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. A 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 Min-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 sends the to office 3 to be filled and delivered to clients. The RFID was proposed to be implemented to improve the system performance in
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 offices 3, \( k \in K \)
- \( C \) set of clients, \( c \in C \)

Given parameters:
- \( C_{ij} \) RFID tag cost (GBP) per item transported from office 1 to office 2
- \( C_i \) RFID reader cost (GBP) required per office 1
- \( C_j \) RFID reader cost (GBP) required per office 2
- \( C_k \) RFID reader cost (GBP) required per office 3
- \( C_i^f \) fixed cost (GBP) required for the RFID management system
- \( C_i^t \) training cost (GBP) per labor at office 1
- \( C_j^t \) training cost (GBP) per labor at office 2
- \( C_k^t \) training cost (GBP) per labor at office 3
- \( C_i^l \) labor cost per hour (GBP) at office 1
- \( C_j^l \) labor cost per hour (GBP) at office 2
- \( C_k^l \) labor cost per hour (GBP) at office 3
- \( C_{ij}^c \) cost (GBP) required for laborer transporting document from room 1 to office 2
- \( C_{jk}^c \) cost (GBP) required for laborer transporting document from room 2 to office 3
- \( R_i \) working rate (items) per laborer at office 1
- \( R_j \) working rate (items) per laborer at office 2
- \( R_k \) working rate (items) per laborer at office 3
- \( R_{ij} \) working rate (items) per laborer required to transport document from office 1 to office 2
- \( R_{jk} \) working rate (items) per laborer required to transport document from office 2 to office 3
- \( H_i \) minimum required number of working hours (h) for laborer at office 1
- \( H_j \) minimum required number of working hours (h) for laborer at office 2
- \( H_k \) minimum required number of working hours (h) for laborer at office 3

Decision variables:
- \( q_{ij} \) quantity of units dispatched from office 1 to office 2
- \( q_{jk} \) quantity of units dispatched from office 2 to office 3
- \( q_{kc} \) quantity of units handed to client c from office 3
- \( x_i \) required number of laborers at office 1
- \( x_j \) required number of laborers at office 2
- \( x_k \) required number of laborers at office 3
- \( x_{ij} \) required number of laborers to transfer units from office 1 to office 2
- \( x_{jk} \) required number of laborers to transfer units from office 2 to office 3
- \( y_i \) \{1: if office 1 is opened, 0: otherwise\}
- \( y_j \) \{1: if collection office 2 is opened, 0: otherwise\}
- \( y_k \) \{1: if collection office 3 is opened, 0: otherwise\}

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, office 2, and office 3 + labor costs at office 1, office 2, and office 3. Also, the number of readers are established. Equations 11-15 determine the required number of laborers at office 1, 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:

3.1 e-constraint

In the e-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 e-based constraints [10]. Thus, the equivalent solution formula (Z) is given by:

$$
\text{Min } Z = \text{Min } Z_1
$$

Subject to:

$$
Z_2 \leq e_i
$$

$$
[ Z_2 ]_{\text{min}} \leq e_i \leq [ Z_2 ]_{\text{max}}
$$

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 (Z1^*, Z2^*, and Z3^*). Subsequently, the model is solved as a single objective model using the following formula [11]:

\[
Min Z = \left[ \frac{w_1 (Z_1 - Z_1^*)}{Z_1^*} + \frac{w_2 (Z_2 - Z_2^*)}{Z_2^*} \right]
\]

(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. Data 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\textsuperscript{11} optimization software to obtain the solution based on the developed MOM.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>C\textsubscript{i}</td>
<td>7.5-9.5</td>
<td>D\textsubscript{j}</td>
<td>100K, 150K</td>
</tr>
<tr>
<td>C\textsubscript{j}</td>
<td>7.5-9.5</td>
<td>D\textsubscript{i}</td>
<td>100K, 150K</td>
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<tr>
<td>C\textsubscript{ijk}</td>
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<td>R\textsubscript{i}</td>
<td>20</td>
</tr>
<tr>
<td>C\textsubscript{i}</td>
<td>30-55</td>
<td>R\textsubscript{j}</td>
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<td>7</td>
<td>C\textsubscript{i}</td>
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Table I. The values of parameters

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

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 ε1 = .028. This solution requires 899001 GBP as a minimum
Table II. Pareto solutions obtained by the ε-constraint

<table>
<thead>
<tr>
<th>#</th>
<th>ε₁</th>
<th>Min Z₁</th>
<th>Min Z₂</th>
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<td>3</td>
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<td>708800</td>
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<td>0.255</td>
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<td>6</td>
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<td>1000310</td>
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<td>8</td>
<td>6</td>
</tr>
<tr>
<td>8</td>
<td>0.49</td>
<td>1292100</td>
<td>0.487</td>
<td>6</td>
<td>8</td>
<td>7</td>
</tr>
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</table>

Table IV. Pareto solutions obtained by the LP-metrics

<table>
<thead>
<tr>
<th>#</th>
<th>w₁</th>
<th>w₂</th>
<th>Min Z₁</th>
<th>Min Z₂</th>
<th>Open Office 1</th>
<th>Open Office 2</th>
<th>Open Office 3</th>
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<tr>
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</table>

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

implementation and operational costs in association with 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