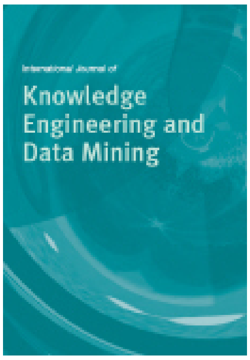

International Journal of Knowledge Engineering and Data Mining

ISSN online: 1755-2095 - ISSN print: 1755-2087
https://www.inderscience.com/ijkedm

A sustainable reverse supply chain network design considering inventory-location-routing problem and cross-docking scheduling under uncertainty

Zahra Ebrahim Qazvini, Mohammad Reza Maleki

DOI: 10.1504/IJKEDM.2022.10049936

Article History:

Received:	25 August 2021
Last revised:	16 August 2022
Accepted:	16 October 2021
Published online:	10 October 2022

A sustainable reverse supply chain network design considering inventory-location-routing problem and cross-docking scheduling under uncertainty

Zahra Ebrahim Qazvini

Department of Industrial Engineering,
University of Eyvanekey,
Semnan, Iran
Email: aebrahimi20@yahoo.com

Mohammad Reza Maleki*

Industrial Engineering Group,
Golpayegan College of Engineering,
Isfahan University of Technology,
Golpayegan 87717-67498, Iran
Email: m.maleki@iut.ac.ir
*Corresponding author

Abstract: Designing an integrated supply chain network (SCN) by considering economic, social, and environmental aspects will increase its sustainability. This paper proposes a bi-objective mixed-integer linear programming model to design a sustainable closed-loop SCN considering location-inventory-routing problem, cross-docking scheduling, vehicles failure, inflation, routes reliability, impact of load on fuel consumption, discount on purchases from suppliers, supplier selection, and order allocation under uncertainty. The proposed bi-objective model minimises the total costs and maximises the created jobs, simultaneously. A scenario-based approach is used to cope with demand uncertainty while a fuzzy multi-objective solution approach is employed to convert the bi-objective model into a single-objective one. Finally, the performance of the proposed bi-objective mathematical model is evaluated using data from a wire and cable industry in Iran.

Keywords: location-inventory-routing problem; closed-loop supply chain; CLSC; cross-docking scheduling; uncertainty.

Reference to this paper should be made as follows: Qazvini, Z.E. and Maleki, M.R. (2022) ‘A sustainable reverse supply chain network design considering inventory-location-routing problem and cross-docking scheduling under uncertainty’, *Int. J. Knowledge Engineering and Data Mining*, Vol. 7, Nos. 3/4, pp.163–189.

Biographical notes: Zahra Ebrahim Qazvini is a PhD candidate of Industrial Engineering at University of Eyvanekey in Iran. She has obtained her MS in Industrial Engineering from the Payame Noor University in Iran. Her research interests include multi-criteria decision-making and supply chain management. She has been the author of the papers published in *International Journal of Management Concepts and Philosophy* and *International Journal of Management and Decision Making*.

Mohammad Reza Maleki is an Assistant Professor at Golpayegan College of Engineering in Isfahan University of Technology. He holds a BS in Industrial Engineering from Isfahan University of Technology. He has also obtained his MS and PhD in Industrial Engineering from Shahed University in Iran. His research interests include statistical process monitoring, profile monitoring, and reliability engineering. He has been the author or co-author of many papers published in high-ranked journals such as *Computers & Industrial Engineering, Quality and Reliability Engineering International*, *Communications in Statistics – Simulation and Computation*, *Communications in Statistics – Theory and Methods*, *Transactions of the Institute of Measurement and Control*, *Journal of Industrial and Business Economics, International Journal of Modeling and Simulation, Journal of Advanced Manufacturing Systems, Arabian Journal for Science and Engineering, Scientia Iranica,* and *Journal of Industrial Integration and Management*.

1 Introduction

Although for many years, the main goal of companies has been to minimise the total costs of the supply chain network (SCN) or maximise their profits, today they are responsible for the social and environmental impacts of their operations (Kannan et al., 2020; Azadmanesh and Maleki, 2021; Mina et al., 2021). Increasing attention to reverse logistics and the closed-loop supply chain (CLSC) have first emerged from public and community awareness, and then governmental laws forced manufacturers to use defective products (Coenen et al., 2018; Rezaei and Maihami, 2020; Ebrahim Qazvini and Maleki, 2021). In fact, according to new considerations, CLSC management involves the ‘design’, ‘control’, and ‘implementation’ of an integrated system to maximise the value obtained from a product over its life cycle by continuously retrieving value from returned products (Jian et al., 2020; Mishra et al., 2020). A review of the literature reveals that many papers have studied forward or reverse logistics separately while only few studies have focused on the design of integrated SCNs (Kazemi et al., 2019). Today, designing a SCN based on forward processes not only ignores the sustainability aspects, but also reduces the market share and competitive advantage (Mathiyazhagan et al., 2020; Alavi et al., 2021). In order to get acquainted with the features of the reverse SCNs, some of the important references presented in this topic are examined below.

A bi-objective mixed-integer programming (MIP) model with the aim of maximising profits and minimising energy consumption was suggested by Soleimani (2018) to design a sustainable CLSC network. Gholipour et al. (2019) used a bi-objective mixed-integer linear programming (MILP) model to organise a green CLSC network. Their model includes both forward and reverse streams and incorporates location-routing problem assumptions. They used a fuzzy solution approach to solve their proposed bi-objective model. A bi-objective MILP model for designing a multi-modal, multi-product, and multi-period CLSC network with the aim of minimising the total costs and environmental emissions was developed by Mardan et al. (2019). They presented an accelerated bender's decomposition algorithm for solving their proposed models in large sizes. Sadeghi et al. (2020) presented an MILP model for designing a CLSC network. They utilised a real data from an automotive part manufacturing and distribution industry in Iran for validation of their model. Govindan et al. (2020) designed an uncertain circular CLSC network considering the location-routing problem using a multi-objective mixed-integer linear programming (MOMILP) model. They presented a fuzzy solution approach to convert the proposed multi-objective model to a single-objective one. They evaluated the efficiency of their proposed model by a real data from an automotive parts production in Iran. A novel integrated approach based on multi-criteria decision-making (MCDM) techniques and mathematical programming model was developed to design the sustainable CLSC network considering location-inventory-routing (LIR) problem, supplier selection, and order allocation under uncertainty by Nasr et al. (2021). They presented a MOMILP model for formulation of their model, and employed a fuzzy goal programming approach to solve their multi-objective model. Nayeri et al. (2020) proposed a sustainable CLSC network using a multi-objective model considering the economic, social, and environmental aspects under uncertainty. They utilised a fuzzy robust optimisation approach to deal with the uncertainty and used the goal programming method to solve the multi-objective model. To control operating costs and CO_2 emissions in a green CLSC network, a bi-objective MIP model was suggested by Huang et al. (2020). They used the epsilon-constraint method for solving their proposed bi-objective model. Parast et al. (2021) introduced a bi-objective MILP model for designing a green reverse supply chain for the perishable products considering 'LIR problem', 'pickup and delivery', and 'vehicle scheduling'. They applied a multi-objective fuzzy solution approach to solve their proposed model under uncertainty conditions. They evaluated the performance of their proposed model by a real data borrowed from a bread distribution industry in Iran. An MIP model for designing a CLSC network with take-back legislation was proposed by Diabat and Jebali (2021). Similarly, An MILP model was developed to design a CLSC network for agriculture crops by Salehi-Amiri et al. (2021). They used both forward and reverse flows to deliver products and collect the returned items, and employed meta-heuristic algorithms to solve their proposed programming model.

In this paper, a bi-objective MILP model for designing a green CLSC network under demand uncertainty is proposed. The proposed mathematical programming model considers the LIR problem, inflation, vehicles failure, cross-docking scheduling, supplier selection and order allocation, discount on purchases from suppliers, routes reliability, as well as the effect of load on fuel consumption. To deal with uncertainty, a scenario-based approach is used while a multi-objective fuzzy solution approach is employed to solve the proposed bi-objective model. Finally, the performance of the proposed bi-objective model and solution approach is evaluated by a real data from a cable and wire industry in Iran. The features of the proposed model along with the research gaps are presented in Table 1. The rest of this paper is organised as follows: The problem definition and the proposed mathematical model are discussed in Section 2. The efficiency of the proposed bi-objective model is investigated by a real data example in Section 3. Finally, the concussion remarks are provided in Section 4.

Table 1 Comparison of the current paper with the papers in literature

Author(s)	*Method/technique*	*Supplier selection*	*Location problem*	*Routing problem*	*Inventory*	*Reverse supply chain*	*Discount*	*Multi-mode transportation*	*Effect of load on fuel consumption*	*Cross-docking scheduling*	*Routes reliability*	*Vehicles failure*	*Inflation*	*Time window*	*Sustainability*			*Uncertainty*		
															Economic	*Environmental*	*Social*	*Fuzzy*	*Stochastic*	*Robust*
Torabi et al. (2013)	MOMILP	-	✓	✓	-	-	-	-	-	-	✓	-	-	-	✓	-	-	✓	-	-
Soysal (2016)	MOMILP	-	-	✓	✓	✓	-	-	✓	-	-	-	-	-	✓	✓	-	-	✓	-
Zhalechian et al. (2016)	MOMIP and meta-heuristic algorithm	-	✓	✓	✓	✓	-	-	✓	-	-	-	-	-	✓	✓	✓	✓	✓	-
Govindan et al. (2017)	AHP and MOMILP	✓	-	✓	-	✓	✓	-	-	-	-	-	-	-	✓	✓	-	✓	-	-
Rezaei and Kheirkhah (2018)	MOMILP and meta-heuristic algorithm	-	✓	-	-	✓	-	-	-	✓	-	-	-	-	✓	✓	✓	-	-	-
Mardan et al. (2019)	MOMILP	-	✓	-	✓	✓	-	✓	-	-	-	-	-	-	✓	✓	-	-	-	-
Sadeghi et al. (2020)	MOMILP	-	✓	✓	-	✓	-	✓	-	-	-	-	-	-	✓	✓	-	-	-	-
Zandkarimkhani et al. (2020)	MOMILP	-	✓	✓	✓	✓	✓	✓	-	-	-	-	-	-	✓	✓	✓	✓	-	-
Govindan et al. (2020)	Fuzzy ANP, DEMATEL, and MOMILP	✓	✓	✓	✓	✓	✓	-	-	-	-	-	-	-	✓	✓	-	✓	-	-
Qazvini et al. (2021)	Fuzzy AHP and MOMILP	✓	✓	✓	✓	-	✓	-	-	-	-	-	-	✓	✓	✓	-	✓	-	-
Nasr et al. (2021)	Fuzzy BWM and MOMILP	✓	✓	✓	✓	✓	✓	✓	-	-	-	-	-	✓	✓	✓	✓	✓	-	-
Govindan et al. (2021)	MOMILP	-	✓	✓	-	✓	-	-	✓	-	-	✓	-	✓	✓	✓	-	✓	-	-
This paper	MOMILP	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	-

2 Problem definition and proposed model

In this section, an uncertain bi-objective MILP model is developed for designing a green CLSC network taking into account LIR problem, inflation, time window, route reliability, vehicles failure, cross-docking scheduling, supplier selection, and discounts on purchases from suppliers. The network under study includes forward flow including suppliers, plant, cross-docking centres and customers and reverse flow includes collection, remanufacturing, and disposal centres. The following are the assumptions of the problem to explain the details of the network under study:

- this network includes forward and reverse flows and is multi-product and multi-period
- the location of 'cross-docking', 'collection', 'remanufacturing', and 'disposal' centres are determined by the model
- there is one plant for producing the products
- the routing problem is multi-depot and capacitated, and is considered between cross-docking centres and customers
- vehicles are heterogeneous and capacitated
- each vehicle is allowed to visit each customer at most once in each time period
- split-delivery is allowed
- storage is allowed for future periods
- demand is considered uncertain
- all defective products should be collected
- inflation is considered certain in each time period
- the possibility of vehicle failure is considered
- reliability is defined for the routes travelled by vehicles
- a time window is defined to return vehicles to cross-docking centres
- there are discount strategies for suppliers
- there are multi-mode transportation for shipping raw materials from suppliers to plant
- the amount of product transported by each vehicle will affect its fuel consumption.

2.1 Mathematical model

Indices

i	Raw material	$(1 \leq i \leq I)$
j	Product	$(1 \leq j \leq J)$
k	Supplier	$(1 \leq k \leq K)$

l	cross	$(1 \leq l \leq L)$
m, n	Cross-docking centre	$(1 \leq m, n \leq M)$
o	Collection centre	$(1 \leq o \leq O)$
p	Remanufacturing centre	$(1 \leq p \leq P)$
q	Disposal centre	$(1 \leq q \leq Q)$
r	Price level	$(1 \leq r \leq R)$
v	Transportation mode	$(1 \leq v \leq V)$
u, u'	Vehicle	$(1 \leq u, u' \leq U)$
t	Time period	$(1 \leq t \leq T)$
s	Scenario	$(1 \leq s \leq S)$

Parameters

SCP_{ikt}	Capacity of supplier k for supplying raw material i in time period t
MCP_{jt}	Capacity of plant to produce product j in time period t
DCP_{jlt}	Capacity of cross-docking centre l for product j in time period t
CCP_{jot}	Capacity of collection centre o for product j in time period t
RCP_{jpt}	Capacity of remanufacturing centre p to process product j in time period t
$DSCP_{jqt}$	Capacity of disposal centre q to dispose product j in time period t
TCP_v	Capacity of transportation mode v
VCP_u	Capacity of vehicle u
$TRCP$	Capacity of truck
WE_j	Weight of product j
CSD_{jmts}	Demand of customer m for product j in time period t, under scenario s
SC_{ikrt}	Price of each unit of raw material i proposed by supplier k at price level r in time period t
MC_{jt}	Cost of producing each unit of product j in time period t
DC_{jlt}	Cost of processing each unit of product j at cross-docking centre l in time period t
CSC_{jmt}	Cost of holding each unit of product j at the warehouse of customer m in time period t
CC_{jot}	Cost of separating each unit of product j at collection centre o in time period t
RC_{jpt}	Cost of processing each unit of product j at remanufacturing centre p in time period t

DSC_{jqt}	Cost of disposing each unit of product j at disposal centre q in time period t
SF_{kt}	Ordering cost to supplier k in time period t
DF_l	Cost of setting up cross-docking centre l
COF_o	Cost of setting up collection centre o
RF_p	Cost of setting up remanufacturing centre p
DSF_q	Cost of setting up disposal centre q
VF_u	Cost of purchasing vehicle u
TC_v	Transportation mode v fare per kilometre
TRC	Truck fare per kilometre
SM_k	Distance among plant and supplier k
MD_l	Distance among plant and cross-docking centre l
DCS_{lm}	Distance among cross-docking centre l and customer m
CS_{mn}	Distance among customer m and customer n
$CSCL_{mo}$	Distance among customer m and collection centre o
CR_{op}	Distance among collection centre o and remanufacturing centre p
RDS_{oq}	Distance among collection centre o and disposal centre q
RM_p	Distance among remanufacturing centre p and plant
$TDCS_{ulm}$	Time distance among cross-docking centre l and customer m using vehicle u
TCS_{umn}	Time distance among customer m and customer n using vehicle u
TSV_{um}	Average service time for customer m by vehicle u
TW	Time window
φ_{ij}	The amount of raw material i used to produce one unit of product j
α_{jmt}	Rate of returned product j from customer m in time period t
β_{jot}	Rate of re-manufacturable product j shipped from collection centre o to remanufacturing centres in time period t
DJ_l	Number of created job by setting up cross-docking centre l
CJ_o	Number of created job by setting up collection centre o
RJ_p	Number of created job by setting up remanufacturing centre p
DSJ_q	Number of created job by setting up disposal centre q

WG_t	Wage of road repair team in time period t
H_{mn}	Possibility of route failure between customer m and customer n
RT_{mn}	Number of time periods required to repair the route between customer m and customer n
ξ_u	Failure possibility of vehicle u
Ω_s	Occurrence probability of scenario s
ϖ	Interest rate
Φ	Minimum acceptable reliability
CF_u	The amount of fuel consumed by the vehicle u per unit distance
ECF_u	The amount of fuel consumed by the vehicle u per kilogram of product
δ^{+}_{ikrt}	The upper limit of the volume of raw material i purchased from the supplier k at price level r in period t
δ^{-}_{ikrt}	The lower limit of the volume of raw material i purchased from the supplier k at price level r in period t
PF	Price of fuel
Ψ	A large number

Variables

$XVR_{umnts}\begin{cases}1\\0\end{cases}$	If vehicle u moves from customer m to customer n in time period t, under scenario s Otherwise
$XVD_{ul}\begin{cases}1\\0\end{cases}$	If vehicle u is assigned to cross-docking centre l Otherwise
$XS_{ikrts}\begin{cases}1\\0\end{cases}$	If supplier k is selected at price level r to purchase raw material i in time period t, under scenario s Otherwise
$XD_l\begin{cases}1\\0\end{cases}$	If cross-docking centre l is setup Otherwise
$XC_o\begin{cases}1\\0\end{cases}$	If collection centre o is setup Otherwise
$XR_p\begin{cases}1\\0\end{cases}$	If remanufacturing centre p is setup Otherwise
$XDS_q\begin{cases}1\\0\end{cases}$	If disposal centre q is setup Otherwise
$\begin{cases}1\end{cases}$	If vehicle u is purchased

	Otherwise
$X_{mnts}\begin{cases}1\\0\end{cases}$	If route between customer *m* and customer *n* is repaired in time period *t*, under scenario *s* Otherwise
$\lambda_{u'umts}\begin{cases}1\\0\end{cases}$	If vehicle *u'* visits customer m before vehicle *u* in time period *t*, under scenario *s* Otherwise
η_{umts}	Arrival time of vehicle *u* to customer *m* in time period *t*, under scenario *s*
RR_{mnts}	Route reliability between customer *m* and customer *n* in time period *t*, under scenario *s*
TR_{uts}	Reliability of the route travelled by the vehicle *u* in time period *t*, under scenario *s*
XSM_{ikrvts}	Amount of raw material *i* purchased from supplier *k* at price level *r* by transportation mode *v* in time period *t*, under scenario *s*
XMD_{jlts}	Amount of product *j* shipped from plant to cross-docking centre *l* in time period *t*, under scenario *s*
$XDCS_{julmts}$	Amount of product *j* shipped from cross-docking centre *l* to customer *m* by vehicle *u* in time period *t*, under scenario *s*
$XCSC_{jmots}$	Amount of product *j* shipped from customer *m* to collection centre *o* in time period *t*, under scenario *s*
XCR_{jopts}	Amount of product *j* shipped from collection centre *o* to remanufacturing centre *p* in time period *t*, under scenario *s*
$XCDS_{joqts}$	Amount of product *j* shipped from collection centre *o* to disposal centre *q* in time period *t*, under scenario *s*
XRM_{jpts}	Amount of product *j* shipped from remanufacturing centre *p* to plant in time period *t*, under scenario *s*
XH_{jmts}	Amount of product *j* stored in warehouse of customer *m* in time period *t*, under scenario *s*
NSM_{vkts}	Number of transportation mode *v* used to ship raw materials from supplier *k* to plant in time period *t*, under scenario *s*
NMD_{lts}	Number of trucks used to ship products from plant to cross-docking centre *l* in time period *t*, under scenario *s*
$NCSC_{mots}$	Number of trucks used to ship products from customer m to collection centre *o* in time period *t*, under scenario *s*
NCR_{opts}	Number of trucks used to ship products from collection centre *o* to remanufacturing centre *p* in time period *t*, under scenario *s*
$NCDS_{oqts}$	Number of trucks used to ship products from collection centre *o* to disposal centre *q* in time period *t*, under scenario *s*
NRM_{pts}	Number of trucks used to ship products from remanufacturing centre *p* to plant in time period *t*, under scenario *s*
θ_{jumts}	The amount of product *j* in vehicle *u* after leaving customer *m* in time period *t*, under scenario *s*

Objective functions

$$\begin{aligned}
\text{Min } Z_1 = {} & \sum_{l} DF_l \times XD_l + \sum_{o} COF_o \times XC_o + \sum_{p} RF_p \times XR_p + \sum_{q} DSF_q \times XDS_q \\
& + \sum_{u} VF_u \times XV_u + \sum_{t,s} \Omega_s \times (1+\varpi)^{-t} \times \Bigg(\sum_{i,k,r,v} SC_{ikrt} \times XSM_{ikrvts} + \sum_{j,l} MC_{jt} \\
& \times XMD_{jlts} + \sum_{j,u,l,m} DC_{jlt} \times XDCS_{julmts} + \sum_{j,m} CSC_{jmt} \times XH_{jmts} + \sum_{j,m,o} CC_{jot} \\
& \times XCSC_{jmots} + \sum_{j,o,p} RC_{jpt} \times XCR_{jopts} + \sum_{j,o,q} DSC_{jqt} \times XCDS_{joqts} + \sum_{i,k,r} SF_{kt} \times XS_{ikrts} \\
& + \sum_{v,k} TC_v \times SM_k \times NSM_{vkts} + \sum_{l} TRC \times MD_l \times NMD_{lts} + \sum_{m,o} TRC \times CSCL_{mo} \\
& \times NCSC_{mots} + \sum_{o,p} TRC \times CR_{op} \times NCR_{opts} + \sum_{o,q} TRC \times RDS_{oq} \times NCDS_{oqts} \\
& + \sum_{p} TRC \times RM_p \times NRM_{pts} + \sum_{m,n} WG_t \times RT_{mn} \times X_{mnts} + PF \\
& \times \sum_{j,u,m>1,n>1} \left(CF_u + ECF_u \times WE_j \times \theta_{jumts} \right) \times CS_{mn} \times XVR_{umnts} + PF \\
& \times \sum_{j,u,l,m>1} \left(CF_u + ECF_u \times WE_j \times \theta_{ju1ts} \right) \times DCS_{lm} \times XVD_{ul} \times XVR_{u1mts} + PF \\
& \times \sum_{j,u,l,m>1} CF_u \times DCS_{lm} \times XVD_{ul} \times XVR_{um1ts} \Bigg)
\end{aligned} \tag{1}$$

The first objective function is to minimise costs. These costs are: the cost of setting up 'cross-docking', 'collection', 'remanufacturing', and 'disposal' centres, cost of purchasing vehicles and raw materials, cost of production at plant, cost of processing the products at cross-docking centres, cost of holding the products at the warehouses of customers, cost of processing the products at the collection, remanufacturing, and disposal centres, cost of ordering to suppliers, transportation cost, and fuel consumption costs by vehicles.

$$\begin{aligned}
\text{Max } Z_2 = \sum_{s} \Omega_s \times \Bigg(& \sum_{j,u,l,m,t} DJ_l \times \frac{XDCS_{julmts}}{DCP_{jlt}} + \sum_{j,m,o,t} CJ_o \times \frac{XCSC_{jmots}}{CCP_{jot}} \\
& + \sum_{j,o,p,t} RJ_p \times \frac{XCR_{jopts}}{RCP_{jpt}} + \sum_{j,o,q,t} DSJ_q \times \frac{XCDS_{joqts}}{DSCP_{jqt}} \Bigg)
\end{aligned} \tag{2}$$

The second objective function is to maximise created job by setting up the cross-docking, collection, remanufacturing, and disposal centres.

Subjected to:

$$TR_{uts} \le RR_{mnts} + \Psi \times (1 - XVR_{umnts}) \qquad \forall u, m, n, t, s \tag{3}$$

$$TR_{uts} \le \sum_{m,n} XVR_{umnts} \qquad \forall u, t, s \tag{4}$$

$$TR_{uts} \geq \Phi \qquad \forall u, t, s \qquad (5)$$

The reliability of the routes travelled by vehicles in each time period is calculated by constraints (3) to (5).

$$RR_{mnts} = 1 - H_{mn} \times \left(1 - \sum_{t'=1}^{t-RT_{mn}} X_{mnt's}\right) \qquad \forall m, n, t, s \qquad (6)$$

$$XVR_{umnts} \leq 1 - \sum_{t'=t-RT_{mn}+1}^{t} X_{mnt's} \qquad \forall u, m, n, t, s \qquad (7)$$

The reliability of the route between customers in each time period is calculated by constraints (6) and (7).

$$\sum_{r,v} XSM_{ikrvts} \leq SCP_{ikt} \qquad \forall i, k, t, s \qquad (8)$$

$$\sum_{l} XMD_{jlts} \leq MCP_{jt} \qquad \forall j, t, s \qquad (9)$$

$$\sum_{u,m} XDCS_{julmts} \leq DCP_{jlt} \qquad \forall j, l, t, s \qquad (10)$$

$$\sum_{m} XCSC_{jmots} \leq CCP_{jot} \qquad \forall j, o, t, s \qquad (11)$$

$$\sum_{o} XCR_{jopts} \leq RCP_{jpt} \qquad \forall j, p, t, s \qquad (12)$$

$$\sum_{o} XCDS_{joqts} \leq DSCP_{jqt} \qquad \forall j, q, t, s \qquad (13)$$

$$\sum_{j,m} XDCS_{julmts} \times WE_j \leq VCP_u \qquad \forall u, l, t, s \qquad (14)$$

The maximum capacity of ‘suppliers’, ‘plant’, ‘cross-docking’, ‘collection’, ‘remanufacturing’, ‘disposal’ centres and ‘vehicles’ are given in constraints (8) to (14), respectively.

$$\frac{\sum_{i,r} XSM_{ikrvts}}{TCP_v} \leq NSM_{vkts} < \frac{\sum_{i,r} XSM_{ikrvts}}{TCP_v} + 1 \qquad \forall v, k, t, s \qquad (15)$$

$$\frac{\sum_{j} XMD_{jlts} \times WE_j}{TRCP} \leq NMD_{lts} < \frac{\sum_{j} XMD_{jlts} \times WE_j}{TRCP} + 1 \qquad \forall l, t, s \qquad (16)$$

$$\frac{\sum_{j} XCSC_{jmots} \times WE_j}{TRCP} \leq NCSC_{mots} < \frac{\sum_{j} XCSC_{jmots} \times WE_j}{TRCP} + 1 \qquad \forall m, o, t, s \qquad (17)$$

$$\frac{\sum_{j} XCR_{jopts} \times WE_j}{TRCP} \le NCR_{opts} < \frac{\sum_{j} XCR_{jopts} \times WE_j}{TRCP} + 1 \qquad \forall o, p, t, s \qquad (18)$$

$$\frac{\sum_{j} XCDS_{joqts} \times WE_j}{TRCP} \le NCDS_{oqts} < \frac{\sum_{j} XCDS_{joqts} \times WE_j}{TRCP} + 1 \qquad \forall o, q, t, s \qquad (19)$$

$$\frac{\sum_{j} XRM_{jpts} \times WE_j}{TRCP} \le NRM_{pts} < \frac{\sum_{j} XRM_{jpts} \times WE_j}{TRCP} + 1 \qquad \forall p, t, s \qquad (20)$$

Number of transportation modes used to ship raw materials among suppliers and plant, number of trucks used to ship products among plant and cross-docking centres, number of trucks used to ship products among customers and collection centres, number of trucks used to ship products among collection and remanufacturing centres, number of trucks used to ship products among collection and disposal centres, and number of trucks used to ship products among remanufacturing centres and plant are calculated using constraints (15) to (20), respectively.

$$XSM_{ikrvts} \le \delta^{+}_{ikrt} + \Psi \times (1 - XS_{ikrts}) \qquad \forall i, k, r, v, t, s \qquad (21)$$

$$XSM_{ikrvts} + \Psi \times (1 - XS_{ikrts}) > \delta^{-}_{ikrt} \qquad \forall i, k, r, v, t, s \qquad (22)$$

$$\sum_{r} XS_{ikrts} \le 1 \qquad \forall i, k, t, s \qquad (23)$$

Constraints (21) to (23) represent the discount on purchases from suppliers.

$$\frac{\sum_{k,r,v} XSM_{ikrvts}}{\varphi_{ij}} \ge \sum_{l} XMD_{jlts} \qquad \forall i, j, t = 1, s \qquad (24)$$

$$\frac{\sum_{k,r,v} XSM_{ikrvts}}{\varphi_{ij}} + \sum_{p} XRM_{jp(t-1)s} \ge \sum_{l} XMD_{jlts} \qquad \forall i, j, t > 1, s \qquad (25)$$

Constraints (24) and (25) provide the inventory balance in plant for the first period and subsequent periods, respectively.

$$XMD_{jlts} \ge \sum_{u,m} XDCS_{julmts} \qquad \forall j, l, t, s \qquad (26)$$

Inventory balance in cross-docking centres is applied in constraint (26).

$$XH_{jmts} = \sum_{u,l} XDCS_{julmts} \times (1 - \xi_u) - CSD_{jmts} - \sum_{o} XCSC_{jmots} \qquad \forall j, m, t = 1, s \qquad (27)$$

$$XH_{jmts} = XH_{jm(t-1)s} + \sum_{u,l} XDCS_{julmts} \times (1-\xi_u) - CSD_{jmts} - \sum_{o} XCSC_{jmots} \quad \forall j, m, t > 1, s \tag{28}$$

The inventory balance in the warehouses of customers for the first period and the subsequent periods is given in constraints (27) and (28), respectively.

$$\sum_{u,l,t'=1}^{t} XDCS_{julmt's} \times (1-\xi_u) \geq \sum_{t'=1}^{t} CSD_{jmt's} + \sum_{o,t'=1}^{t} XCSC_{jmot's} \quad \forall j, m, t < T, s \tag{29}$$

$$\sum_{u,l,t'=t} XDCS_{julmt's} \times (1-\xi_u) = \sum_{t'=t} CSD_{jmt's} + \sum_{o,t'=t} XCSC_{jmot's} \quad \forall j, m, t = T, s \tag{30}$$

Satisfying customers demand is considered by constraints (29) and (30).

$$\sum_{o} XCSC_{jmots} = \alpha_{jmt} \times \sum_{u,l} XDCS_{julmts} \times (1-\xi_u) \quad \forall j, m, t, s \tag{31}$$

The amount of product returned from customers is calculated by constraint (31).

$$\sum_{m} XCSC_{jmots} = \sum_{p} XCR_{jopts} + \sum_{q} XCDS_{joqts} \quad \forall j, o, t, s \tag{32}$$

$$\sum_{p} XCR_{jopts} = \beta_{jot} \times \sum_{m} XCSC_{jmots} \quad \forall j, o, t, s \tag{33}$$

Inventory balances in collection centres are given in constraints (32) and (33).

$$\sum_{o} XCR_{jopts} = XRM_{jpts} \quad \forall j, p, t, s \tag{34}$$

Constraint (34) represents the inventory balance in the remanufacturing centres.

$$\eta_{u'mts} + \Psi \times \lambda_{u'umts} \geq \eta_{umts} + TSV_{um} \quad \forall u' \neq u, m > 1, t, s \tag{35}$$

$$\eta_{umts} + \Psi \times (1 - \lambda_{u'umts}) \geq \eta_{u'mts} + TSV_{u'm} \quad \forall u' \neq u, m > 1, t, s \tag{36}$$

Vehicles scheduling for visiting the customers are controlled by constraints (35) and (36).

$$\eta_{unts} + \Psi \times (1 - XVR_{umnts}) \geq \eta_{umts} + TCS_{umn} + TSV_{um} \quad \forall u, m, n > 1, t, s \tag{37}$$

$$TW + \Psi \times (1 - XVR_{um1ts}) \geq \eta_{umts} + TDCS_{ulm} \times XVD_{ul} + TSV_{um} \quad \forall u, l, m > 1, t, s \tag{38}$$

Sub-tour elimination is considered in constraints (37) and (38). Also, the time window for returning the vehicles to cross-docking centres is guaranteed by constraint (38).

$$\theta_{jumts} + \Psi \times (1 - XVR_{umnts}) \geq \theta_{junts} + XDCS_{julnts} \quad \forall j, u, l, m, n > 1, t, s \tag{39}$$

$$\theta_{ju1ts} \geq \sum_{m} XDCS_{julmts} \quad \forall j, u, l, t, s \tag{40}$$

Amount of products in vehicles after leaving the customers are calculated by constraints (39) and (40).

$$XSM_{ikrvts} \leq \Psi \times XS_{ikrts} \qquad \forall i, k, r, v, t, s \qquad (41)$$

The condition for purchasing from suppliers is given in constraint (41).

$$XMD_{jlts} \leq \Psi \times XD_l \qquad \forall j, l, t, s \qquad (42)$$

$$XDCS_{julmlts} \leq \Psi \times XD_l \qquad \forall j, u, l, m, t, s \qquad (43)$$

The location conditions for cross-docking centres are considered in constraints (42) and (43).

$$XCSC_{jmots} \leq \Psi \times XC_o \qquad \forall j, m, o, t, s \qquad (44)$$

$$XCR_{jopts} \leq \Psi \times XC_o \qquad \forall j, o, p, t, s \qquad (45)$$

$$XCDS_{joqts} \leq \Psi \times XC_o \qquad \forall j, o, q, t, s \qquad (46)$$

The location conditions for collection centres are considered in constraints (44) to (46).

$$XCR_{jopts} \leq \Psi \times XR_p \qquad \forall j, o, p, t, s \qquad (47)$$

$$XRM_{jpts} \leq \Psi \times XR_p \qquad \forall j, p, t, s \qquad (48)$$

The location conditions for remanufacturing centres are considered in constraints (47) and (48).

$$XCDS_{joqts} \leq \Psi \times XDS_q \qquad \forall j, o, q, t, s \qquad (49)$$

The location conditions for disposal centres are considered in constraint (49).

$$\sum_m XVR_{umnts} = \sum_m XVR_{unmts} \qquad \forall u, n, t, s \qquad (50)$$

If vehicles enter a customers' site, they should leave it; constraint (50) controls this requirement for cross-docking centres in each time period, and each scenario.

$$\sum_m XVR_{umnts} \leq 1 \qquad \forall u, n, t, s \qquad (51)$$

Constraint (51) states that each vehicle is allowed to visit each customer at most once, in each time period and scenario.

$$\sum_l XVD_{ul} \leq 1 \qquad \forall u \qquad (52)$$

Constraint (52) ensures that each vehicle is assigned to a maximum of one cross-docking centre.

$$\sum_l XVD_{ul} \leq \Psi \times XV_u \qquad \forall u \qquad (53)$$

A vehicle will be assigned to a cross-docking centre, if purchased. This condition considers in constraint (53).

$$XDCS_{julmts} \leq \Psi \times XVD_{ul} \qquad \forall j,u,l,m,t,s \tag{54}$$

$$XDCS_{julnts} \leq \Psi \times \sum_{m} XVR_{umnts} \qquad \forall j,u,l,n,t,s \tag{55}$$

The two conditions for delivering products to customers are that the vehicle be assigned to a cross-docking centre and the vehicle visits the customers. These two conditions are considered in constraints (54) and (55), respectively.

$$\sum_{u} XVD_{ul} \leq \Psi \times XD_{l} \qquad \forall l \tag{56}$$

According to constraint (56), if a cross-docking centre is not setup, it will not be possible to allocate vehicles to that cross-docking centre.

2.2 Linearisation process

In the first objective function, there are three nonlinear terms including $\theta_{jumts} \times XVR_{umnts}$, $\theta_{ju1ts} \times XVD_{ul}$, and $XVD_{ul} \times XVR_{um1ts}$. To linearise these terms, we define three new variables including one binary variable and two positive variables as shown in Table 2.

Therefore, the linearised objective function is as follows:

$$\begin{aligned}
\text{Min } Z_1 = {} & \sum_{l} DF_l \times XD_l + \sum_{o} COF_o \times XC_o + \sum_{p} RF_p \times XR_p + \sum_{q} DSF_q \times XDS_q \\
& + \sum_{u} VF_u \times XV_u + \sum_{t,s} \Omega_s \times (1+\varpi)^{-t} \times \Bigg(\sum_{i,k,r,v} SC_{ikrt} \times XSM_{ikrvts} + \sum_{j,l} MC_{jt} \\
& \times XMD_{jlts} + \sum_{j,u,l,m} DC_{jlt} \times XDCS_{julmts} + \sum_{j,m} CSC_{jmt} \times XH_{jmts} + \sum_{j,m,o} CC_{jot} \\
& \times XCSC_{jmots} + \sum_{j,o,p} RC_{jpt} \times XCR_{jopts} + \sum_{j,o,q} DSC_{jqt} \times XCDS_{joqts} + \sum_{i,k,r} SF_{kt} \times XS_{ikrts} \\
& + \sum_{v,k} TC_v \times SM_k \times NSM_{vkts} + \sum_{l} TRC \times MD_l \times NMD_{lts} + \sum_{m,o} TRC \times CSCL_{mo} \\
& \times NCSC_{mots} + \sum_{o,p} TRC \times CR_{op} \times NCR_{opts} + \sum_{o,q} TRC \times RDS_{oq} \times NCDS_{oqts} \\
& + \sum_{p} TRC \times RM_p \times NRM_{pts} + \sum_{m,n} WG_t \times RT_{mn} \times X_{mnts} + PF \\
& \times \sum_{j,u,m>1,n>1} \left(CF_u + ECF_u \times WE_j \times \theta X_{jumnts} \right) \times CS_{mn} + PF \\
& \times \sum_{j,u,l,m>1} \left(CF_u + ECF_u \times WE_j \times \theta DR_{jul1mts} \right) \times DCS_{lm} + PF \\
& \times \sum_{j,u,l,m>1} CF_u \times DCS_{lm} \times DR_{ulm1ts} \Bigg)
\end{aligned} \tag{57}$$

Constraints (58) to (65), which are derived from new variables, should also be added to the model.

$$\theta X_{jumnts} \geq \theta_{jumts} - \Psi \times (1 - XVR_{umnts}) \qquad \forall j, u, m, n, t, s \tag{58}$$

$$\theta X_{jumnts} \leq \theta_{jumts} \qquad \forall j, u, m, n, t, s \tag{59}$$

$$\theta X_{jumnts} \leq \Psi \times XVR_{umnts} \qquad \forall j, u, m, n, t, s \tag{60}$$

$$DR_{ulmnts} - XVD_{ul} - XVR_{umnts} + 1.5 \geq 0 \qquad \forall u, l, m, n, t, s \tag{61}$$

$$1.5 \times DR_{ulmnts} - XVD_{ul} - XVR_{umnts} \leq 0 \qquad \forall u, l, m, n, t, s \tag{62}$$

$$\theta DR_{julmnts} \geq \theta_{jumts} - \Psi \times (1 - DR_{ulmnts}) \qquad \forall j, u, l, m, n, t, s \tag{63}$$

$$\theta DR_{julmnts} \leq \theta_{jumts} \qquad \forall j, u, l, m, n, t, s \tag{64}$$

$$\theta DR_{julmnts} \leq \Psi \times DR_{ulmnts} \qquad \forall j, u, l, m, n, t, s \tag{65}$$

Table 2 Auxiliary variables in the linearisation process

Nonlinear term	*Equivalent linearisation variable*	*Variable type*
$\theta_{jumts} \times XVR_{umnts}$	θX_{jumnts}	Positive
$XVD_{ul} \times XVR_{umnts}$	DR_{ulmnts}	Binary
$\theta_{jumts} \times XVD_{ul} \times XVR_{umnts}$		Positive

2.3 Multi-objective solution approach

There are many methods to solve a multi-objective model under uncertainty (Guo et al., 2019; Tavana et al., 2020; Fu et al., 2021). One of the most effective methods is the method presented by Torabi and Hassini (2008). This method is based on fuzzy theory. In this paper, this method is used to solve the proposed bi-objective model under uncertainty. This method is given below:

Notations

ϑ	The relative importance of minimum satisfaction degree of objective functions.
μ_0	Minimum satisfaction degree of objective functions.
w_f	The relative importance weight of the f^{th} objective's degree of satisfaction.
γ_f	The satisfaction degree for objective function *f*.

Mathematical model

$$\begin{aligned} &\text{Max } \vartheta \times \mu_0 + (1 - \vartheta).\sum_f w_f.\gamma_f \\ &s.t. \\ &\mu_0 \leq \gamma_f \\ &\sum_f w_f = 1 \end{aligned} \tag{66}$$

3 Case study

In this section, using data from a wire and cable industry in Iran, the performance of the proposed bi-objective model is evaluated. The company produces a variety of high voltage cables, spray cables in various sizes, automotive cables, and telecommunication and control cables. In this research, four products of this company include flexible wire (1 × 1.5 mm^2) (product 1), flexible wire (1 × 2.5 mm^2) (product 2), flexible wire (1 × 6 mm^2) (product 3), flexible wire (1 × 10 mm^2) (product 4) will be examined. The company makes use of two raw materials, including 8 mm copper wire and polyvinyl chloride (PVC) granules, to produce its products. The products are produced in sizes of 100 metres and for the production of each unit (i.e., 100 metres) of products 1, 2, 3 and 4, respectively 0.75, 1.1, 1.5 and 2.5 kg of PVC granules and 1.2, 2, 4.8 and 8 kg of 8 mm copper wire is needed. In this study, there are six customers (wire and cable distributor stores) in Tehran city, four potential suppliers in Islamshahr, Kashan, Isfahan and Arak, three potential cross-docking centres in Parand, Islamshahr and Robat Karim, three potential collection centres in Tehran, Robat Karim, and Parand, two potential remanufacturing centres in Saveh and Parand and three potential disposal centres in Saveh, Islamshahr and Parand. Some case study data are given in Tables 3–5.

Table 3 Distance between customers (km)

CS_{mn}	$n = 1$	$n = 2$	$n = 3$	$n = 4$	$n = 5$	$n = 6$	$n = 7$
$m = 1$	0	69.3	75.6	69.5	68.9	69.2	68.4
$m = 2$	69.3	0	6.2	1	1.1	1.2	1.9
$m = 3$	75.6	6.2	0	5.6	5.5	4.9	6
$m = 4$	69.5	1	5.6	0	1	1.1	1.9
$m = 5$	68.9	1.1	5.5	1	0	0.7	0.5
$m = 6$	69.2	1.2	4.9	1.1	0.7	0	0.4
$m = 7$	68.4	1.9	6	1.9	0.5	0.4	0

Table 4 Demand of customers for products in each time period and scenario

CSD_{jmts}		$t = 1$			$t = 2$			$t = 3$			$t = 4$		
		$s = 1$	$s = 2$	$s = 3$	$s = 1$	$s = 2$	$s = 3$	$s = 1$	$s = 2$	$s = 3$	$s = 1$	$s = 2$	$s = 3$
$j = 1$	$m = 1$	0	0	0	0	0	0	0	0	0	0	0	0
	$m = 2$	33	34	36	30	32	33	29	30	32	35	37	39
	$m = 3$	32	34	36	43	45	47	43	45	48	28	30	32
	$m = 4$	47	50	52	44	46	49	32	34	36	45	47	50
	$m = 5$	28	30	32	33	35	37	32	34	36	31	32	34
	$m = 6$	31	33	35	31	33	35	37	39	41	41	44	46
	$m = 7$	40	43	45	41	44	46	29	31	33	39	41	43
$j = 2$	$m = 1$	0	0	0	0	0	0	0	0	0	0	0	0
	$m = 2$	38	40	42	32	33	35	29	31	33	31	32	34
	$m = 3$	32	34	36	30	32	34	36	38	40	29	31	33
	$m = 4$	37	39	41	27	29	30	30	32	34	39	41	43

Table 4 Demand of customers for products in each time period and scenario (continued)

CSD_{jmts}		$t = 1$			$t = 2$			$t = 3$			$t = 4$		
		$s = 1$	$s = 2$	$s = 3$	$s = 1$	$s = 2$	$s = 3$	$s = 1$	$s = 2$	$s = 3$	$s = 1$	$s = 2$	$s = 3$
$j = 2$	$m = 5$	27	29	31	29	31	32	30	31	33	31	33	34
	$m = 6$	32	34	36	35	37	39	38	40	43	29	31	32
	$m = 7$	32	33	35	32	34	36	30	32	34	31	33	34
$j = 3$	$m = 1$	0	0	0	0	0	0	0	0	0	0	0	0
	$m = 2$	24	26	27	25	26	28	32	34	36	35	37	39
	$m = 3$	29	30	32	31	33	34	30	32	34	25	26	27
	$m = 4$	28	30	31	28	30	31	32	34	36	30	32	33
	$m = 5$	30	32	34	33	35	37	33	35	37	33	35	37
	$m = 6$	26	27	29	30	32	34	36	38	40	35	37	39
	$m = 7$	25	26	28	29	30	32	36	38	40	32	34	36
$j = 4$	$m = 1$	0	0	0	0	0	0	0	0	0	0	0	0
	$m = 2$	25	26	27	24	25	26	34	36	38	30	32	34
	$m = 3$	29	31	32	29	30	32	33	35	37	27	29	31
	$m = 4$	26	27	29	24	25	26	30	32	34	24	25	27
	$m = 5$	28	30	32	28	30	32	30	32	34	33	35	37
	$m = 6$	31	32	34	32	33	35	24	25	27	32	33	35
	$m = 7$	25	26	28	28	29	31	25	27	28	31	33	35

Table 5 Cost of purchasing each unit of raw materials from suppliers

SC_{ikrt}		$r = 1$			
		$t = 1$	$t = 2$	$t = 3$	$t = 4$
$i = 1$	$k = 1$	25,710	25,780	25,600	25,340
	$k = 2$	25,600	25,550	25,460	25,470
	$k = 3$	25,000	24,500	25,100	25,000
	$k = 4$	24,300	24,800	25,000	24,900
$i = 2$	$k = 1$	225,400	223,900	225,100	226,080
	$k = 2$	226,750	224,850	225,900	225,800
	$k = 3$	227,950	226,880	227,140	227,630
	$k = 4$	227,300	227,120	227,090	227,110

SC_{ikrt}		$r = 2$			
		$t = 1$	$t = 2$	$t = 3$	$t = 4$
$i = 1$	$k = 1$	25,390	25,410	25,480	25,320
	$k = 2$	25,160	25,100	25,090	25,070
	$k = 3$	24,250	23,750	24,350	24,250
	$k = 4$	23,550	24,000	24,250	24,150

Table 5 Cost of purchasing each unit of raw materials from suppliers (continued)

SC_{ikrt}		$r = 2$			
		$t = 1$	$t = 2$	$t = 3$	$t = 4$
$i = 2$	$k = 1$	220,892	219,420	220,600	221,560
	$k = 2$	222,215	220,350	221,380	221,280
	$k = 3$	225,410	224,660	225,300	225,190
	$k = 4$	225,210	225,350	224,990	225,160

SC_{ikrt}		$r = 3$			
		$t = 1$	$t = 2$	$t = 3$	$t = 4$
$i = 1$	$k = 1$	25,040	25,100	25,120	24,990
	$k = 2$	24,820	24,780	24,890	24,650
	$k = 3$	23,750	23,250	23,850	23,750
	$k = 4$	23,080	23,560	23,750	23,660
$i = 2$	$k = 1$	218,640	217,180	218,350	219,300
	$k = 2$	219,950	218,100	219,120	21,900
	$k = 3$	223,240	222,570	223,500	222,980
	$k = 4$	223,630	223,540	223,500	223,560

By running the proposed mathematical model in GAMS software using CPLEX solver for $w_1 = 0.6$ and $w_2 = 0.4$, the optimal values of objective functions and decision variables are obtained, which are given below:

- The optimal values of the first and second objective functions are 4,099,178,448 and 63.49, respectively.
- Raw material 1 (i.e., PVC granules) is purchased from suppliers 3 and 4, and raw material 2 (i.e., 8 mm copper wire) is purchased from suppliers 1 and 2.
- Cross-docking centre 2 (Islamshahr) is setup.
- Collection centre 1 (Tehran) is setup.
- Remanufacturing centre 1 (Saveh) is setup.
- Disposal centre 2 (Islamshahr) is setup.
- All vehicles are purchased.
- The optimal routes travelled by vehicle 1 in each time period and scenario is shown in Table 6.

  For example, the first row of Table 6 states that vehicle 1 goes from cross-docking centre 2 to customer 2 in time period 1 and under scenario 1, then, it visits customers 7, 3, 4, 5 and 6, respectively, and finally, it returns to cross-docking centre 2.
- The amount of raw materials shipped from suppliers to plant in each time period and scenario are shown in Table 7.

  For example, the number 632.73 in the first row and second column of Table 7 shows that 632.73 kg of raw material 1 (i.e., PVC granules) was purchased from supplier 3 in price level 1, in time period 1 and under scenario 2, and by transportation mode 1 has been transferred to the plant.

- The amount of products shipped from plant to cross-docking centres in each time period and scenario are represented in Table 8.
- The amount of products delivered to customers by vehicles in each time period and scenario are shown in Table A1 (see Appendix).

For example, the number 235 in the first row and first column of Table 8 indicates that 235 packages of product 1 are shipped from plant to cross-docking centre 2 in time period 1, under scenario 1.

Table 6 The optimal routes travelled by vehicle 1 in each time period and scenario

Vehicle	*Time period*	*Scenario*	*Optimal routes*
$u = 1$	$t = 1$	$s = 1$	$l = 2 \rightarrow m2 \rightarrow m7 \rightarrow m3 \rightarrow m4 \rightarrow m5 \rightarrow m6 \rightarrow l = 2$
		$s = 2$	$l = 2 \rightarrow m4 \rightarrow m3 \rightarrow m5 \rightarrow m7 \rightarrow m2 \rightarrow m6 \rightarrow l = 2$
		$s = 3$	$l = 2 \rightarrow m6 \rightarrow m5 \rightarrow m4 \rightarrow m2 \rightarrow m3 \rightarrow m7 \rightarrow l = 2$
	$t = 2$	$s = 1$	$l = 2 \rightarrow m7 \rightarrow m6 \rightarrow m5 \rightarrow m3 \rightarrow m4 \rightarrow l = 2$
		$s = 2$	$l = 2 \rightarrow m4 \rightarrow m5 \rightarrow m2 \rightarrow m3 \rightarrow m6 \rightarrow m7 \rightarrow l = 2$
		$s = 3$	$l = 2 \rightarrow m2 \rightarrow m5 \rightarrow m3 \rightarrow m4 \rightarrow l = 2$
	$t = 3$	$s = 1$	$l = 2 \rightarrow m5 \rightarrow m4 \rightarrow m6 \rightarrow m7 \rightarrow m2 \rightarrow m3 \rightarrow l = 2$
		$s = 2$	$l = 2 \rightarrow m5 \rightarrow m7 \rightarrow m4 \rightarrow m2 \rightarrow m3 \rightarrow l = 2$
		$s = 3$	$l = 2 \rightarrow m2 \rightarrow m3 \rightarrow m7 \rightarrow m4 \rightarrow m5 \rightarrow m6 \rightarrow l = 2$
	$t = 4$	$s = 1$	$l = 2 \rightarrow m5 \rightarrow m2 \rightarrow m3 \rightarrow m4 \rightarrow m6 \rightarrow l = 2$
		$s = 2$	$l = 2 \rightarrow m5 \rightarrow m2 \rightarrow m3 \rightarrow m4 \rightarrow m6 \rightarrow m7 \rightarrow l = 2$
		$s = 3$	$l = 2 \rightarrow m2 \rightarrow m4 \rightarrow m3 \rightarrow m6 \rightarrow m5 \rightarrow m7 \rightarrow l = 2$

Table 7 The amount of raw materials shipped from suppliers to plant

XSM_{ikrvts}					*s = 1*	*s = 2*	*s = 3*
$i = 1$	$k = 3$	$r = 1$	$v = 1$	$t = 1$	0	632.73	659.24
				$t = 2$	589.26	0	0
				$t = 3$	0	0	295.05
			$v = 2$	$t = 3$	155.14	216.51	0
	$k = 4$		$v = 1$	$t = 2$	0	571.9	0
				$t = 4$	0	508.94	0
			$v = 2$	$t = 1$	605.11	0	0
				$t = 2$	0	0	552.63
				$t = 4$	483.72	0	539.03
$i = 2$	$k = 1$		$v = 1$	$t = 2$	0	0	1768.43
				$t = 3$	496.45	692.84	944.17
			$v = 2$	$t = 1$	1,936.36	2,024.75	2,109.57
				$t = 2$	1,885.64	1,830.07	0
	$k = 2$	$r = 3$	$v = 1$	$t = 4$	4,000	4,000	4,000
			$v = 2$	$t = 4$	4,000	4,000	4,000

Table 8 The amount of products shipped from plant to cross-docking centres

XMD_{jlts}			$s = 1$	$s = 2$	$s = 3$
$j = 1$	$l = 2$	$t = 1$	235	252	268
		$t = 2$	257	264	277
		$t = 3$	219	238	253
		$t = 4$	245	258	272
$j = 2$		$t = 1$	264	278	254
		$t = 2$	242	209	238
		$t = 3$	151	205	251
		$t = 4$	215	229	241
$j = 3$		$t = 1$	251	220	210
		$t = 2$	248	273	267
		$t = 3$	113	155	208
		$t = 4$	221	234	246
$j = 4$		$t = 1$	242	253	264
		$t = 2$	246	240	233
		$t = 3$	73	97	129
		$t = 4$	196	207	220

4 Conclusions

Integrating operational and strategic decisions into the SCN design can lead to significant cost reduction and efficiency enhancement. In this paper, an integrated CLSC network was designed for the wire and cable industry by integrating decisions related to LIR problem, cross-docking scheduling, supplier selection, and reverse logistics. The proposed model includes both forward and reverse flows that minimises total costs and maximises the created jobs. This paper employed a fuzzy scenario-based approach to overcome uncertainty and solve the proposed bi-objective model. The results of implementing the proposed model in a wire and cable industry in Iran confirmed its efficiency and effectiveness. Problem size is one of the limitations of the model developed in this study. The MOMILP proposed here can be effectively solved for small problems. The large problem with a large number of dimensions is NP-hard and requires heuristics or meta-heuristics algorithms. Therefore, developing heuristic and/or meta-heuristic algorithms to solve the proposed mathematical programing model in large scales is recommended for future studies.

References

Alavi, B., Tavana, M. and Mina, H. (2021) ‘A dynamic decision support system for sustainable supplier selection in circular economy’, *Sustainable Production and Consumption*, Vol. 27, pp.905–920, Elsevier.

Azadmanesh, A. and Maleki, M.R. (2021) ‘Sustainable performance evaluation: a practical approach based on fuzzy best-worst method and fuzzy inference system’, to appear in *International Journal of Applied Decision Sciences*, DOI: 10.1504/IJADS.2022.10036838.

Coenen, J., van Der Heijden, R.E. and van Riel, A.C. (2018) 'Understanding approaches to complexity and uncertainty in closed-loop supply chain management: past findings and future directions', *Journal of Cleaner Production*, Vol. 201, pp.1–13, Elsevier.

Diabat, A. and Jebali, A. (2021) 'Multi-product and multi-period closed loop supply chain network design under take-back legislation', *International Journal of Production Economics*, Vol. 231, p.107879, Elsevier.

Ebrahim Qazvini, Z. and Maleki, M.R. (2021) 'A triple bottom line multi-criteria decision making framework for supplier selection', *International Journal of Management and Decision Making*, DOI: 10.1504/IJMDM.2022.10040899.

Fu, Y., Zhou, M., Guo, X. and Qi, L. (2021) 'Stochastic multi-objective integrated disassembly-reprocessing-reassembly scheduling via fruit fly optimization algorithm', *Journal of Cleaner Production*, Vol. 278, p.123364, Elsevier.

Gholipour, S., Salehian, F., Lamouchi, H. and Mina, H. (2019) 'A green closed-loop supply chain network: a bi-objective mixed integer linear programming model', *International Journal of Operational Research*, Vol. 41, No. 4, pp.492–513.

Govindan, K., Darbari, J.D., Agarwal, V. and Jha, P.C. (2017) 'Fuzzy multi-objective approach for optimal selection of suppliers and transportation decisions in an eco-efficient closed loop supply chain network', *Journal of Cleaner Production*, Vol. 165, pp.1598–1619, Elsevier.

Govindan, K., Mina, H., Esmaeili, A. and Gholami-Zanjani, S.M. (2020) 'An integrated hybrid approach for circular supplier selection and closed loop supply chain network design under uncertainty', *Journal of Cleaner Production*, Vol. 242, p.118317, Elsevier.

Govindan, K., Nasr, A.K., Mostafazadeh, P. and Mina, H. (2021) 'Medical waste management during coronavirus disease 2019 (COVID-19) outbreak: a mathematical programming model', *Computers & Industrial Engineering*, p.107668, Elsevier.

Guo, Y., Yang, H., Chen, M., Cheng, J. and Gong, D. (2019) 'Ensemble prediction-based dynamic robust multi-objective optimization methods', *Swarm and Evolutionary Computation*, Vol. 48, pp.156–171, Elsevier.

Huang, L., Murong, L. and Wang, W. (2020) 'Green closed-loop supply chain network design considering cost control and CO_2 emission', *Modern Supply Chain Research and Applications*, Vol. 2, No. 1, pp.42–59.

Jian, J., Li, B., Zhang, N. and Su, J. (2021) 'Decision-making and coordination of green closed-loop supply chain with fairness concern', *Journal of Cleaner Production*, Vol. 298, p.126779.

Kannan, D., Mina, H., Nosrati-Abarghooee, S. and Khosrojerdi, G. (2020) 'Sustainable circular supplier selection: a novel hybrid approach', *Science of the Total Environment*, Vol. 722, p.137936, Elsevier.

Kazemi, N., Modak, N.M. and Govindan, K. (2019) 'A review of reverse logistics and closed loop supply chain management studies published in IJPR: a bibliometric and content analysis', *International Journal of Production Research*, Vol. 57, Nos. 15–16, pp.4937–4960.

Mardan, E., Govindan, K., Mina, H. and Gholami-Zanjani, S.M. (2019) 'An accelerated benders decomposition algorithm for a bi-objective green closed loop supply chain network design problem', *Journal of Cleaner Production*, Vol. 235, pp.1499–1514, Elsevier.

Mathiyazhagan, K., Rajak, S., Panigrahi, S.S., Agarwal, V. and Manani, D. (2020) 'Reverse supply chain management in manufacturing industry: a systematic review', *International Journal of Productivity and Performance Management*, Vol. 70, No. 4, pp.859–892.

Mina, H., Kannan, D., Gholami-Zanjani, S.M. and Biuki, M. (2021) 'Transition towards circular supplier selection in petrochemical industry: a hybrid approach to achieve sustainable development goals', *Journal of Cleaner Production*, Vol. 286, p.125273, Elsevier.

Mishra, M., Hota, S.K., Ghosh, S.K. and Sarkar, B. (2020) 'Controlling waste and carbon emission for a sustainable closed-loop supply chain management under a cap-and-trade strategy', *Mathematics*, Vol. 8, No. 4, p.466.

Nasr, A.K., Tavana, M., Alavi, B. and Mina, H. (2021) 'A novel fuzzy multi-objective circular supplier selection and order allocation model for sustainable closed-loop supply chains', *Journal of Cleaner Production*, Vol. 287, p.124994, Elsevier.

Nayeri, S., Paydar, M.M., Asadi-Gangraj, E. and Emami, S. (2020) 'Multi-objective fuzzy robust optimization approach to sustainable closed-loop supply chain network design', *Computers & Industrial Engineering*, Vol. 148, p.106716, Elsevier.

Parast, Z.Z.D., Haleh, H., Darestani, S.A. and Amin-Tahmasbi, H. (2021) 'Green reverse supply chain network design considering location-routing-inventory decisions with simultaneous pickup and delivery', *Environmental Science and Pollution Research*, pp.1–22, DOI: 10.1007/s11356-021-13770-4.

Qazvini, Z.E., Haji, A. and Mina, H. (2021) 'A fuzzy solution approach to supplier selection and order allocation in green supply chain considering the location-routing problem', *Scientia Iranica*, Vol. 28, No. 1, pp.446–464.

Rezaei, S. and Kheirkhah, A. (2018) 'A comprehensive approach in designing a sustainable closed-loop supply chain network using cross-docking operations', *Computational and Mathematical Organization Theory*, Vol. 24, No. 1, pp.51–98.

Rezaei, S. and Maihami, R. (2020) 'Optimizing the sustainable decisions in a multi-echelon closed-loop supply chain of the manufacturing/remanufacturing products with a competitive environment', *Environment, Development and Sustainability*, Vol. 22, No. 7, pp.6445–6471.

Sadeghi, A., Mina, H. and Bahrami, N. (2020) 'A mixed integer linear programming model for designing a green closed-loop supply chain network considering location-routing problem', *International Journal of Logistics Systems and Management*, Vol. 36, No. 2, pp.177–198.

Salehi-Amiri, A., Zahedi, A., Akbapour, N. and Hajiaghaei-Keshteli, M. (2021) 'Designing a sustainable closed-loop supply chain network for walnut industry', *Renewable and Sustainable Energy Reviews*, Vol. 141, p.110821, Elsevier.

Soleimani, H. (2018) 'A new sustainable closed-loop supply chain model for mining industry considering fixed-charged transportation: a case study in a travertine quarry', *Resources Policy*, p.101230, Elsevier.

Soysal, M. (2016) 'Closed-loop inventory routing problem for returnable transport items', *Transportation Research Part D: Transport and Environment*, Vol. 48, pp.31–45, Elsevier.

Tavana, M., Khosrojerdi, G., Mina, H. and Rahman, A. (2020) 'A new dynamic two-stage mathematical programming model under uncertainty for project evaluation and selection', *Computers & Industrial Engineering*, Vol. 149, p.106795, Elsevier.

Torabi, S.A. and Hassini, E. (2008) 'An interactive possibilistic programming approach for multiple objective supply chain master planning', *Fuzzy Sets and Systems*, Vol. 159, No. 2, pp.193–214.

Torabi, S.A., Baghersad, M. and Meisami, A. (2013) 'Emergency relief routing and temporary depots location problem with considering roads restoration', in *Proceedings of the 24th Annual Conference of the Production and Operations Management Society*, pp.1–10.

Zandkarimkhani, S., Mina, H., Biuki, M. and Govindan, K. (2020) 'A chance constrained fuzzy goal programming approach for perishable pharmaceutical supply chain network design', *Annals of Operations Research*, Vol. 295, No. 1, pp.425–452.

Zhalechian, M., Tavakkoli-Moghaddam, R., Zahiri, B. and Mohammadi, M. (2016) 'Sustainable design of a closed-loop location-routing-inventory supply chain network under mixed uncertainty', *Transportation Research Part E: Logistics and Transportation Review*, Vol. 89, pp.182–214, Elsevier.

Appendix

Table A1 The amount of products delivered to customers by vehicles in each time period and scenario

$XDCS_{julmts}$				$t = 1$			$t = 2$			$t = 3$			$t = 4$		
j	u	l	m	$s = 1$	$s = 2$	$s = 3$	$s = 1$	$s = 2$	$s = 3$	$s = 1$	$s = 2$	$s = 3$	$s = 1$	$s = 2$	$s = 3$
1	1	2	5	0	0	37	0	17.3	0	0	0	0	0	0	0
1	2	2	2	0	39	12.4	0	0	0	0	0	0	0	0	0
1	2	2	4	0	34	0	0	0	0	0	0	0	0	0	0
1	2	2	7	0	0	53	10.2	0	0	0	0	0	0	0	0
1	3	2	2	35	0	0	0	0	0	0	0	0	0	0	0
1	3	2	3	0	0	7.5	0	0	0	0	0	0	0	0	0
1	3	2	5	0	3.1	0	0	0	0	0	0	0	0	0	0
1	3	2	6	0	0	39.4	0	0	0	0	0	0	0	0	0
1	4	2	2	0	0	0	0	36	0	0	0	35.4	0	0	44
1	4	2	3	0	38	0	48.5	0	0	0	0	54.7	0	0	0
1	4	2	4	35.7	0	0	0	0	54.3	29.5	38.7	0	50.4	52.6	0
1	4	2	5	0	0	0	0	22.6	0	0	0	5.6	34	0	0
1	4	2	6	0	36	0	0	36	38.2	0	0	0	0	49	0
1	4	2	7	33.8	0	0	0	50	52.4	0	34.2	0	0	0	47.4
1	5	2	2	45.5	0	28	0	0	0	32	33.2	0	39.5	41.8	0
1	5	2	3	0	0	33	0	50.7	34	49	51.3	0	31.8	0	36.4
1	5	2	4	0	0	57.5	55.5	0	0	0	0	41	0	0	0
1	5	2	5	31.3	0	0	37	0	41.5	0	38.2	0	0	35	0
1	5	2	6	0	49	0	0	0	0	40	0	0	0	0	51.2
1	5	2	7	0	0	0	0	0	0	32	0	36.4	0	0	0
1	6	2	2	36.7	0	0	0	0	37.2	0	0	0	0	0	0
1	6	2	3	0	22.3	0	0	0	19	0	0	0	0	34	0
1	6	2	4	52	30.5	0	0	51	0	0	0	0	0	0	56
1	6	2	5	0	0	0	0	0	0	36	0	35	0	0	37.3
1	6	2	6	0	0	0	34	0	0	0	42.3	44.5	45.7	0	0
1	6	2	7	0	0	0	37	0	0	0	0	0	43	45.2	0

Table A1 The amount of products delivered to customers by vehicles in each time period and scenario (continued)

$XDCS_{julmts}$				$t = 1$			$t = 2$			$t = 3$			$t = 4$		
j	u	l	m	$s = 1$	$s = 2$	$s = 3$	$s = 1$	$s = 2$	$s = 3$	$s = 1$	$s = 2$	$s = 3$	$s = 1$	$s = 2$	$s = 3$
2	1	2	2	44.5	0	3.1	0	39	16.3	0	0	0	0	2.2	40
2	1	2	3	37.5	40	0	34.6	0	40	0	0	0	0	0	0
2	1	2	4	0	43.8	46	0	0	0	0	0	0	0	0	0
2	1	2	5	31.6	0	36.2	66.4	58	36	0	0	0	22.4	0	0
2	1	2	6	0	0	0	40	0	0	0	0	0	0	0	0
2	1	2	7	0	75.7	0	0	0	0	0	0	0	0	0	0
2	2	2	2	0	46.8	46	0	0	25	0	0	0	0	0	0
2	2	2	3	0	0	0	0	37	0	0	0	46	0	0	0
2	2	2	4	41.5	0	0	63.2	0	0	0	0	0	0	0	50
2	2	2	5	0	0	0	0	0	0	0	0	38.7	0	34.5	0
2	2	2	6	0	0	0	0	42.4	0	0	0	0	0	0	26.2
2	2	2	7	0	0	39.5	0	0	0	0	0	0	9	37.3	0
2	3	2	2	0	0	0	37.7	0	0	0	0	38.9	0	0	0
2	3	2	3	0	0	42.2	0	0	0	0	0	0	0	0	37.4
2	3	2	4	0	0	0	0	33.3	28.9	0	0	39.4	0	47.4	0
2	3	2	5	0	34	0	0	0	0	0	0	0	0	0	0
2	3	2	6	36.3	38.6	41	0	0	44.7	0	0	49	34	0	0
2	3	2	7	72.3	0	0	0	0	42.5	0	0	39.1	0	0	38.5
2	4	2	4	0	0	0	0	0	5.5	2.2	36	0	43.8	0	0
2	4	2	5	0	0	0	0	0	0	0	0	0	13.4	0	0
2	4	2	6	0	0	0	0	0	0	0	0	0	0	35.2	0
2	4	2	7	0	0	0	0	0	0	0	35.7	0	0	0	0
2	5	2	2	0	0	0	0	0	0	33	35.4	0	35.3	34.3	0
2	5	2	3	0	0	0	0	0	0	0	42.3	0	31.8	0	0
2	5	2	5	0	0	0	0	0	0	0	12	0	0	0	0

Table A1 The amount of products delivered to customers by vehicles in each time period and scenario (continued)

$XDCS_{julmts}$				t = 1			t = 2			t = 3			t = 4		
j	u	l	m	s = 1	s = 2	s = 3	s = 1	s = 2	s = 3	s = 1	s = 2	s = 3	s = 1	s = 2	s = 3
2	5	2	6	0	0	0	0	0	0	42	0	0	0	0	11
2	5	2	7	0	0	0	0	0	0	33.4	0	0	0	0	0
2	6	2	3	0	0	0	0	0	0	40	0	0	0	34	0
2	6	2	5	0	0	0	0	0	0	0	0	0	0	0	38.4
2	6	2	6	0	0	0	0	0	0	0	44	0	0	0	0
2	6	2	7	0	0	0	0	0	0	0	0	0	25.3	0	0
3	1	2	2	28.4	0	0	0	55.7	0	0	0	0	41.2	43.6	46
3	1	2	3	34	18.2	0	23.3	0	38.5	0	0	0	0	0	0
3	1	2	4	0	0	35	0	0	0	0	0	0	0	0	37.5
3	1	2	5	9	0	38.7	0	18.4	43.4	0	0	0	39	41.3	0
3	1	2	6	0	0	0	34.3	0	0	0	0	0	0	0	0
3	1	2	7	0	30.5	0	0	0	0	0	15.6	0	0	0	0
3	2	2	2	0	30.7	32	0	0	73.1	0	0	0	0	0	0
3	2	2	3	0	17	0	14	73.7	0	0	0	0	29.3	30.5	0
3	2	2	4	57.4	33.8	0	42.5	0	35.6	0	0	0	34.7	0	1
3	2	2	5	49.3	0	0	0	0	0	0	0	0	0	0	43.7
3	2	2	6	0	0	0	0	14.3	6	0	0	0	0	0	45.3
3	2	2	7	0	0	32.8	36.3	0	0	0	0	0	36.7	39	0
3	3	2	2	0	0	0	66	13.7	0	0	0	1	0	0	0
3	3	2	3	0	0	37.4	31.8	0	0	0	0	0	0	0	31.6
3	3	2	4	0	0	0	0	40	0	0	0	0	0	37	0
3	3	2	5	13.5	58.5	0	0	0	0	0	0	0	0	0	0
3	3	2	6	30.7	32	34.3	0	22.3	32.8	0	0	0	40.6	43	0
3	3	2	7	29.3	0	0	0	34.8	37.2	0	0	23.8	0	0	41.2
3	4	2	3	0	0	0	0	0	0	0	0	37.7	0	0	0
3	4	2	4	0	0	0	0	0	0	0	32.6	0	0	0	0

Table A1 The amount of products delivered to customers by vehicles in each time period and scenario (continued)

$XDCS_{julmts}$				$t = 1$			$t = 2$			$t = 3$			$t = 4$		
j	u	l	m	$s = 1$	$s = 2$	$s = 3$	$s = 1$	$s = 2$	$s = 3$	$s = 1$	$s = 2$	$s = 3$	$s = 1$	$s = 2$	$s = 3$
3	4	2	5	0	0	0	0	0	0	0	19.3	0	0	0	0
3	4	2	7	0	0	0	0	0	0	0	27	0	0	0	0
3	5	2	4	0	0	0	0	0	0	0	0	40.1	0	0	0
3	5	2	5	0	0	0	0	0	0	0	19.3	0	0	0	0
3	5	2	7	0	0	0	0	0	0	0	0	21.2	0	0	0
3	6	2	5	0	0	0	0	0	0	36.4	0	40.7	0	0	0
3	6	2	6	0	0	0	0	0	0	39.3	41.5	43.7	0	0	0
3	6	2	7	0	0	0	0	0	0	37.3	0	0	0	0	0
4	4	2	2	0	0	0	63.4	18.2	0	0	0	20.6	0	0	37.7
4	4	2	3	10.8	34.6	24.6	22.8	0	0	0	0	34.3	0	0	0
4	4	2	4	0	0	0	0	0	23.1	33	13.3	0	26.5	27.7	1.5
4	4	2	5	0	7.1	36	0	13	0	0	0	0	36.1	3	0
4	4	2	6	0	36.3	34.6	0	37.4	40	0	0	0	0	35.3	0
4	4	2	7	63	3.5	0	0	0	4	0	0	0	0	0	39
4	5	2	2	0	0	30.5	0	48.5	0	0	0	0	32.5	35.5	0
4	5	2	3	21.6	0	11	0	37.3	0	8.3	34.5	6.7	29.7	0	34
4	5	2	4	0	0	31.7	26.6	0	5.7	0	0	37.3	0	0	2.3
4	5	2	5	32.6	0	0	51.5	0	75.5	0	0	0	0	35.3	0
4	5	2	6	35	0	0	0	0	0	26.5	0	0	0	0	39.3
4	5	2	7	0	86	0	0	0	0	0	0	0	0	0	0
4	6	2	2	28	29.3	0	0	0	49.6	0	0	0	1	0	0
4	6	2	3	0	0	0	32	0	35	5	0	0	0	32	0
4	6	2	4	28.4	29.5	0	0	27.7	0	0	22	0	0	0	26
4	6	2	5	0	27	0	14	58	0	0	0	0	0	0	40.5
4	6	2	6	0	0	4	36	0	0	0	27.6	30	36	2	0
4	6	2	7	22.2	0	91.3	0	0	0	0	0	0	34.5	36.7	0