colony Algorithm for Multi-objective RFID Network Planning." Journal of Network and Computer Applications 42: 143–162.

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

11. Al-e-hashem, M. S. M. J., Malekly, H., Aryanezhad, M. B. (2011). A Multi-Objective Robust Optimization Model For Multi-Product Multi-Site Aggregate Production Planning In A Supply Chain Under Uncertainty. International Journal of Production Economics, 134 (1), 28–42.