

Multi-criteria optimization for a cost-effective design of an RFID-based meat supply chain

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Abstract

Purpose – In this paper, the authors investigated a proposed RFID (radio frequency identification)-based meat supply chain to monitor quality and safety of meat products they purchase from supermarkets. The supply chain consists of farms, abattoirs and retailers. The purpose of this work presented in this paper was to determine a cost-effective trade-off decision obtained from a developed multi-criteria optimization model based on three objectives. These objectives include customer satisfaction in percentage of product quantity as requested by customers, product quality in numbers of meat products and the total implementation cost. Furthermore, this work was aimed at determining the number and locations of farms and abattoirs that should be established and quantities of products that need to be transported between entities of the proposed supply chain.

Design/methodology/approach – To this aim, a tri-criteria optimization model was developed. The considered criteria were used for minimizing the total implementation cost and maximizing customer satisfaction and product quality. In order to obtain Pareto solutions based on the developed model, four solution approaches were employed. Subsequently, a new decision-making algorithm was developed to select the superior solution approach in terms of values of the three criteria.

Findings – A case study was applied to examine the applicability of the developed model and the performance of the proposed solution approaches. The computational results proved the applicability of the developed model in obtaining a trade-off among the considered criteria and solving the RFID-based meat supply chain design problem.

Practical implications – The developed tri-criteria optimization model can be used by decision makers as an aid to design and optimize food supply chains.

Originality/value – This article presents a development of (i) a cost-effective optimization approach for a proposed RFID-based meat supply chain seeking a trade-off among three conflicting criteria; and (ii) a new decision making algorithm which can be used for any multi-criteria problem to select the best Pareto solution.

Keywords: Meat supply chain; Multi-criteria optimization; Customer satisfaction; Decision making algorithm.

1. Introduction

Meat supply chains generally constitute four different echelons which forms a network including farms, abattoirs, retailers and customers. In recent years, safety and quality of food products, which are supplied through a food supply chain network, has been one of major issues on which consumers demand more transparent information relating to food they purchase at supermarkets (Ahmed, 2008; Lever & Miele, 2012). A study by Peattie, Peattie & Jamal (2006) suggested that consumers often spend a considerable amount of time and effort seeking out fresh food by reading information such as expiry dates shown

43 on product labels to ensure that they purchase a good quality of food products. One way to
44 provide the prompt information on food status is to implement the RFID technology. In the
45 past decade, implementation of RFID technology has been gaining an ever-increasing
46 popularity as it enhances traceability of safety and quality of food products (Chrysochou
47 et al., 2009; Manos & Manikas, 2010; Zailani et al., 2010).

48 Through a literature review, little research works were found for investigating the RFID-
49 enabled supply chains seeking a compromised solution between the benefits of the RFID
50 implementation in supply chains and its need for additional costs in relevance to the supply
51 chain network design. In this paper, the authors examined a proposed RFID-based three-
52 echelon meat supply chain seeking a compromised solution based on objective functions
53 relating to the total implementation cost, customer satisfaction in percentage of satisfying
54 customers' demand in product quantity, and product quality in numbers of meat products.
55 To this aim, a tri-criteria mixed integer linear programming model was developed. The
56 work also includes the determination of (i) number and locations of farms and abattoirs
57 that should be established and (ii) quantities of livestock transported from farms to abattoirs
58 and meat products transported from abattoirs to retailers. By solving the tri-criteria
59 optimization problem, four solution approaches were investigated. These are compromise
60 programming, goal programming, weighted Tchebycheff and utility function. A developed
61 decision making algorithm was employed to select the superior solution approach based on
62 computational results values. This approach can be used as a reference for decision makers
63 to obtain a **cost-effective design** of food supply chains.

64 **2. Prior studies**

65 Multi-objective optimization refers to an optimization of multiple decision making
66 objectives concurrently. These objectives are possibly conflicting and competing.
67 According to a thesis work of Almaraz, 2014, in a multi-objective problem, it is impossible
68 to obtain a single ideal solution but a trade-off among a number of objectives, since there
69 is a contradictory among the objectives. Pareto optimal solutions are obtained based on
70 multiple conflicting criteria. Multi-criteria optimization models were applied into supply
71 chain network designs for solving production-distribution planning problems (Gen &
72 Heng, 1997; Deb, 2001; Shen & Daskin, 2005; Shen & Daskin, 2005; Sabri & Beamon,
73 2009; Pandu, 2009; Hu & Li, 2009;). These problems can be strategic in such as the facility
74 location-allocation problem or tactical in such as the flow of product quantities. Costs or
75 profits are among one of other issues that may need to be considered (Jayaraman and Pirkul
76 2001, Syam 2002 and Syarif, Yun, and Gen 2002, Jayaraman and Ross 2003, Yan, Yu, and
77 Cheng 2003). Altiparmak, Gen, Lin, and Paksoy (2006) proposed a genetic algorithm
78 focusing on minimization of inbound and outbound distribution costs and maximization of
79 customer services in terms of delivery time and capacity of distribution centers. Selim,
80 Araz & Ozkarahan (2008) presented a multi-criteria optimization model to cope with a
81 production-distribution planning problem in a supply chain. Fuzzy goal programming was

82 used to incorporate decision maker's imprecise goal levels for each objective. Ferrio and
83 Wassick (2008) formulated a mixed integer linear programming model for configuring and
84 optimizing the design of a multi-product chemical supply chain network which consists of
85 production sites, arbitrary numbers of distribution centers, and customers. Schütz,
86 Tomasgard and Ahmed (2008) formulated a decision support system using a two-stage
87 stochastic program with respect to minimizing costs of investment and operations of a
88 supply chain. Tuzkaya and Onut (2009) studied a three-level supply chain including
89 supplier, warehouses, and manufacturers seeking the best distribution plan of products. Li
90 et al. (2009) developed a multi-objective optimization model to configure distribution
91 center locations; the considered objectives were minimization of the transportation cost,
92 transportation and production carbon emissions. Chang (2010) presented a single-objective
93 mathematical model to optimize a multiple level supply chain network design
94 encompassing suppliers, factories, distribution centers and retailers. The considered
95 objective was to minimize the total cost including purchasing and transportation cost of
96 raw materials and products, manufacturing cost of products in factories, and storage cost
97 of products in distribution centers. Alumur et al. (2012) proposed a profit maximization
98 modeling framework for a reverse logistics network design problem. The same method was
99 also used by Sadjady and Davoudpour (2012) to tackle a two-level supply chain network
100 design problem. The problem was formulated as a mono-criteria optimization model to
101 minimize total cost, which include costs in transportation, lead-times and inventory for
102 products and opening and operating costs for facilities. Pourrousta et al. (2012) developed
103 a multi-objective model to minimize total cost and delivery time of products in a multi-
104 echelon supply chain network. Liu and Papageorgiou (2014) proposed a multi-criteria
105 optimization model for tackling a production–distribution and capacity planning problem
106 in a supply chain using the ϵ -constraints and Lexicographic min–max methods.

107 **3. Mathematical formulation**

108 In this study, a meat supply chain comprises three echelons: farms, abattoirs and retailers,
109 was studied. In this chain, farms supply livestock to abattoirs where slaughtered livestock
110 as packed meat products are transported to retailers. The RFID technology was proposed
111 for tracing safety and quality of meat products during the transportation process from farms
112 to abattoirs and from abattoirs to retailers (Mohammed & Wang, 2015). Fig. 1 depicts the
113 structure illustration of the investigated meat supply chain.

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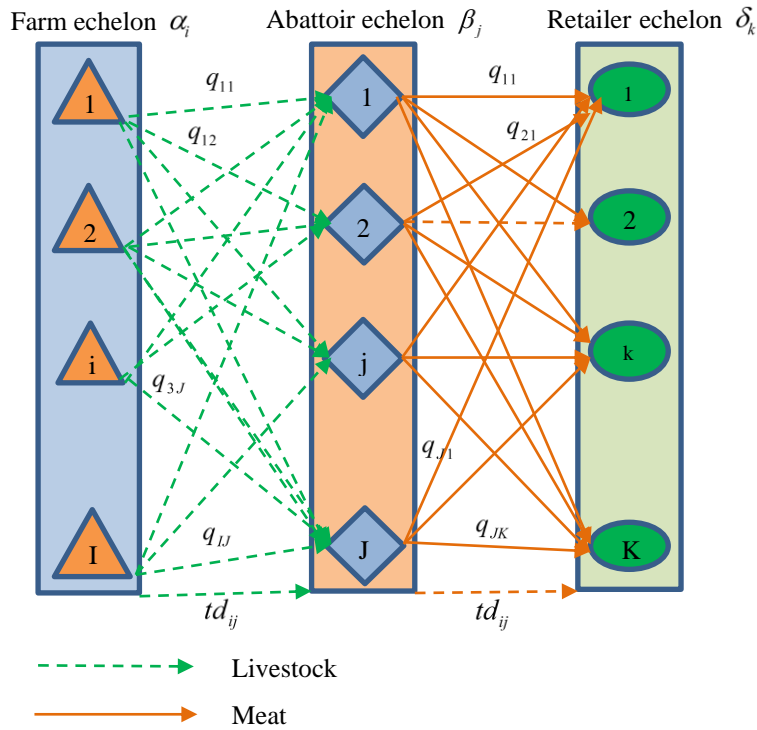
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130 Fig. 1. The structure of the meat supply chain network.

131 To formulate the tri-criteria model, the following indices, parameters and decision
132 variables are presented:

133 Indices

134 I index used for a potential location of farm i , $1 \leq i \leq I$

135 J index used for a potential location of abattoir j , $1 \leq j \leq J$

136 K index for a fixed location of retailer k , $1 \leq k \leq K$

137

138 Cost parameters:

139 C_i^a cost (£) of RFID equipment and implementation required for farm i

140 C_j^b cost (£) of RFID equipment and implementation required for abattoir j

141 C_i^t RFID tag cost (£) for each item at farm i

142 C_j^t RFID tag cost (£) for each item at abattoir j

143 TC_{ij} unit transportation cost (£) per mile from farm i to abattoir j

144 TC_{jk} unit transportation cost (£) per mile from abattoir j to retailer k

145 LC_i^a unit labor cost (£) per hour at farm i

146 LC_j^b unit labor cost (£) per hour at abattoir j

147

148 Parameters of capacity, demand and transportation distance:

149 S_i^α maximum supply capacity (units) of farm i

150 S_j^β maximum supply capacity (units) of abattoir j

151 W_v transportation capacity (units) per vehicle (v)

152 D_j^β minimum demand (in units) of abattoir j

153 D_k^δ minimum demand (in units) of retailer k

154 d_{ij} travel distance (mile) from farm i to abattoir j

155 d_{jk}^n travel distance (mile) from abattoir j to retailer k

156

157 Labor parameters:

158 $R_i^{l\alpha}$ working rate (items) per laborer (l) at farm i

159 $R_j^{l\beta}$ working rate (items) per laborer (l) at abattoir j

160 $N_i^{h\alpha}$ minimum required number of working hours (h) for laborer l at farm i

161 $N_j^{h\beta}$ minimum required number of working hours (h) for laborer l at abattoir j

162

163 Other parameters

164 Q_{ij} healthiness percentage of livestock transported from farm i to abattoir j

165 F_{jk} freshness percentage of meat products ~~pieces~~ transported from abattoir j to retailer k

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167 Decision variables:

168 q_{ij} quantity of units transported from farm i to abattoir j

169 q_{jk} quantity of units transported from abattoir j to retailer k

170 x_i^α number of required laborers at farm i

171 x_j^β number of required laborers at abattoir j

172

173 Non-negative and binary decision variables:

174 $y_i^\alpha = \begin{cases} 1: & \text{if farm } i \text{ is open} \\ 0: & \text{otherwise} \end{cases}$

176 $y_j^\beta = \begin{cases} 1: & \text{if abattoir } j \text{ is open} \\ 0: & \text{otherwise} \end{cases}$

178

179 The criteria functions are formulated as follows:

180 The minimum total cost $F_1 =$ costs of RFID equipment and implementation + RFID tag
 181 cost for each item + transportations costs – labor costs saved after the RFID
 182 implementation, **i.e.**,

$$\begin{aligned}
 \text{Min } F_1 = & \sum_{i \in I} C_i^\alpha y_i^\alpha + \sum_{j \in J} C_j^\beta y_j^\beta + \sum_{i \in I} C_i^{\alpha} q_{ij} + \sum_{j \in J} C_j^{\beta} q_{jk} \\
 & + \sum_{i \in I} \sum_{j \in J} TC_{ij} \left[q_{ij} / W_v \right] d_{ij} + \sum_{j \in J} \sum_{k \in K} TC_{jk} \left[q_{jk} / W_v \right] d_{jk} \\
 & - \sum_{i \in I} LC_i^\alpha x_i^\alpha N_i^{h\alpha} - \sum_{j \in J} LC_j^\beta x_j^\beta N_j^{h\beta}
 \end{aligned} \tag{1}$$

183 The maximum customer satisfaction $F_2 =$ the fulfilment of demand in percentage of product
 184 quantity as requested by customers, **i.e.**,

$$\text{Max } F_2 = \sum_{k=1}^K \left(\frac{\sum_{j=1}^J q_{jk}}{D_k^\delta} \right) \tag{2}$$

185 Maximum product quality $F_3 =$ healthiness of livestock transported from farms to abattoirs
 186 + freshness of meat pieces transported from abattoirs to retailers, **i.e.**,

$$\text{Max } F_3 = \sum_{i=1}^I Q_{ij} y_i^\alpha + \sum_{j=1}^J F_{jk} y_j^\beta \tag{3}$$

187 Several constraints are grouped in different categories as follows:

188 Capacity constraints: show the capacity constraints of farms and abattoirs.

$$\sum_{i \in I} q_{ij} \leq S_i^\alpha y_i^\alpha \quad \forall j \in J \tag{4}$$

$$\sum_{j \in J} q_{jk} \leq S_j^\beta y_j^\beta \quad \forall k \in K \tag{5}$$

189 Demand constraints: ensure that the demands in quantity of products of all abattoirs and
 190 retailers are satisfied.

$$\sum_{i \in I} q_{ij} \geq D_j^\beta \quad \forall j \in J \tag{6}$$

$$\sum_{j \in J} q_{jk} \geq D_k^\delta \quad \forall k \in K \tag{7}$$

$$D_j^\beta \geq \sum_{k \in K} q_{jk} \quad \forall j \in J \tag{8}$$

191

192 Working rate constraints: determine the required number of laborers at farms and abattoirs.

$$\sum_{j \in J} q_{ij} \leq x_i^\alpha R_i^{l\alpha} \quad \forall i \in I \quad (9)$$

$$\sum_{k \in K} q_{jk} \leq x_j^\beta R_j^{l\beta} \quad \forall j \in J \quad (10)$$

193

194 Restriction constraints: restrict the decision variables to binary and non-negative.

$$q_{ij}, q_{jk} \geq 0, \quad \forall i, j, k; \quad (11)$$

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

195

196 Finally, $0.75 \leq Q_{ij} \leq 1$ and $0.75 \leq F_{jk} \leq 1$ constraints, which limit the healthiness percentage (Q)
 197 and the freshness percentage (F) to be between 0.75 and 1 (based on decision makers'
 198 preferences).

199

200 4. Multi-criteria optimization methodology

201 Multi-criteria optimization involves the simultaneous optimization of a number of decision
 202 making criteria which are conflicting and often competing. In order to solve this type of
 203 optimization problem, researchers deal with a set of solutions known as Pareto optimal
 204 solutions. Nevertheless, it can be a case that none of these Pareto solutions is better than
 205 the others considering all the criteria. Different approaches can be aided in solving such a
 206 problem. In this study, four different solution approaches were investigated aimed to obtain
 207 four sets of Pareto solutions to be selected as the best one in terms of solution quality

208 4.1. Compromise programming approach

209 The compromise programming approach is its ability to achieve efficient points in a non-
 210 convex Pareto curve (Chankong & Haimes, 1983). This method based on optimizing one
 211 criterion function and shifting the other to the constraint set to be restricted to an assigned
 212 value (ϵ). The equivalent solution formula F is presented as follows.

$$\begin{aligned} \text{Min } F = & \sum_{i \in I} C_i^\alpha y_i^\alpha + \sum_{j \in J} C_j^\beta y_j^\beta + \sum_{i \in I} C_i^{t\alpha} q_{ij} \quad (13) \\ & + \sum_{j \in J} C_j^{t\beta} q_{jk} + \sum_{i \in I} \sum_{j \in J} TC_{ij} \left[q_{ij} / W_v \right] d_{ij} + \sum_{j \in J} \sum_{k \in K} TC_{jk} \left[q_{jk} / W_v \right] d_{jk} \\ & - \sum_{i \in I} LC_i^\alpha x_i^\alpha N_i^{h\alpha} - \sum_{j \in J} LC_j^\beta x_j^\beta N_j^{h\beta} \end{aligned}$$

213

214 Additional constraints:

215

$$\sum_{k=1}^K \left(\frac{\sum_{j=1}^J q_{ij}}{D_k^\delta} \right) \geq \varepsilon_1 \quad (14)$$

$$\left[\sum_{k=1}^K \left(\frac{\sum_{j=1}^J q_{ij}}{D_k^\delta} \right) \right]^{\min} \leq \varepsilon_1 \leq \left[\sum_{k=1}^K \left(\frac{\sum_{j=1}^J q_{ij}}{D_k^\delta} \right) \right]^{\max} \quad (15)$$

$$\sum_{i=1}^I Q_{ij} y_i^\alpha + \sum_{j=1}^J F_{jk} y_j^\beta \geq \varepsilon_2 \quad (16)$$

$$\left[\sum_{i=1}^I Q_{ij} y_i^\alpha + \sum_{j=1}^J F_{jk} y_j^\beta \right]^{\min} \leq \varepsilon_2 \leq \left[\sum_{i=1}^I Q_{ij} y_i^\alpha + \sum_{j=1}^J F_{jk} y_j^\beta \right]^{\max} \quad (17)$$

216

217 In this paper, criterion function one is selected to be optimized based on Eq.13 and shifting
 218 criterion function two and three to be constraints (Eq. 14 and 16 respectively); An increase
 219 to the ε value (Eq.15 and 17) yields Pareto solutions.

220 4.2. Goal programming approach

221 The purpose of the goal programming approach is to find a solution that minimizes
 222 undesirable deviations between the objective functions and their corresponding goals
 223 (Charnes, Cooper & Ferguson, 1955; Colapinto, Jayaraman & Marsiglio, 2015). The
 224 solution functions are expressed as follows:

$$\text{Min } F \quad (18)$$

$$\frac{\zeta^1}{G^1} \leq F \quad (19)$$

$$\frac{v^2}{G^2} \leq F \quad (20)$$

$$\frac{v^3}{G^3} \leq F \quad (21)$$

225

226 The equivalent criteria functions are expressed as follows.

$$\text{Min } F_1 = \sum_{i \in I} C_i^\alpha y_i^\alpha + \sum_{j \in J} C_j^\beta y_j^\beta + \sum_{i \in I} C_i^{t\alpha} q_{ij} + \sum_{j \in J} C_j^{t\beta} q_{jk} \quad (22)$$

$$\begin{aligned} &+ \sum_{i \in I} \sum_{j \in J} TC_{ij} \left[q_{ij} / W_v \right] d_{ij} \\ &+ \sum_{j \in J} \sum_{k \in K} TC_{jk} \left[q_{jk} / W_v \right] d_{jk} - \sum_{i \in I} LC_i^\alpha x_i^\alpha N_i^{h\alpha} - \sum_{j \in J} LC_j^\beta x_j^\beta N_j^{h\beta} \\ &+ \zeta^1 - \nu^1 = G^1 \end{aligned}$$

$$\text{Max } F_2 = \sum_{k=1}^K \left(\frac{\sum_{j=1}^J q_{ij}}{D_k^\delta} \right) + \zeta^2 - \nu^2 = G^2 \quad (23)$$

$$\text{Max } F_3 = \sum_{i=1}^I Q_{ij} y_i^\alpha + \sum_{j=1}^J F_{jk} y_j^\beta + \zeta^3 - \nu^3 = G^3 \quad (24)$$

227 Where

G^1	goal of the criterion 1
G^2	goal of the criterion 2
G^3	goal of the criterion 3
ζ^1	negative deviation variable of the criterion 1
ζ^2	negative deviation variable of the criterion 2
ζ^3	negative deviation variable of the criterion 3
ν^1	positive deviation variable of the criterion 1
ν^2	positive deviation variable of the criterion 2
ν^3	positive deviation variable of the criterion 3

228 Subject to an additional non-negativity restriction:

$$\zeta, \nu \geq 0, \quad (25)$$

229

230 4.3. Weighted Tchebycheff approach

231 With this approach, the multi-objective possibilistic model can be transformed into a
 232 single-objective model F . The purpose of the single-objective model is to minimize the
 233 distance between the ideal objective vector F^* and the feasible objective surface
 234 (Miettinen, 1998). The solution approach function F can be formulated as follows:

235

$$\text{Min } F = \left(\sum_{n=1}^3 l_n |F_n - F^*|^p \right)^{\frac{1}{p}} \quad (26)$$

236

237 Subject to constraints 4-12. Noticeably, the values of objective functions vary depending
238 on the value of p . Usually, p is set as 1 or 2. But, other values of p can also be used. In this
239 case study, p is set as 1.

240

241 4.4. Utility function approach

242

243 In the utility function approach, the effectiveness utility of each Pareto solution is
244 determined by summing the scaled criteria functions. The scalar value λ for each criterion
245 is determined by decision maker according to the importance for each criterion (Stoll,
246 1999). In this work, the criterion function (or utility function) U is expressed as follows:

247

$$U(F_1, F_2) = \left\{ \sum_{n=1}^2 \lambda_n F_n \mid \lambda_n < 1, \sum_{n=1}^2 \lambda_n = 1 \right\} \quad (27)$$

248

249 4.5. Decision making algorithm

250 In this paper, the selection algorithm is based onto two stages; in the first stage the best
251 trade-off solution is selected for each set of solutions. Selecting the superior approach is
252 determined in the subsequent stage. The next two sub-sections present the two stages
253 respectively.

254 4.5.1. Global criterion approach

255 There are several methods for selecting the most suitable solution in a multi-objective
256 problem. In this case, the global criterion method was used for determining the best
257 solution by minimizing the distance to the ideal objective value F_n^* (Pandur, 2009). The
258 decision making formula is expressed as follows:

$$\text{Min } F = \left(\sum_{n=1}^3 |F_n - F_n^*|^\rho \right)^{1/\rho}; \quad 1 \leq \rho \leq \infty \quad (28)$$

259

260 In this approach, the solution with the minimum distance is selected as a best solution.
261 Generally, ρ is 1; However, other values of ρ also can be used.

262 4.5.2. The developed approach

263 The idea of the developed approach for selecting the best approach is based on selecting
264 the solution approach that is closest to the ideal solution. In this approach, S^* represents the
265 average superiority value for each approach; (i) determine the average mean value for the
266 three criterion functions, (ii) sum the three average mean values, and (iii) select the
267 approach with the lowest superiority value. The selection formula is presented as follows:

$$S^* = \sum_{n=1}^3 \frac{F_n}{F_n^*} \quad (29)$$

268 Where F_i^* is the ideal value for each criterion. This value is determined by optimizing the
 269 criteria functions individually.

270 5. Application and comparison: South East London as a case study

271 A case study is presented to demonstrate the applicability of the developed tri-criteria
 272 model and compare the performance of the proposed solution approaches in terms of the
 273 criteria values. In the case study, the South-East area of London encompasses 4 farms (I),
 274 7 retailers (K) and 4 abattoir (J) suppliers. Table 1 shows the collected data which are
 275 chosen in a defined range (based on assumptions). Data, which are related to locations of
 276 farms, abattoirs and retailers, were collected from the Meat Committee in the UK (HMC,
 277 2015). The transportation distances between supply chain facilities were estimated using
 278 Google-Maps. The demand reported in Table 1 is the total demand over a one-year period.
 279 The prices of RFID equipment and its implementation were estimated based on the
 280 marketing prices.

281

282

Table 1. Parameters used for the case study

$I = 4$	$C_j^\beta = 1.1\text{K}-8\text{K} (\pounds)$	$D_k^\gamma = 100-800$	$d_{ij} = 23- 400$
$J = 7$	$TC_{jk} = 20 (\pounds)$	$d_{jk} = 110 - 162$	$LC_i^\alpha = 6.5 (\pounds)$
$K = 4$	$S_i^\alpha = 2.5\text{K}-4.4\text{K}$	$W_v = 100$	$LC_j^\beta = 6.5 (\pounds)$
$C_i^\alpha = 4.4\text{K}-8.8\text{K} (\pounds)$	$S_j^\beta = 1.2\text{K}-1.8\text{K}$	$R_i^{1\alpha} = 50$	$F_{jk} = 0.75-1$
$TC_{ij} = 20 (\pounds)$	$D_j^\beta = 800-1.3\text{K}$	$R_j^{1\beta} = 50$	$Q_{ij} = 0.75-1$
$C_i^t = 0.15 (\pounds)$		$C_j^t = 0.15 (\pounds)$	

283

284

285

286 The tri-criteria optimization problem described in Section 3 was investigated using four
 287 different approaches. This was carried out using the LINGO¹¹ software on a computer with
 288 corei5-CPU 2.60 GHz, RAM 4.00 GB.

289 Table 2 elucidates the values obtained using equation 1-3, respectively. Each value was
 290 optimized based on each criterion for obtaining the ideal solution. As shown in Table 2,
 291 the total cost can be minimized to £194,180 based on the criterion function one, while in
 292 this solution the criterion function two and three worsen to 75% and 8,885 items of meat
 293 products respectively. On the antithesis, if the second criterion function F_2 was only
 294 considered, customer satisfaction would increase to 100%. However, the total cost
 295 increases to £491,000. Finally, considering the third criterion F_3 individually, the objective
 296 of product quality, which increases to 13,099 items of meat product leading to an increase
 297 in the total cost of £481,390 and customer satisfaction of 99%. In this situation, the
 298 contradictory is manifested between these three criteria functions. However, moving
 299 toward an enhancement in **customer** satisfaction and product quality in supply chains
 300 requires significantly higher cost investment.

301

302 **Table 2. The values of the three criteria obtained by the individual optimization.**

Criterion function	Min F_1 (£)	Max F_2 (%)	Max F_3 (Items)
F_1	194180	0.75	8885
F_2	491000	1	13099
F_3	481390	0.99	13099

303

304 As discussed above, it can be easily noticed that there is no solution which is optimal as it
 305 is impossible to obtain an optimal solution towards the three criteria at a time. To this aim,
 306 four solution approaches were employed for seeking the Pareto sets derived from co-
 307 optimizing the three contradicting criteria by minimizing total cost F_1 , maximizing
 308 **customer** satisfaction F_2 and maximizing product quality F_3 .

309

310 Pareto optimal solutions can be obtained using: (i) the compromise programming approach
 311 by altering the incremental epsilon value of 526 between 8,885 to 13,099 for criterion two
 312 (Eq.15) and of **0.025** between 0.75 to 1 for criterion three (Eq.17); (ii) the goal
 313 programming approach by assigning eight different goals for the three criteria ; (iii) the
 314 weighted Tchebycheff approach using the ideal values of the three criteria functions
 315 illustrated in Table 2_were given as ideal values F_1^* , F_2^* , F_3^* for the solution function F using
 316 Eq.26; and (iv) the utility function approach using different scalar values λ .

317 Table 3 shows four sets of Pareto optimal solutions which were obtained using the four
 318 solution approaches. These solutions also include numbers of farms and abattoirs that
 319 should be established. Shown in Table 3, the third column shows the values of the first

320 criterion function (F_1), obtained values of the second and third criterion functions (F_2 and
 321 F_3) in terms of percentage and items are presented in the fourth and fifth columns,
 322 respectively. The last two columns (right-end) correspond to the number of farms and
 323 abattoirs that should be established.

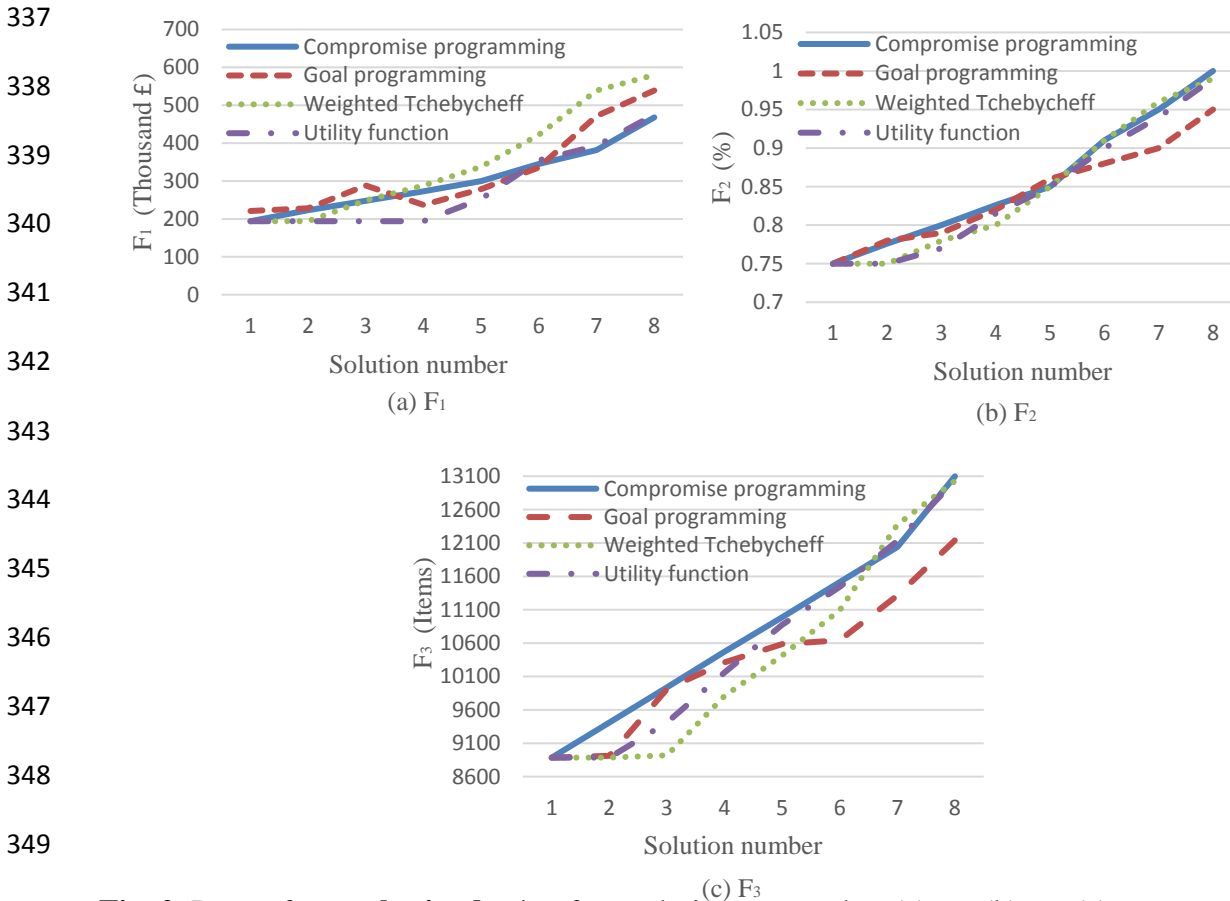
324 **Table 3.** Pareto solutions obtained by using four different approaches.

Solution approach	#	Min (F_2) (£)	Max (F_2) (%)	Max (F_3) (items)	Open farms	Open abattoirs
Compromise programming	1	194180	0.75	8885	1 0 0 1	0 1 0 1
	2	223257	0.776	9411	1 0 1 1	0 1 0 1
	3	248214	0.8	9937	1 0 1 1	0 1 0 1
	4	273171	0.826	10473	0 0 1 1	0 1 0 1
	5	300475	0.85	10989	1 0 1 1	1 0 1 1
	6	345228	0.91	11515	1 1 1 1	1 1 0 1
	7	382940	0.95	12041	1 1 1 1	1 0 1 1
	8	468475	1	13099	1 1 1 1	0 1 1 0
Goal programming	1	221655	0.75	8885	1 1 1 1	1 1 1 1
	2	228705	0.78	8913	0 1 1 1	1 1 1 0
	3	288810	0.79	9912	1 0 0 1	0 1 0 1
	4	237050	0.82	10311	1 1 1 1	1 1 1 1
	5	279835	0.86	10586	1 0 0 1	1 0 1 1
	6	336480	0.88	10642	1 1 1 1	1 1 1 1
	7	4724750	0.9	11313	1 1 1 1	1 1 0 1
	8	5391300	0.95	12141	0 0 1 1	0 1 1 0
Weighted Tchebycheff	1	194180	0.75	8885	1 0 0 1	0 1 0 1
	2	194180	0.75	8885	1 0 0 1	0 1 0 1
	3	249231	0.78	8920	1 0 1 1	1 1 1 1
	4	288557	0.8	9808	1 1 1 1	1 1 1 1
	5	338858	0.85	10414	1 1 1 1	1 1 1 1
	6	422451	0.91	11094	1 1 1 1	1 1 0 1
	7	539128	0.96	12376	1 1 1 1	1 1 1 1
	8	580471	0.99	13029	1 0 0 1	0 1 0 1
Utility function	1	194180	0.75	8885	1 0 0 1	0 1 0 1
	2	194180	0.75	8885	1 0 0 1	0 1 0 1
	3	194180	0.77	9411	0 0 1 1	0 1 0 1
	4	194180	0.815	10162	1 0 1 1	1 0 1 1
	5	253475	0.85	10876	1 1 1 1	1 1 0 1
	6	355336	0.9	11444	1 1 1 1	1 0 1 1
	7	392720	0.94	12131	1 1 1 1	0 1 1 0
	8	475660	0.99	13032	1 1 1 1	0 1 1 1

325 For instance, solution number 4 was obtained using the compromise programming
 326 approach by assigning $\varepsilon_1 = 0.825$ and $\varepsilon_2 = 10,470$; accordingly, it gives the minimum total
 327 cost of £273,171, the maximum customer satisfaction of 82.6% and the maximum product
 328 quality of 10,473 items of meat products. This solution also includes an establishment of
 329 farms three and four (0 0 1 1) and abattoirs two and four (0 1 0 1). As observed in Table 3,
 330 Pareto optimal solutions cannot be obtained according to one criterion without worsening
 331 its performance in other criteria.

332 5.1. Selecting the superior approach

333 To design the meat supply chain network, decision makers often need to find a solution
 334 based on a number of alternative possibilities using a decision making approach. Fig. 2
 335 illustrates Pareto fronts based on optimizing the three criteria using four solution
 336 approaches.



350 **Fig. 2.** Pareto fronts **obtained** using four solution approaches (a) F_1 , (b) F_2 , (c) F_3 .

351 Fig. 2 also shows the small difference in obtained criteria values in terms of minimum total
 352 cost, maximum **customer** satisfaction and maximum product quality using the four
 353 different approaches. This leads to the difficulty in selection of the best solution. Hence, a
 354 decision making algorithm (described in sub-section 4.5.) was used. At the first stage-the
 355 global criterion approach was employed to select the best Pareto solution for each set of
 356 solutions. In this case, Pareto solutions number 3, 2, 3 and 5 (shown in Table 3) were
 357 determined as the best solutions using the four different solution approaches as described
 358 in section 4, respectively. These solutions were achieved with the minimum distances to
 359 their ideal criteria values; the values of these distances are 1.69, 1.63, 1.741 and 1.749,
 360 respectively. The developed selection technique was then applied to select the superior
 361 approach using Eq.29. Accordingly, the obtained superiority values for the compromise

362 programming approach is 2.568, the goal programming approach is 2.637, weighted
 363 Tchebycheff approach is 2.743 and the utility function approach is 2.97. It apparently
 364 shows that the superiority of the compromise programming approach to tackles the
 365 considered tri-criteria problem as it gives the lowest value of 2.568. Its solution (number 3
 366 in Table 3) was obtained by assigning $\varepsilon_1 = 0.825$ and $\varepsilon_2 = 9,937$. Fig. 3 illustrates the
 367 optimal meat supply chain network design based on the determined solution.

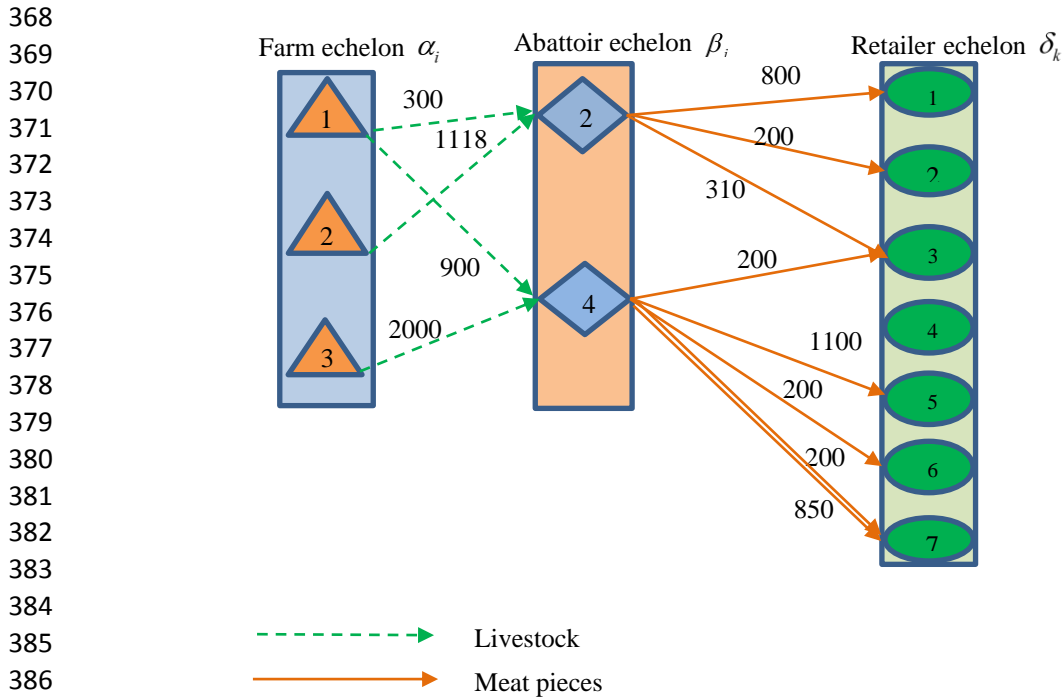


Fig. 3. The optimal meat supply chain network design.

390 Subsequently, three farms located in Warwickshire, Leicestershire, and the Yorkshire are
 391 determined to be established and two abattoirs located in Birmingham and Warrick. For
 392 the selected solution, the minimum total cost is £248,214, the maximum customer
 393 satisfaction is 80% and the maximum product quality is 9,937 items of meat products. The
 394 distribution plan of products was also determined; 900 livestock are to be transported from
 395 farm one (located in Warwickshire) to abattoir four (located in Warrick) and 800 items of
 396 meat products are to be transported from abattoir two (located in Birmingham) to retailer
 397 one.

6. Conclusion

400 In this paper, a multi-criteria mixed integer linear programming model was developed for
 401 solving an issue of a three-echelon RFID-based meat supply chain design based on three
 402 criteria: total cost of implementation, customer satisfaction (%) in a fulfillment of the
 403 demand in product quantities, and product quality in numbers of meat product. To reveal
 404 Pareto solutions based on the developed model, four solution approaches were investigated.

405 A numerical case study was studied for examining the applicability of the developed model
406 using four different solution approaches. Moreover, a decision making algorithm was
407 developed to select the best solution approach. It proved the superiority of the compromise
408 programming approach. This study shows that the developed tri-criteria optimization
409 model can be useful for obtaining a compromised solution between economic costs and
410 customer satisfaction of the proposed RFID-enabled meat supply chain.

411 An interesting research avenue derived from this work is recommended as follows:

- 412 1. Developing a fuzzy tri-criteria programming model to cope with the uncertainty in
413 costs, demands, healthiness percentage of livestock and freshness percentage of
414 meat products.
- 415 2. Solving the multi-criteria optimization problem by a meta-heuristic algorithm may
416 be useful for handling large-sized problems.

417 **Acknowledgements**

418 The authors would like to express their gratitude to the Higher Committee for Education
419 Development (HCED) in Iraq for the financial support in this study. Also, the authors are
420 thankful for constructive comments of the anonymous reviewers.

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