ECO-GRESILIENT: COALESCING INGREDIENT OF ECONOMIC, GREEN AND RESILIENCE IN SUPPLY CHAIN NETWORK DESIGN

Ahmed Mohammed[1,2], Irina Harris[1] and Reda Nujoom[2]
[1]Cardiff Business School, Cardiff University, Aberconway Building, Colum Dr, Cardiff, UK CF10 3EU
[2]School of Engineering, University of Portsmouth, Portsmouth, UK, PO1 3DJ
Mohammeda9@port.ac.uk, harrisi1@cardiff.ac.uk, reda.nujoom@port.ac.uk

Keywords: Supply chain resilience; Go green; RALF; Fuzzy AHP; multi-criteria decision making; Multi-objective optimization..

Abstract: This research presents a new approach that considers green and resilience dimensions in addition to economic (eco-gresilient, henceforth) aspects to design an eco-gresilient supply chain network. Thus, fuzzy AHP (analytical hierarchy process) is used to determine the relative weight of evaluation criteria for each resilience pillars (robustness, agility, leanness and flexibility (RALF)), and then it is used for assigning the importance weight for each potential facility with respect to RALF. The determined weights revealed via fuzzy AHP are then integrated into a multi-objective optimization model to identify the number of facilities that should be established in the meat supply chain. Three objective functions were formulated and include minimization of total cost and environmental impact and maximization of value of resilience (V-RALF). The ε-constraint approach is used to obtain a set of Pareto solutions. The effectiveness of the developed eco-gresilient multi-objective model is presented on a case study in the meat sector.

1 INTRODUCTION

The economic aspect represents the traditional concerns in the supply chain design. Nevertheless, environmental concerns have been increasingly discussed in the supply chain management literature where decision makers are required to address increasing regulations related to green development.

Recently, there has been an increasing interest in private and public sector and academia in improving supply chain resilience to act against disruptions that occur due unexpected events such as natural disasters, earthquake, floods, and potential catastrophic failures (Levalle and Nof, 2015). Despite various definitions presented in the literature, the required resilience pillars are not well identified from practical or theoretical perspectives. Recently, Purvis et al. (2016) proposed a supply chain framework highlighting the necessary ‘ingredients’ to achieve resilience and it includes specific management paradigms: robustness, agility, leanness and flexibility (RALF).

In the context of supply chain network design, it should consider economic, environmental and resilience (Perrings, 2006). Thus, there is a need for a survival plan through an integrated approach that simultaneously considers resilience to efficiently cope with unexpected disruptions and green dimension to manage increasing global requirements to reduce the environmental impact (Govindan et al., 2017).

Multi-objective optimization in the supply chain design has been widely applied in academia (Mohammed et al., 2017a, b, c; Mohammed and Wang, 2017 and 2015). Most recently, Govindan et al. (2017) reviewed researches in the field of green supply chains network design under uncertainty. Mohammed and Wang (2017b) developed a mathematical programming model for optimizing location-allocation problem towards a green meat supply chain using LP-metrics, ε-constraint and goal programming.

Research of resilient supply chain design has been increasing steadily in recent times. Nooraie et al. (2015) formulated a multi-objective model includes minimization of investment costs, minimization of the variance of the total cost and minimization of the financial risk aiming to obtain a trade-off among them using a relaxation heuristic method. Dixit et al. (2016) proposed a multi-objective model to maximize supply chain resilience in minimizing unfulfilled demand and transportation cost post-disaster. NSGA-II and Co-Kriging approaches were adopted to solve the model. However, the literature review revealed that there is no research that integrates supply chain resilience (for example with respect to RALF) and the environmental impact.

This research paper presents a new multi-objective optimization model for an eco-gresilient meat supply chain network design in identifying the optimal number of facilities that should be established. The model considers the optimization of three objectives: minimizing the total costs and CO_2 emissions throughout the supply chain and maximizing the value of resilience (V-RALF) as a third objective. Initially, the weight for each resilience pillar and corresponding weight for each potential facility are determined using fuzzy AHP based on decision makers' experts. Then, the weights obtained by the fuzzy AHP are integrated in the objective function that considers the four resilience pillars. Based on the developed model, the ε-constraint method is used to solve multi-objective optimisation model.

2 DEVELOPING THE ECO-GRESILIENT APPROACH

We Figure 1 illustrates the meat supply chain that is used in the study which encompasses of multi-tier network: farms, abattoirs and retailers. This research aims to obtain an eco-gresilient meat supply chain network design in identifying the optimal number of farms and abattoirs that should be established according to emerging economic, green and resilience responsibilities.

The eco-gresilient approach is developed as follows:

1. The fuzzy AHP technique is utilized to determine relative weights for resilience pillars (i.e., robustness, agility, leanness and flexibility).
2. A fuzzy technique is used to determine the weight for each potential farm and abattoir according to their resilience performance.
3. A multi-objective optimization model is developed towards the optimization of minimum total cost and environmental impact and maximum V-RALF. The latter is developed by integrating the weights obtained from the fuzzy techniques.
4. ε-constraint is used to generate Pareto solutions for multi-objective optimization model.

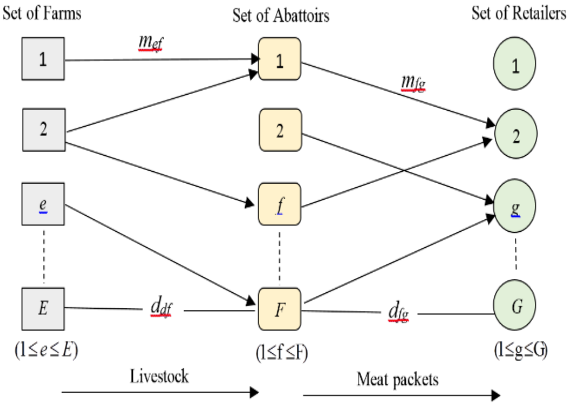

Figure 1: Structure of the meat supply chain network under study.

2.1 Weighting RALF and facilities

In this research, fuzzy AHP is used to determine the importance weight for each resilience pillar. Fuzzy AHP is a decision-making algorithm presented by incorporating the crisp AHP with the fuzzy set theory (Saaty, 2000). In this algorithm, fuzzy numbers are presented by a membership function that is a real number between 0 and 1. Table 1 presents the linguistic variables used for evaluating the four resilience pillars. Decision makers need to evaluate the importance of each pillar using the given linguistic variables. The Fuzzy AHP is applied as described in Srichetta and Thurachon, 2012.
Afterward, the steps were subsequently used to determine the weight of each potential facility with respect to resilience pillar. Table 1 presents the linguistic variables used for evaluating farms and abattoirs with respect to each resilience pillar based on decision makers 'experts.

Table 1: Linguistic variables used for weighting resilience pillars and potential facilities.

Evaluating pillars	Fuzzy number (a,n,m)
Equally important (EI)	(0.1, 0.1, 0.3)
Weakly important (WI)	(0.1, 0.3, 0.5)
Strongly more important (SMI)	(0.3, 0.5, 0.7)
Very strongly important (VSI)	(0.5, 0.7, 0.9)
Extremely important (EI)	(0.7, 0.9, 0.10)
Evaluating facilities	**Fuzzy number (a,n,m)**
Very Low (VL)	(1, 1, 3)
Low (L)	(1, 3, 5)
Medium (M)	(3, 5, 7)
High (H)	(5, 7, 9)
Very High (VH)	(7, 9, 9)

2.2 Model Formulation

The multi-objective optimization model supports strategic decision in determining the optimal number of farms and abattoirs that should be established with respect to eco-gresilient performance. Three objective functions are formulated which include minimization of the total cost (TC), environmental impacts (EI), and maximization of value of robustness, agility, leanness and flexibility (V-RALF).

Sets

E set of farms $(1\ldots\ e\ldots\ E)$

F set of abattoirs $(1\ldots\ \mathrm{f}\ldots\ \mathrm{F})$

G set of retailers $(1\ldots\ \mathrm{g}\ldots\ \mathrm{G})$

Input parameters

C_e^p purchasing cost per unit of livestock ordered from farm *e*

C_f^p purchasing cost per unit of meat packets (units) ordered from abattoir *f*

C_{ef}^t unit transportation cost per mile from farm *e* to abattoir *f*

C_{fg}^t unit transportation cost per mile from abattoir *f* to retailer *g*

C_e^o operating cost per hour required at farms *e*

C_f^o operating cost per hour required at abattoir *f*

C_e^a administration cost per order from fame *e*

C_f^a administration cost per order from abattoir *f*

R_e working rate per labourer at farm *e*

R_f working rate per labourer at abattoir *f*

N_e minimum required number of working hours for labourer at farm *e*

N_f minimum required number of working hours for labourer at abattoir *f*

d_{ef} transportation distance (mile) of livestock from farm *e* t abattoir *f*

d_{fg} transportation distance (mile) of processed meats from abattoir *f* to retailer *g*

C_l transportation capacity (units) per lorry

C_e maximum supply capacity (units) of farm *e*

C_f maximum supply capacity (units) of abattoir *f*

D_f minimum demand (in units) of abattoir *f*

D_g minimum demand (units) of retailer *g*

CO_{2e} CO_2 emission in grams for opening farm *e*

CO_{2f} CO_2 emission in grams for opening abattoir *f*

CO_{2ef} CO_2 emission in grams per mile for each lorry travelling from farm *e* to abattoir *f*

CO_{2fg} CO_2 emission in grams per mile for lorry travelling from abattoir *f* to retailer *g*

W_e^R Weight of robustness obtained from fuzzy AHP from the perspective of decision makers at abattoirs

W_f^R Weight of robustness obtained from fuzzy AHP from the perspective of decision makers at retailers

W_e^A Weight of agility obtained from fuzzy AHP from the perspective of decision makers at abattoirs

W_f^A Weight of agility obtained from fuzzy AHP from the perspective of decision makers at retailers

W_e^L Weight of leanness obtained from fuzzy AHP from the perspective of decision makers at abattoirs

W_f^L Weight of leanness obtained from fuzzy AHP from the perspective of decision makers at retailers

W_e^F Weight of flexibility obtained from fuzzy AHP from the perspective of decision makers at abattoirs

W_f^F Weight of flexibility obtained from fuzzy AHP from the perspective of decision makers at retailers

w_e^R weight of farm *e* with respect to redundancy obtained from fuzzy AHP

w_f^R weight of abattoir *f* with respect to redundancy obtained from fuzzy AHP

w_e^A weight of farm *e* with respect to agility obtained from fuzzy AHP

w_f^A weight of abattoir *f* with respect to agility obtained from fuzzy AHP

w_e^L weight of farm *e* with respect to leanness obtained from fuzzy AHP

w_f^L weight of abattoir *f* with respect to leanness obtained from fuzzy AHP

w_e^F weight of farm *e* with respect to flexibility obtained from fuzzy AHP

w_f^F weight of abattoir *f* with respect to flexibility obtained from fuzzy AHP

Output Decision variables

m_{ef} quantity of livestock transported from farm *e* to abattoir *f*

m_{fg} quantity of meat packets (units) transported from abattoir *f* to retailer *g*

x_e number of required labourers at farm *e*

x_f number of required labourers at abattoir *f*

Binary decision variables:

$$y_e = \begin{cases} 1\text{: if farm } e \text{ is open} \\ 0\text{: otherwise} \end{cases}$$

$$y_f = \begin{cases} 1\text{: if abattoir } f \text{ is open} \\ 0\text{: otherwise} \end{cases}$$

2.2.1 Model formulation

$$\begin{aligned} Min\ TC = {} & \sum_{e\in E}\sum_{f\in F} C_e^p m_{ef} + \sum_{f\in F}\sum_{g\in G} C_f^p m_{fg} \\ & + \sum_{e\in E}\sum_{f\in F} C_{ef}^a m_{ef} + \sum_{f\in F}\sum_{g\in G} C_{fg}^a m_{fg} + \\ & \sum_{e\in E}\sum_{f\in F} C_{ef}^o x_e N_e + \sum_{f\in F}\sum_{g\in G} C_{fg}^o x_f N_f + \\ & \sum_{e\in E}\sum_{f\in F} C_{ef}^t \left\lceil \frac{m_{ef}}{W} \right\rceil d_{ef} + \sum_{f\in F}\sum_{g\in G} C_{fg}^t \left\lceil \frac{m_{fg}}{W} \right\rceil d_{fg} \end{aligned} \tag{1}$$

$$\begin{aligned} Min\ EI = {} & \sum_{e\in E} CO_{2e} y_e + \sum_{f\in F} CO_{2f} y_f + \\ & \sum_{e\in E}\sum_{f\in F} CO_{2ef} \left\lceil \frac{m_{ef}}{W} \right\rceil d_{ef} + \sum_{f\in F}\sum_{g\in G} CO_{2fg} \left\lceil \frac{m_{fg}}{W} \right\rceil d_{fg} \end{aligned} \tag{2}$$

$$\begin{aligned} Max\ V - RALF = {} & W_e^R \left(\sum_{e\in E} w_e^R y_e \right) + W_f^R \left(\sum_{f\in F} w_f^R y_f \right) \\ & + W_e^A \left(\sum_{e\in E} w_e^A y_e \right) + W_f^A \left(\sum_{f\in F} w_f^A y_f \right) \\ & + W_e^L \left(\sum_{e\in E} w_e^L y_e \right) + W_f^L \left(\sum_{f\in F} w_f^L y_f \right) \\ & + W_e^F \left(\sum_{e\in E} w_e^F y_e \right) + W_e^F \left(\sum_{e\in E} w_e^F y_e \right) \end{aligned} \tag{3}$$

Subject to:

$$\sum_{e\in E} m_{ef} \le C_e y_e \qquad \forall\ \mathrm{f} \in F \tag{4}$$

$$\sum_{f\in F} m_{fg} \le C_f y_f \qquad \forall\ \mathrm{g} \in G \tag{5}$$

$$\sum_{e\in E} m_{ef} \ge \mathrm{D}_f \qquad \forall\ \mathrm{f} \in F \tag{6}$$

$$\sum_{f\in F} m_{fg} \ge \mathrm{D}_g \qquad \forall\ \mathrm{g} \in G \tag{7}$$

$$\mathrm{D}_f \ge \sum_{g\in G} m_{fg} \qquad \forall\ \mathrm{f} \in F \tag{8}$$

$$\sum_{f\in F} m_{ef} \le x_e\ \mathrm{R}_e \qquad \forall\ \mathrm{e} \in E \tag{9}$$

$$\sum_{g\in G} m_{fg} \le x_f\ \mathrm{R}_f \qquad \forall\ \mathrm{f} \in F \tag{10}$$

$$m_{ef}, m_{fg} \ge 0 \quad \forall e, f, g \tag{11}$$

$$y_e, y_f \in \{1,0\}, \quad \forall e, f \tag{12}$$

Eq. 1 refers to objective function to minimize the total transportation costs, which includes purchasing cost, operating cost, administration cost and transportation cost. Eq. 2 refers to the second objective function that minimises the environmental impact, in particular CO_2 emissions from opening network facilities and transportation. Eq. 3 refers to the third objective function that aims to maximize the value of supply chain resilience in term of maximizing resilience pillars i.e. RALF. The weights for each pillar and each farm and abattoirs (with respect to RALF) revealed from the fuzzy AHP are used to formalize the maximization of V-RALF. Eq. 4 restricts the quantity of livestock transported from farms to abattoirs so that it cannot exceed the capacity of farms. Eq. 5 ensures the quantity flow of meat packets from abattoirs to retailer does not overcome the capacity of abattoirs. Eqs. 6-8 ensure that the demands of abattoir *f* and retailer *g* are fulfilled from farms *e* and abattoirs *f*, respectively. Eqs. 9 and 10 indicate the required number of labourers at farms and abattoirs. Eqs. 11 and 12 limit the non-binary and non-negativity restrictions on decision variables.

2.3 Revealing Pareto solutions

In this research, the ε-constraint method is employed towards the optimization of the three objectives. This method transforms the multi-objective model to a mono-objective model by keeping one of the function as an objective function, and treating other functions as constraints limited to ε values (Ehrgott, 2005). In this work, minimization of total cost is used as an objective function while minimization of environmental impact and maximization of V-RALF are moved to be ε-based constraints. The equivalent solution formula (S) is given by:

$$Min\ S = Min\ \mathrm{TC} \tag{13}$$

Subject to:

$$EI \le \varepsilon_1 \quad (14)$$

$$[EI]^{\min} \le \varepsilon_1 \le [EI]^{\max} \quad (15)$$

$$V - RALF \ge \varepsilon_2 \quad (16)$$

$$[V - RALF]^{\min} \le \varepsilon_2 \le [V - RALF]^{\max} \quad (17)$$

In addition to Eqs. 4-12.

3 APPLICATION AND EVALUATION OF THE ECO-GRESILIENT APPROACH

In this section, a case study is utilized to validate the effectiveness of the developed eco-gresilient approach to determine (1) the optimal number of farms and abattoirs that should be established with respect to economic, green and resilient responsibilities, and (2) trade-off solutions among three objectives: minimising total cost, environmental impact and maximising the value of supply chain resilience. The example includes 3 farms, 4 abattoirs to supply 7 retailers. Table 2 presents values for input parameters used in the model formulation discussed in Section 3. The supply capacity of farm e (C_e) is generated in a range 1,500 – 1,800 livestock. The data is collected from the meat committee in the UK (HMC, 2010). The travel distances between farms and abattoirs and between abattoirs and retailers are estimated using the Google map. Also, the demand values presented in Table 2, is the total demand over a one year period. LINGO[11] software was used to solve presented problem on a personal computer with a Corei5 3.2GHz processor, 8GB RAM.

Table 2: Input parameters.

$E = 3$	$C_e^t = 1\text{-}1.5$	$d_{fg} = 110\text{-}205$
$F = 4$	$C_{fg}^t = 1\text{-}1.5$	$C_l = 50$
$G = 7$	$C_e^a = 3\text{-}4.5$	$C_e = 1500\text{-}1800$
$C_e^p = 130\text{–}150$	$C_f^a = 3\text{-}4.5$	$C_f = 1600\text{-}2000$
$C_f^p = 160\text{–}190$	$d_{ef} = 43\text{-}250$	$N_e = 9$
$C_e^o = 8\text{-}9.5$	$C_f^o = 10\text{-}11$	$N_f = 9$
$D_f = 1250\text{-}1450$	$D_g = 1100\text{-}1300$	$CO_{2ef} = 271\text{-}294$
$CO_{2fg} = 271\text{-}294$	$CO_{2e} = 82000\text{-}85000$	$CO_{2f} = 220000\text{-}250000$
$R_e = 60$ $R_f = 15$		

A decision maker (ADM) from an abattoir was asked to evaluate the importance of resilience pillars and the potential three farms (f1, f2 and f3) with respect to each pillar, and two decision makers ($RDM_1$and RDM_2) from two retailers in the UK were asked to evaluate the importance of resilience pillars and the potential four abattoirs (a1, a2, a3 and a4) with respect to each resilience pillar.

Next, fuzzy AHP is applied for allocating the importance weight for each resilience pillar (robustness, agility, leanness and flexibility) based on decision makers' experts obtained in the previous step. Table 3 shows the obtained weight for each pillar. As can be seen in Table 3, the importance weight order is Agility>Robustness>flexibility>Leanness based on ADM's experts, and Agility> flexibility> Robustness>Leanness based on RDMs' experts. Fuzzy AHP steps is then applied to determine the importance weights of the potential three farms and four abattoirs using the input parameters obtained from the previous step. Table 4 shows the results corresponding to the relevant facilities. Based on the obtained results, farm 2 and abattoir 3 revealed the highest resilience performance with respect to RALF compared to farm 3 and abattoir 2 which revealed the worst resilience performance.

The developed multi-objective optimization model that integrates the obtained weights is optimized using the ε-constraint method as follows:

1. Table 5 lists the minimum and maximum values for each objective. These values are determined by applying Eqs. 18-23, respectively. For instance, the minimum and maximum values of the total cost are 344,703 and 501,868, respectively. These values are used for assigning ε values.

Table 3: Weights of RALF.

Pillar	R	A	L	F
DM		**ADM**		
Weight	0.196	**0.585**	0.042	0.175
DM		**RDM1/RDM2**		
Weight	0.123	**0.438**	0.036	0.400

Table 4: Weights of facilities with respect to RALF.

	R	A	L	F	Global
f1	0.654	0.210	0.141	0.053	0.343
f2	0.841	0.211	0.198	0.068	**0.383**
f3	0.467	0.164	0.084	0.053	0.272
a1	0.397	0.131	0.101	0.087	0.269
a2	0.221	0.073	0.061	0.112	0.214
a3	0.397	0.131	0.142	0.112	**0.298**
a4	0.221	0.102	0.061	0.087	0.218

$$\begin{aligned} Min\ TC = & \sum_{e\in E}\sum_{f\in F} C_e^p m_{ef} + \sum_{f\in F}\sum_{g\in G} C_f^p m_{fg} \\ & + \sum_{e\in E}\sum_{f\in F} C_{ef}^a m_{ef} + \sum_{f\in F}\sum_{g\in G} C_{fg}^a m_{fg} + \\ & \sum_{e\in E}\sum_{f\in F} C_{ef}^o x_e N_e + \sum_{f\in F}\sum_{g\in G} C_{fg}^o x_f N_f + \\ & \sum_{e\in E}\sum_{f\in F} C_{ef}^t \left\lceil \frac{m_{ef}}{W} \right\rceil d_{ef} + \sum_{f\in F}\sum_{g\in G} C_{fg}^t \left\lceil \frac{m_{fg}}{W} \right\rceil d_{fg} \end{aligned} \tag{18}$$

$$\begin{aligned} Min\ EI = & \sum_{e\in E} CO_{2e} y_e + \sum_{f\in F} CO_{2f} y_f + \\ & \sum_{e\in E}\sum_{f\in F} CO_{2ef} \left\lceil \frac{m_{ef}}{W} \right\rceil d_{ef} + \sum_{f\in F}\sum_{g\in G} CO_{2fg} \left\lceil \frac{m_{fg}}{W} \right\rceil d_{fg} \end{aligned} \tag{19}$$

$$\begin{aligned} Min\ V-RALF = & W_e^R \left(\sum_{e\in E} w_e^R y_e \right) + W_f^R \left(\sum_{f\in F} w_f^R y_f \right) \\ & + W_e^A \left(\sum_{e\in E} w_e^A y_e \right) + W_f^A \left(\sum_{f\in F} w_f^A y_f \right) \\ & + W_e^L \left(\sum_{e\in E} w_e^L y_e \right) + W_f^L \left(\sum_{f\in F} w_f^L y_f \right) \\ & + W_e^F \left(\sum_{e\in E} w_e^F y_e \right) + W_e^F \left(\sum_{e\in E} w_e^F y_e \right) \end{aligned} \tag{20}$$

$$\begin{aligned} Max\ TC = & \sum_{e\in E}\sum_{f\in F} C_e^p m_{ef} + \sum_{f\in F}\sum_{g\in G} C_f^p m_{fg} \\ & + \sum_{e\in E}\sum_{f\in F} C_{ef}^a m_{ef} + \sum_{f\in F}\sum_{g\in G} C_{fg}^a m_{fg} + \\ & \sum_{e\in E}\sum_{f\in F} C_{ef}^o x_e N_e + \sum_{f\in F}\sum_{g\in G} C_{fg}^o x_f N_f + \\ & \sum_{e\in E}\sum_{f\in F} C_{ef}^t \left\lceil \frac{m_{ef}}{W} \right\rceil d_{ef} + \sum_{f\in F}\sum_{g\in G} C_{fg}^t \left\lceil \frac{m_{fg}}{W} \right\rceil d_{fg} \end{aligned} \tag{21}$$

$$\begin{aligned} Max\ EI = & \sum_{e\in E} CO_{2e} y_e + \sum_{f\in F} CO_{2f} y_f + \\ & \sum_{e\in E}\sum_{f\in F} CO_{2ef} \left\lceil \frac{m_{ef}}{W} \right\rceil d_{ef} + \sum_{f\in F}\sum_{g\in G} CO_{2fg} \left\lceil \frac{m_{fg}}{W} \right\rceil d_{fg} \end{aligned} \tag{22}$$

$$\begin{aligned} Max\ V-RALF = & W_e^R \left(\sum_{e\in E} w_e^R y_e \right) + W_f^R \left(\sum_{f\in F} w_f^R y_f \right) \\ & + W_e^A \left(\sum_{e\in E} w_e^A y_e \right) + W_f^A \left(\sum_{f\in F} w_f^A y_f \right) \\ & + W_e^L \left(\sum_{e\in E} w_e^L y_e \right) + W_f^L \left(\sum_{f\in F} w_f^L y_f \right) \\ & + W_e^F \left(\sum_{e\in E} w_e^F y_e \right) + W_e^F \left(\sum_{e\in E} w_e^F y_e \right) \end{aligned} \tag{23}$$

2. Minimizing the total cost is used as an objective function where the environmental impact and V-RALF aspects are considered as constraints as previously presented in Eqs. 20-24. The range between the maximum and minimum values for objective functions two (environmental impact) and three (V-RALF) are segmented into ten segments, the points in between are assigned as ε values in Eq. (21 and 23). However, it can be segmented in more or less number of segments to get more or less number of Pareto solutions.

3. Table 6 lists Pareto solutions obtained by solving the problem formulation using ε-constraint (Eqs. 13-17). These solutions represent trade-offs among minimizing the total cost and environmental impact and maximization of V-RALF. As shown in Table 6, these solutions are also associated with the correspondence number of farms and abattoirs that should be established. For instance, solution#1 leads to a total cost of 361,348, a CO_2 emission of 211,000 and a value of resilient (V-RALF) of 2. This solution requires an establishment of farm two (0 1 0) to supply livestock to abattoirs two and four (0 1 0 1). This solution is obtained via an allocation of ε1=211,075 and ε2 = 2. Pareto fronts among the TC, EI and V-RALF are illustrated in Figure 2. Finally, decision makers need to select the final Pareto solution to design their supply chain network.

Table 5: Maximum and minimum values related to TC, EI and V-RALF.

Objective functions	Max	Min
TC	501868	344703
EI	517847.785	180075.077
V-RALF	2.7901	1.93109

Table 6: Pareto solutions.

	ε values		Objective function solutions			Opened Facilities	
#	ε_1	ε_2	Min TC	Min EI	Max V-RALF	Farms	Abattoirs
1	211075	2	361348	211000	2	0 1 0	1 0 1 0
2	241075	2.095	370350	241075	2.095	0 1 0	1 0 1 0
3	271075	2.190	389550	268223	2.200	1 1 0	1 0 1 0
4	304075	2.285	409515	304000	2.285	1 1 0	1 0 1 1
5	337075	2.380	427626	335262	2.390	0 1 1	1 0 1 1
6	370075	2.475	446631	369998	2.482	1 1 0	1 0 1 1
7	404075	2.570	465843	404000	2.600	1 1 1	1 1 1 0
8	437075	2.655	470052	437005	2.655	1 1 0	1 1 1 1
9	490075	2.732	481118	488200	2.744	1 1 1	1 1 1 1
10	517847	2.790	492512	509121	2.790	1 1 1	1 1 1 1

makers' preferences. In this research, solution#5 is selected as a final trade-off solution among the values of the three objectives to design the eco-gresilient meat supply chain network. This solution leads to a minimum total cost of 427,626, a minimum CO_2 emission of 335,262 and a maximum value of resilience pillars (V-RALF) of 2.390. With respect to the allocation of facilities, this solution requires an establishment of two farms to supply livestock to three abattoirs. This solution is obtained via an allocation of ε1= 337,075 and ε2 = 2.38.

4 CONCLUSIONS

Economic, green and resilient supply chain network design has become a new challenge for supply chain managers aiming to design a robust supply chain network that not merely consider economic and green objectives, but also be resilient to sustain its operations under any disruption.

This study has motivated by this challenge in emerging economic, green and resilience responsibilities in the design and optimization of a supply chain network. A hybrid MCDM-multi-objective optimization model is developed to design an eco-gresilient supply chain network. Fuzzy AHP is used to determine the weight for resilience pillars which include robustness, agility, leanness and flexibility (RALF) based on decision makers 'experts. Next, fuzzy AHP is also used to determine the importance weight for the potential facilities with respect to their resilience performance. The obtained weights are then integrated into a developed multi-objective optimization model used for allocating the optimal number of facilities that should be established.

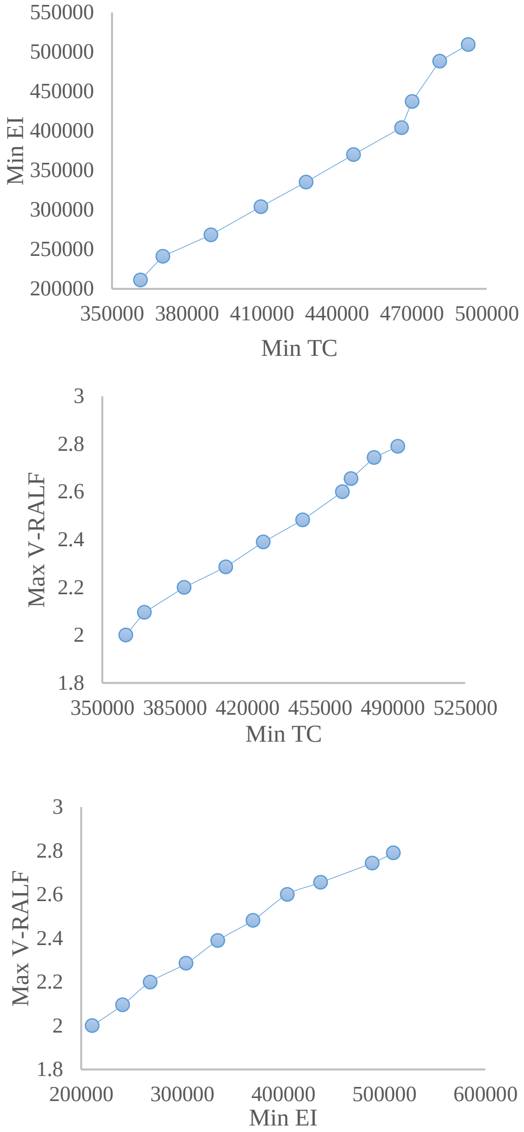

Figure 2: Pareto fronts among TC, EI and V-RALF.

The model includes a formulation of three objectives including minimization of the total cost and environmental impact in particular the CO_2 emissions and maximization the value of supply chain resilience in terms of maximizing resilience pillars (Maximization of V-RALF) as a third objective. Finally, the ε-constraint method is used to obtain trade-offs among the three objectives via optimizing the developed multi-objective model. The applicability of the developed model is validated through a case study. The results demonstrate that the model can be used as an aid for enterprises to design an eco-gresilient supply chain network. Furthermore, it can be used by supply chain managers of related facilities to improve their resilience performance.

The current work avenue includes the re-development of the current model incorporating the social aspect and uncertainties in the input data such as demands, supply capacities of related facilities and CO_2 emissions. Finally, the rank reversal approach can be applied to help the decision makers in selecting the final Pareto solution.

REFERENCES

Bing Bing, X., Bloemhof-Ruwaard, J., Chaabane, A., van der Vorst, J., 2015. Global reverse supply chain redesign for household plastic waste under the emission trading scheme. J. Clean. Prod. 103, 28-39.

Dixit, V., Seshadrinath, N., Tiwari, M.K. 2016. Performance measures based optimization of supply chain network resilience: A NSGA-II + Co-Kriging approach. Computers & Industrial Engineering 93, 205–214.

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

Govindan, K., Fattahi, M., Keyvanshokooh, E. 2017. Supply chain network design under uncertainty: A comprehensive review and future research directions, European Journal of Operational Research, doi: 10.1016/j.ejor.2017.04.009.

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: Logistics and Transportation Review 66, 1-22.

HMC, UK. 2010. http://www.halalhmc.org/, Available: http://www.halalhmc.org/test-demo.htm . (Accessed Jan 19, 2017).

IBM, 2008. Supply Chain Risk Management: A Delicate Balancing Act. IBM Global Business Services, New York, NY.

Levalle, R.R., Nof, S.Y. 2015. A resilience by teaming framework for collaborative supply networks. Computers & Industrial Engineering, 90, 67–85.

Miranda-Ackerman, M.A., Azzaro-Pantel, C., Aguilar-Lasserre, A.A. 2017. A green supply chain network design framework for the processed food. Computers & Industrial Engineering, 109, 369–389.

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, China, 2015a, 79-86.

Mohammed A. and Wang Q. 2017. Multi-criteria optimization for a cost-effective design of an RFID-based meat supply chain. British Food Journal, 119, 3, 676-689.

Mohammed A. and Wang Q. and Li X. 2017a. Developing a meat supply chain network design using a multi-objective possibilistic programming approach. British Food Journal, 119, 3, 690-706.

Mohammed, A. andWang, Q., 2017b. The fuzzy multi-objective distribution planner for a green meat supply chain. International J. Pro Eco., 184, 47–58

Mohammed, A., Wang, Q., Alyahya, S. and Binnette, N. 2017c. Design and optimization of an RFID-enabled automated warehousing system under uncertainties: A multi-criterion fuzzy programming approach. The International Journal of Advanced Manufacturing Technology. 91 (5), 1661-1670.

Nooraie, S.V., Parast, M.M. 2015. A multi-objective approach to supply chain risk management: Integrating visibility with supply and demand risk. Int. J. Production Economics 161 (2015) 192–200.

Srichetta, P. and Thurachon, W. 2012. Applying Fuzzy Analytic Hierarchy Process to Evaluate and Select Product of Notebook Computers. International Journal of Modeling and Optimization, 2 (2), 168-173.

Pereira, C.R., Silva, A.L., 2015. Key Organisational Factors For Building Supply Chain Resilience: A Multiple Case Study Of Buyers And Suppliers. J. Oper. Supply Chain Manag. 8, 77–95.

Perrings, C. Resilience and sustainable development. Environ. Dev. Econ. 2006, 11, 417–427.

Purvis, L., Spall, S., Naim, M. and Spiegler, V. 2016. Developing a resilient supply chain strategy during 'boom' and 'bust', Production Planning & Control, 27:7-8, 579-590, DOI: 10.1080/09537287.2016.1165306.

Saaty, T.L., 2000. Fundamentals of decision making and priority theory with the analytic hierarchy process, vol. 6. Rws Publications.

Soni, U., Jain, V., Kumar, S. 2014. Measuring supply chain resilience using a deterministic modeling approach. Computers & Industrial Engineering. 74, 11–25.

Tiwari, A., Chang, P.C., Tiwari, M.K., Kandhway, R. 2016. A Hybrid Territory Defined evolutionary algorithm approach for closed. Computers & Industrial Engineering, 99, 432–447.