A MULTI-OBJECTIVE INTEGRATED MODEL FOR CLOSED-LOOP SUPPLY CHAIN CONFIGURATION AND SUPPLIER SELECTION CONSIDERING UNCERTAIN DEMAND AND DIFFERENT PERFORMANCE LEVELS

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Abstract. In the supply chain management, configuration of supply chain is the most important decision in the long term and supplier selection and order allocation are the most important decision in the medium-term that are considered separately. Considering these together can overcome the sub-optimality. This paper deals with an integrated model that has two phases. In the first phase, we present a framework for supplier selection criteria in Closed Loop Supply Chain (CLSC). In addition, we define two performance levels for each supplier based on the quantity and capability of purchasing from it to be closer to real world problem. The output of this phase is the score of each supplier in each criterion in each level. In the second phase, we propose a nonlinear multi-objective mixed integer model that determines the number and location of all facilities (strategic decision), flow in each echelon of CLSC (tactical decision) and supplier selection and order allocation (hybrid decision). The objective functions maximize profit and scores of suppliers and minimize total pollution. To solve the model, we have created a transformation based on the piecewise linearization method. The mathematical programming model illustrated by a real numerical example.

1. Introduction. Today’s highly competitive market and changes in customer behavior with the rapid growth in technology and globalization forced organizations to act as a member of supply chain instead of independent organizations. The success of a supply chain depends on coordination and integration of all members to act as an effective network.

There are two types of supply chain: forward supply chain and reverse supply chain. Forward supply chain is set of activity that converts raw materials to the final product and convey to the final customers. Reverse supply chain is set of collection and recycling of returned products. Economic considerations, government laws and pressure of environmental organizations are cause of reverse supply chain logic. Processes in the reverse supply chain are collection, disassembling and refurbishing.

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Returned products are disassembled in disassembly sites and they are divided into two kinds of parts. Useless parts are sent to disposal sites and usable parts are cleaned, refurbished, and then transmitted into part inventory and after quality control stored in the part inventory. Military and commercial aircraft are examples of these products. The purpose of refurbishing is increasing the quality of products. Quality standards are less rigorous than those for new products. Although the quality of products is improved by refurbishing, remaining, service life is generally less than the average service life of new ones. [36] Closed-loop Supply Chain (CLSC) is the result of use of forward supply chain and reverse supply chain simultaneously.

In the CLSC, the new parts are bought from external suppliers. Price is one of the important criteria in the supplier selection because purchasing costs are more than 50% of all companies expenses [29]. In addition, other criteria are important in the supplier selection. Kahraman, et al. categorized supplier selection criteria into four groups including supplier criteria, product performance criteria, service performance factors and cost index [22]. Product performance criteria in the CLSC have more important rather than open loop because the products should have some characteristics such as durability, strength, and lightweight to be reusable and recoverable. Environmental criteria are one of another group of characteristics that should be considered in closed-loop configuration. Recyclability, use of clean technology and less pollution are examples of environmental criteria. Let us not forget conservation of environment is one of the goals of CLSC. Recently, some papers have focused on green supplier selection. Delivery and defective rate are examples of service performance criteria. Defective rate have high influence in the number and capacity of disassembly and refurbishing sites and modify the total flow in the supply chain.

In the current studies, researcher assume just one performance level for suppliers but in the real world organizations based on capital capability can upgrade their performance in various criteria. Consider a monopoly market that suppliers provide only one organization’s raw material. Smallholder supplier cannot act in a high level of performance in criteria such as green criteria categories. However, by increasing the amount of purchase of the same supplier, it can upgrade its performance to higher level. Although multiple levels of performance in each criteria could be defined, to avoid complicated calculations, we defined only two levels of performance for each supplier in each criteria. If the purchasing amount of the one supplier were more than a predetermined limit, supplier treats in the second level of performance. But smallholder supplier cannot upgrade own performance to the second level and treats in first level and only try to survive. This assumption is the reason of integrating the supplier selection and SCND in our paper. This assumption has practical and theoretical importance. Its practical importance is its adapting to the real world and its theoretical importance is providing an integrated model to overcome the sub optimality. Here we interact between the suppliers and buyers. Because by increasing the amount of buy, the supplier can upgrade own performance level and by increasing the performance level, the score of supplier increase in suppliers evaluation.

Supply Chain Network Design (SCND) is the most important decision in supply chain management that will affect all the other decisions and have the greatest impact on the supply chain profitability. SCND deals with determining the number, location and capacity of each facility in the supply chain. Administrative costs such as transportation cost and operational cost in each facility have an essential role in
the performance of the supply chain that must consider in the SCND. Inattention to these costs cause sub-optimal solution in the real world. Network design in CLSC has more difficulty because of economic aspects and the effects of it on other aspects of human life, such as the environment and sustainability of natural resources ([11], [27]).

Because SCND is a strategic decision, we should consider changing in parameter over the time. In the real world, parameters because of tangible and intangible reason have an amount of uncertainty. For modeling and solving problems in uncertainty, there are several methods. If we do not have information about parameters treatment and human judgment determines these parameters, using fuzzy theory would be useful. However, if we know the behavior of the parameter, we can assign a probability distribution function to this parameter. For example, demand in a market that observed previously in the past is an uncertain parameter that can be modelled with a probability distribution function.

Because of increasingly attention to the hybrid vehicles in transportation, in this paper, we assume two types of transportation vehicle between each facility. One type is a vehicle with Internal Combustion Engine (ICE) that has more pollution and less cost from other type with Hybrid Motors (HM). As mentioned earlier, reducing pollution is one of the goals of the CLSC. In this paper, the total amount of pollution considered as an objective function that must be minimized. Assuming several types of transportation vehicle in the supply chain has considered in previous articles, but considering HM in SCND is a novel assumes that has been formulated in this paper.

In this article, we configure a general CLSC network that includes manufacturers, distributors, retailers, disassembly sites, refurbishing sites and part-inventories. If the inventory of part inventory is not sufficient, new parts have been purchased from external suppliers. The main target is determining the optimal number of product and part in each echelon of CLSC and number and location of facilities. We propose an integrated model that has two phases. In the first phase, a new framework for supplier selection criteria is presented which is based on four categories. The framework enables decision makers to determine the final score of each supplier in each criterion based on the proposed fuzzy approach. In the second phase, the CLSC formulated as nonlinear multi-objective mixed-integer model. As we know, our article is the first paper that consider two level of performance for suppliers and two kind of vehicle for transportation subsequently in a closed loop supply chain. The objective functions are a total score of suppliers and profit that must be maximized and total pollution that must be minimized. For solving, at first we linearized the model with piecewise linear transformation and then for dealing with multi-objective model, Fuzzy Analytical Hierarchy Process (FAHP) is combined with compromise programming to determine the weights of each objective function precisely. Finally, a numerical example is written to show how does this model work. This example is solved by GAMS (General Algebraic Modelling System). Simultaneous application of the supplier selection, vehicle selection and network configuration, enables us to an integrated management in supply chain performance and rid from sub optimality. Our model indeed is an appropriate tool for supply-chain chef manger to control managed supply chain seamlessly. This paper is organized as follows. The literature review is presented in section 2. The problem is defined in section 3. The proposed model presented in section 4. The solution method presented in section 5. A
numerical example to show our proposed method efficiency presented in section 6. Finally, in section 7 conclusion is presented.

2. Literature review. Here in the literature review section we summarized five subjects that have been studied in our field as ClosedCloop, supplier selection, green supply chain, uncertain demand and networks briefly as bellows:

2.1. Closed-loop supply chain. Some literature reviews have been published for reverse logistics and CLSC configuration. Thierry, et al. divided reverse logistics options to reuse, resale, repair, refurbishing, remanufacturing, cannibalization, and recycling [36]. Fleischmann, et al. defined reverse logistics as the process of planning, implementing and controlling the inbound flow and storage of secondary goods and related information opposite to the traditional supply chain directions for the purpose of recovering value and proper disposal [10]. pokhare & Mutha focused on all aspects of reverse logistics from networking and inventory analysis, collection of used products, determining the pricing, use, resale, and remanufacturing. They also came to conclusion that research publication on reverse logistics is increased especially after 2005 [33]. Giri & Sharma analyzed a closed-loop serial supply chain for both single manufacturingCremanufacturing cycle and multiple manufacturingCremanufacturing cycles using sequential and global optimizations and with a numerical results show that the global optimization is better than the sequential optimization [14].

2.2. Supplier selection. In the field of supplier selection and evaluation, many articles have been published. Weber, et al. sent a questionnaire to several companies. They identified the most important criteria, including price, delivery, quality, facilities, geographic location, and technology [40]. De Boer, et al. presented a literature review of all phases in the supplier selection process from initial problem definition, over the formulation of criteria, the qualification of potential suppliers, and final choice among the qualified suppliers [8]. Humphreys, et al. presented a new framework to select the best suppliers based on environmental criteria such as solid waste, chemical waste, air emission, water waste disposal, and energy [19]. Lee, et al. defined green supplier selection criteria by Delphi method and evaluated suppliers by FAHP model [26]. Ghodsypour & OBrein proposed a new model to select the best supplier and determine the order allocation. They used AHP to consider qualitative criteria [13]. Amin & Zhang present an integrated model that has two phases. In the first phase, a framework for supplier selection criteria is presented and in the second phase proposes a multi-objective mixed-integer linear programming (MILP) to a CLSC [2]. In our article, we spouse two level for suppliers performance that suppliers can select proper performance level considering the amount of buy, which is closer to reality. Kannan, et al. developed a most prevalent integrated approach for green supplier selection and order allocation problem with the aim of improving green supply chain management initiatives [23].

2.3. Green supply chain. Recently, some article focus in the green supply chain also HMs in transportation issue that reduce carbon emission. Kabza define HM as a system that use a combination of an ICE, an electric motor, and a battery aim to avoid inefficient operation of the IEC and thereby reducing fuel consumption [21]. The CO2 equivalent index is a popular and credible index that can easily quantify environmental impact and has already been used by various researchers to assess the environmental impact of logistics activities (see [17], [35]). Zhai, et
al. present a mathematical approach to cost benefit analysis of using clean energy systems to partially supply the electricity needs of global industrial productions in the case of General Motors (GM) to reduce greenhouse gas emissions [42]. Xie et al. consider the tradeoff between risk and return. They investigate the selection of cleaner products in two different supply chain structures. The findings are that supply chain structures and risk-averse behavior have significant impacts on the selection of cleaner products [41]. Gang et al. present a model for selecting cleaner products with the consideration of the tradeoff between risk and the return of players. They found that supply chain structures and risk-averse behavior have significant impacts on the selection of cleaner products. They recommend that for a better environmental performance, a supply chain with a lower risk tolerance level and vertical integration should be chosen [12].

2.4. Uncertain demand. The use of uncertainty in SCND models is a natural extension of a deterministic approach because some of the model parameters, in practice, are not certain. Tsiakis, et al. took into account a two-stage stochastic programming model for a SCND problem with uncertain demands. They proposed a large-scale MILP model for their problem [37]. Guillen, et al. presented a stochastic MILP model for a multi-objective SCND problem, considering profit, customer satisfaction, and financial risk as objectives in a three echelon supply chain. The problem was solved by the e-constraint approach and branch-and-bound techniques [16]. Goh, et al. developed a stochastic multi-stage global SCND model regarding supply, demand, exchange and disruption as uncertain parameters in a forward logistic [15]. Azaron, et al. developed a multi-objective stochastic programming approach for supply chain design under uncertainty. Demands of markets, supplies of suppliers, processing, transportation and capacity expansion costs were all considered as uncertain parameters [9]. Azaron, et al. In [4] developed a different method for solving the model that presented in [3]. Fallah, et al. Study the competition between two closed-loop supply chains including manufacturers, retailers and recyclers in an uncertain environment. Market demands considered price sensitive and also the amount of returned products sensitive to incentives. The primary goal of their paper is to investigate the impact of simultaneous and Stackelberg competitions between two closed-loop supply chains on their profits, demands and returns. A game theoretic approach which is empowered by possibility theory applied to obtain the optimal solutions under uncertain condition [9]. Pual, et al. present a literature review on risk and disruption in supply chain systems. Emphasis is given on the real-life risk factors, such as imperfect production processes, risk and disruption in production, supply, demand, and transportation. They classified disruption risk into four categories: (i) Disruption in production, (ii) Disruption in supply, (iii) Disruption in transportation, and (iv) Fluctuation in demand [31].

2.5. Network. To gain the benefits results from integrated design of forward and reverse supply chain networks and to support the whole life cycle of a product, a number of papers has addressed the design of CLSC networks in recent years. Fleischmann, et al. developed a generic model for the design of closed-loop logistics networks. They considered the forward flow together with the reverse flow, allowing the simultaneous definition of the optimal distribution and recovery networks [10]. Listes proposed a generic scenario-based stochastic programming model for the design of integrated forward/reverse SCND. A decomposition method was presented to solve the model in large-sized instances based on the branch-and-cut procedure.
To this aim, both case-based and general models are considered by researchers. Uster, et al. designed a closed-loop supply chain network in which the forward network is existed and only collection and recovery centers must be located. The model optimizes the direct and reverse flows simultaneously. An exact solution method was developed based on Benders decomposition technique. Pati, et al. formulated a mixed-integer goal programming model to determine the facility location, route and flow of different varieties of recyclable wastepaper in the multi-item, multi-echelon and multi-facility decision making framework. Peidro, et al. introduced a novel tactical supply chain planning model by integrating procurement, production and distribution planning activities into a multi-echelon, multi-product, multi-level and multi-period supply chain network. Chen summarizes the recent research on the economics of a CLSC system incorporating remanufacturing for deteriorating goods in electronic market using an analytical approach. Shu & Sun consider an integrated distribution network design problem in which all the retailers face uncertain demand. Their target is to minimize the cost resulted from the distribution center location, transportation, and inventory. They formulate it as a two-stage nonlinear discrete stochastic optimization problem.

The contribution of our paper in comparison to the existing literature is as follows:

- Preparation a new framework for supplier evaluation and selection that enables decision makers to determine the importance of each category.
- Consideration two level of performance for each supplier in each criteria based on the capacity of purchased products.
- Consideration of demand uncertainty in the CLSC network design problem.
- Consideration two type of transportation vehicle with determine cost and pollution based on common and green vehicles.
- Presentation one of the most general CLCS configuration that enable us to overcome the sub-optimality in the literature articles.
- Linearization of the model by using a piecewise linear transformation.

3. Problem definition. In this study, a CLSC network is investigated that consists of several potential locations for manufacturer, distributor, disassembly site, refurbishing site and part inventory. Each facility has a fixed cost if established. Manufacturers and refurbishing site can service to all kinds of products and parts, but have to set-up for them with a determine set-up cost. All facilities have a known and limited capacity. In this network, several products that are composed of several parts are sent from manufacturers to retailers. The exact demand of products in each market is not specified, so the demand assumed as a probabilistic variable with known distribution functions. Manufacturers based on predicted demand, produce products. Distributors are in charge of the packaging and labelling of the products of the chain and send the products to the retailers. In each market, we have one retailer that purchase the final products and collects the returned products. Each retailer of this chain orders its goods early (as long as a given time unit) before the beginning of each period, which is called lead time. After the customers used the product, a percent of them return. The returned products sent to disassembly sites. All returned products could be disassembled. Separated parts which couldn’t be reused sent to disposal sites as waste. Reusable parts are taken to refurbishing site to be cleaned and refurbished. These parts are added to part inventory as new
According to the demand and refurbished parts, the manufacturer purchases new parts from external suppliers. Not only the cost of parts is important for manufacturers, but also he should consider other criteria such as environmental and social responsibility. Suppliers in each criteria have two levels of performance and if the purchasing amount was more than a predetermined level, can upgrade to the second level of performance. Price of new parts are not the same in all suppliers and factors such as distance between supplier and manufacturers and bargaining power of managers change the price of parts for manufacturers. This CLSC have two types of transportation: HM that have low pollution and high costs and ICE that have high pollution and low cost.

In this paper, there are three types of decision: a) Strategic decisions that determine the number and location of all facilities. b) Tactical decisions that determine the flow in each echelon of CLSC. c) Hybrid decisions because of the score of each supplier in each criteria is depended on the purchasing amount of it, supplier selection and order allocation are intertwined.

4. Proposed model. In this section, the proposed model is described. First, the manufacturers identify potential suppliers and define appropriate criteria. Then, decision makers evaluate suppliers by proposed fuzzy model. The results of this phase are the scores of each supplier in any criteria in two performance levels. In the next phase, the CLSC network is formulated as nonlinear multi-objective mixed-integer model. In this stage, the related variables (strategic, tactical and hybrid decision variables) are calculated.

4.1. Evaluation of suppliers. In this section, a new method based on linguistic variables and Triangular Fuzzy Numbers (TFNs) is proposed for supplier assessment. TFN is the most popular method in fuzzy number definition. TFNs can be denoted as $X = (a, n, b)$ and $Y = (c, m, d)$, where $n$ and $m$ are the central values, $a$ and $c$ are the left spreads, and $b$ and $d$ are the right spreads. Then $C = (a + c, n + m, b + d)$ is the addition of these two numbers. Besides, $D = (a * c, n * m, b * d)$ is the multiplication of them ($23, 43$).

Here, our framework is based on 4 categories of criteria: ability, responsibility, green and process related. A large part of studies in this area focused in ability category which consist of Delivery (Lead time), Experience and Financial ability. This is useful when we work only based on profit but in the recent years other criteria such as responsibility (consist of training and number of personnel), green (consist of green packaging and using of clean technology) and the process related category (consist of process flexibility and process safety) are important categories in supplier selection in CLSC.

As mentioned before we consider two level of performance in each criterion for each supplier such that suppliers based on purchasing amount can upgrade own performance to the second level. In this stage we modified Amin & Zhang approach that decision makers state two score for each supplier in any criteria [$2$]. The steps of this phase are as follows:

Step 1. The manufacturers determine the decision making group. Three or five managers can contribute in decision making process. Suppose that there are $N$ decision makers ($n = 1, 2, ..., N$), and $L$ criteria ($l = 1, 2, ..., L$). Moreover, there are $K$ eligible suppliers ($k = 1, 2, ..., K$).
Supplier selection criteria in CLSC

Green

Responsibility

Process-related

Ability

Delivery (lead time)
Technology
Experience
Financial ability
Transportation infrastructure
Capital investment
Productivity
Availability of raw material
Defect rate

Management
Reputation
Training
Warranties
Innovation
Environmental related certification
Social responsibility
Research and development
Number of personnel

Light weight
Strength
Durability
Green packaging
Recyclable
Part safety
Reduction of waste
Using of clean technology
Using of environmental friendly materials
Pollution reduction capability
Energy consumption
Management for hazardous substances

Design process
Process capability
Process flexibility
Process safety
Process improvement

Figure 1. Proposed supplier selection criteria classification

Step 2. Let $U = VL, L, ML, M, MH, H, VH$ be the linguistic set used to express opinions on the group of criteria. This scale is adopted from [1]. The linguistic variables of $U$ can be quantified using TFN (please refer to figure. 2). Each decision maker establishes a level of importance for each category by using linguistic variables and TFNs ($ca_x$ represents importance of category $x$, $x = 1, ..., 4$). Then, they are combined by equation 1 and the weights of categories are calculated as:

$$ca_x = \left( ca_{x1} + ca_{x2} + ... + ca_{xN} \right) / N \quad (1)$$

Step 3. Let $w_{xl,n}$ represents the importance of criterion $l$ in category $x$ by decision maker $n$. Decision makers establish a level of importance by equation 2.

$$w_{xl} = \left( w_{xl1} + w_{xl2} + ... + w_{xlN} \right) / N \quad (2)$$

Step 4. Let $su_{xlkw}$ represents the assessment of supplier $k$ in performance level $w$ based on criterion $l$ in category $x$ which is performed by decision maker $n$ and $Su_{xlkw}$ The aggregated weight of supplier $k$ in performance level $w$ based on criterion $l$ in category $x$ that calculated by equation 3.

$$su_{xlkw} = \left( su_{xlkw1} + su_{xlkw2} + ... + su_{xlkwN} \right) / N \quad (3)$$
Step 5. In this step, weights of categories are multiplied by weights of criteria and aggregated weights. Equation (4) shows the formula. In this equation $s_{klw}$ is a TFN. Now, the numbers should be defuzzified. In this paper, a simple method is applied to defuzzifying the numbers. A defuzzified number of $s_{klw} = (a, n, b)$ is calculated by equation (5).

$$s_{klw} = \sum_{x=1}^{3} S u_{xklw} \ast w_{xl} \ast c a_{x}$$  \hspace{1cm} (4)$$

$$a_{klw} = (a + n + b) / 3$$  \hspace{1cm} (5)$$

$a_{klw}$ is score of supplier $k$ in criteria $l$ in performance level $w$.

4.2. Mathematical model.

4.2.1. Notation. All the symbols that are used in the mathematical model are as follows:

Sets and indexes
- $i \in I$ set of parts
- $j \in J$ set of products
- $k \in K$ set of potential suppliers
- $m \in M$ set of potential manufacturers
- $d \in D$ set of potential distributors
- $c \in C$ set of retailer (markers)
- $s \in S$ set of potential disassembly sites
- $r \in R$ set of potential refurbishing sites
- $p \in P$ set of potential part inventories
- $t \in \{1, 2\}$ set of transportation vehicle
Parameters

\( cf_{jmdt} \) transportation cost of a unit of produce \( j \) from manufacturer \( m \) to distributor \( d \) with vehicle \( t \)

\( te_{jct} \) transportation cost of a unit of product \( j \) from distributor \( d \) to retailer \( c \) with vehicle \( t \)

\( th_{jcs} \) transportation cost of a unit of product \( j \) from retailer \( c \) to disassembly site \( s \) with vehicle \( t \)

\( rf_{ibrt} \) transportation cost of a unit or part \( i \) from disassembly site \( b \) to refurbishing site \( r \) with vehicle \( t \)

\( tm_{ipt} \) transportation cost of a unit of part \( i \) from refurbishing site \( b \) to part inventory \( p \) with vehicle \( t \)

\( pn_{ipt} \) transportation cost of a unit of part \( i \) from part inventory \( p \) to manufacturer \( m \) with vehicle \( t \)

\( ps_{ikt} \) CO\(_2\) equivalent emission per unit of part \( i \) shipped from supplier \( k \) to manufacturer \( m \) by vehicle \( t \)

\( pf_{jmt} \) CO\(_2\) equivalent emission per unit of product \( j \) shipped from manufacturer \( m \) to distributor \( d \) by vehicle \( t \)

\( pe_{jct} \) CO\(_2\) equivalent emission per unit of product \( j \) shipped from distributor \( d \) to retailer \( c \) by vehicle \( t \)

\( ph_{ics} \) CO\(_2\) equivalent emission per unit of product \( i \) shipped from retailer \( c \) to disassembly site \( s \) by vehicle \( t \)

\( pfs_{irs} \) CO\(_2\) equivalent emission per unit of part \( i \) shipped from disassembly site \( s \) to refurbishing site \( r \) by vehicle \( t \)

\( pm_{ipt} \) CO\(_2\) equivalent emission per unit of part \( i \) shipped from refurbishing site \( r \) to part inventory \( p \) by vehicle \( t \)

\( pm_{ipt} \) CO\(_2\) equivalent emission per unit of part \( i \) shipped from part inventory \( p \) to manufacturer \( m \) by vehicle \( t \)

\( fm_{m} \) fixed cost of opening manufacturer \( m \)

\( fd_{d} \) fixed cost of opening distributor \( d \)

\( fs_{s} \) fixed cost of opening disassembly site \( s \)

\( fr_{r} \) fixed cost of opening refurbishing site \( r \)

\( fp_{p} \) fixed cost of opening part inventory \( p \)

\( om_{jm} \) operating cost of product \( j \) in manufacturer \( m \)

\( od_{jd} \) operating cost of product \( j \) in distributor \( d \)

\( oc_{jc} \) operating cost of product \( j \) in retailer \( c \)

\( os_{is} \) operating cost of part \( i \) in disassembly site \( s \)

\( or_{ir} \) operating cost of part \( i \) in refurbishing site \( r \)

\( op_{ip} \) operating cost of part \( i \) in part inventory \( p \)

\( cs_{is} \) max capacity of disassembly site \( s \) for part \( i \)

\( cp_{ip} \) max capacity of part inventory \( p \) for part \( i \)

\( cd_{jd} \) max capacity of distributor \( d \) for product \( j \)

\( cr_{r} \) max capacity of refurbishing site \( r \)

\( cm_{m} \) max capacity of manufacturer \( m \)

\( Sm_{jm} \) set-up cost of manufacturer \( m \) for product \( j \)

\( Sr_{ir} \) set-up cost of refurbishing site \( r \) for part \( i \)

\( spr_{ikmt} \) price of part \( i \) that purchased from supplier \( k \) by manufacturer \( m \) and transported with vehicle \( t \)

\( bk \) predetermined amount to improve the performance level in supplier \( k \)

\( Bug \) the maximum budget for opening the facilities in the chain

\( q_{ij} \) unit requirements for part \( i \) to produce one unit of product \( j \)

\( e_{j} \) return percent of product \( j \)

\( w_{i} \) percent of uselessness of part \( i \)

\( s_{ij} \) price of one unit of product \( j \) in retailer \( c \)

\( se_{jc} \) salvage value of one unit of the residual product \( j \) in retailer \( c \)

\( sn_{jc} \) shortage cost of one unit of unmet demand for product \( j \) in retailer \( c \)

\( D_{jc} \) demand of product \( j \) in retailer \( c \)

\( E(D_{jc}) \) expected demand of product \( j \) in retailer \( c \)

\( F(D_{jc}) \) cumulative distribution function of variable \( D_{jc} \)
Decision variables:

\( s_{ikmt} \) : quantity of product \( j \) shipped from supplier \( k \) to manufacturer \( m \) by vehicle \( t \)

\( f_{jmdt} \) : quantity of product \( j \) shipped from manufacturer \( m \) to distributor \( d \) by vehicle \( t \)

\( e_{jdct} \) : quantity of product \( j \) shipped from distributor \( d \) to retailer \( c \) by vehicle \( t \)

\( h_{jcdt} \) : quantity of product \( j \) shipped from retailer \( c \) to disassembly site \( s \) by vehicle \( t \)

\( l_{isrt} \) : quantity of part \( i \) shipped from disassembly site \( s \) to refurbishing site \( r \) by vehicle \( t \)

\( m_{irpt} \) : quantity of part \( i \) shipped from refurbishing site \( r \) to part inventory \( p \) by vehicle \( t \)

\( n_{ipmt} \) : quantity of part \( i \) shipped from part inventory \( p \) to manufacturer \( m \) by vehicle \( t \)

\( o_{jm} \) : quantity of product \( j \) manufactured at manufacturer \( m \)

\( t_{is} \) : quantity of part \( i \) disassembled in disassembly site \( s \)

\( x_{jc} \) : quantity of product \( j \) sent to retailer \( c \)

\( xm_{m} \) : binary variable equals to 1 if a manufacturer is located in candidate location \( m \) and equals to 0 otherwise

\( xd_{d} \) : binary variable equals to 1 if a distributor is located in candidate location \( d \) and equals to 0 otherwise

\( xs_{s} \) : binary variable equals to 1 if a disassembly site is located in candidate location \( s \) and equals to 0 otherwise

\( xr_{r} \) : binary variable equals to 1 if a refurbishing site is located in candidate location \( r \) and equals to 0 otherwise

\( xp_{p} \) : binary variable equals to 1 if a part inventory is located in candidate location \( p \) and equals to 0 otherwise

\( xk_{k} \) : binary variable equals to 1 if supplier \( k \) selected and equals to 0 otherwise

\( Sm_{jm} \) : binary variable equals to 1 if manufacturer \( m \) sets up to product \( j \) and equals to 0 otherwise

\( Srx_{ir} \) : binary variable equals to 1 if refurbishing site \( r \) sets up to part \( i \) and equals to 0 otherwise

\( y_{1kl} \) : binary variable equals to 1 if supplier \( k \) in criterion \( l \) act in the first performance level

\( y_{2kl} \) : binary variable equals to 1 if supplier \( k \) in criterion \( l \) act in second performance level

4.2.2. Model formulation. The mathematical formulation of the addressed problem is presented as follows:

Objective functions:

As mentioned in above, three important and conflicting objective functions are considered in the formulation of this problem: (1) maximizing total suppliers score, (2) maximization of total income and (3) minimization of total pollution generated.

Total suppliers score: equation states if supplier exist in second performance level the score of second performance level included in calculation of objective function and score of first performance level considered elsewhere.

\[
\max z_1 = \sum_k \sum_l y_{1kl} \times a_{kl1} + y_{2kl} \times a_{kl2}
\]
Total income: at first we compute the profit of product \( j \) in retailer \( c \). We define \((x \wedge D) = \min\{x, D\}\) and \( a^+ = \max\{0, a\}\).

Profit of product \( j \) in retailer \( c \) = \( s_{jc}(x_{jc} \wedge D_{jc}) + sv_{jc}(x_{jc} - D_{jc})^+ - sc_{jc}(D_{jc} - x_{jc})^+ \) (7)

The first term in equation 7 represents the income of product \( j \) in retailer \( c \) in the CLSC, which is equal to the price of one unit multiplied by the amount of sold product. The second term exhibits the salvage value of extra product and the third term explains the shortage cost for unmet demand. We are exploiting the newsboy problem style for calculating the inventory managing systems: manager anticipates the demand of the next period of time and orders it at an appropriate time before the beginning of the next period; unsold products and lost sales at the end of the period lead to the salvage value and shortage cost respectively. In this way, demand uncertainty is considered in the model. We simplify above equation as equation 8 as shown in the appendix.

\[
\sum_{j} \left( s_{jc} + sc_{jc} \right) x_{jc} + \left( sv_{jc} - s_{jc} - sc_{jc} \right) \int_{0}^{x_{jc}} F(D_{jc}) dD_{jc} - E(D_{jc}) sc_{jc} (8)
\]

Since the amount of \( E(D_{jc})sc_{jc} \) is constant, has been discarded from calculations.

Purchasing cost: equation 9 implies the total purchasing cost that purchased from external supplier.

\[
\sum_{i} \sum_{k} \sum_{m} \sum_{t} spr_{ikmt} s_{ikmt} (9)
\]

Fixed cost: equation 10 implies the total fixed opening costs of facilities.

\[
\sum_{m} fm_{m} x_{m} + \sum_{d} fd_{d} x_{d} + \sum_{s} f_{s}s_{s} x_{s} + \sum_{r} fr_{r} x_{r} + \sum_{p} fp_{p} x_{p} (10)
\]

Set up cost: equation 11 shows the total set up cost: the first term exhibits the set up cost of manufacturers and the second term exhibits the set up cost of refurbishing sites.

\[
\sum_{m} \sum_{j} sm_{mj} s_{mj} + \sum_{i} \sum_{r} spr_{ir} x_{ir} (11)
\]

Handling cost of forward flow: equation 12 considers the total handling cost of forward flow. The first term exhibits the transportation cost of part inventory to the manufacturers, second term shows the operating costs in manufacturers, third term exhibits the transportation cost of products to the distributors and fourth term declares the operating costs in distributors when fifth term defines the transportation cost of distributors to the retailers and the last term exhibits the operating costs in retailers.

\[
\sum_{i} \sum_{p} \sum_{m} \sum_{t} tn_{ipt} m_{ipt} + \sum_{j} \sum_{m} \sum_{t} o_{jm} m_{jm} + \sum_{j} \sum_{m} \sum_{d} \sum_{t} f_{jmdt} f_{jmdt} + \sum_{j} \sum_{d} o_{jd} \sum_{m} \sum_{t} f_{jmdt} + \sum_{j} \sum_{d} \sum_{c} \sum_{t} c_{jdt} t_{jdt} + \sum_{j} \sum_{c} \sum_{d} \sum_{t} e_{jdt} (12)
\]

Handling cost of reverse flow: equation 13 implies the total handling cost of reverse flow: the first term exhibits the transportation cost of returned product to disassembly sites, the second term exhibits the operating costs in disassembly sites, third term declares the transportation cost of disassembled parts to refurbishing sites. Fourth term exhibits the operating costs in refurbishing sites where fifth term
exhibits the transportation cost of refurbished parts to part inventory.

\[
\sum_{j} \sum_{c} \sum_{s} \sum_{l} \sum_{t} h_{jct} h_{jct} + \sum_{j} \sum_{s} \sum_{l} \sum_{t} q_{ji} \sum_{c} \sum_{t} h_{jct} + \sum_{j} \sum_{s} \sum_{l} \sum_{t} l_{isrt} l_{isrt} + \\
\sum_{i} \sum_{r} \sum_{s} \sum_{t} \sum_{l} m_{irpt} m_{irpt} + \sum_{i} \sum_{p} \sum_{r} \sum_{t} m_{irpt}
\]

Therefore, the total income formulation is as follow:

\[
\max z_{2} = \left( \sum_{j} \sum_{c} \left( s_{jc} + sc_{jc} \right) x_{jc} + \left( sv_{jc} - s_{jc} - sc_{jc} \right) \frac{s_{jc}}{F(D_{jc})dD_{jc}} \right)
\]

\[
\begin{align*}
&+ \sum_{i} \sum_{m} \sum_{l} \sum_{t} sp_{ikmt} s_{ikmt} + \sum_{m} \sum_{d} \sum_{t} fm_{m} x_{m} + \sum_{d} \sum_{t} sd_{d} x_{d} + \sum_{s} \sum_{t} fs_{s} x_{s} \\
&+ \sum_{p} \sum_{t} sp_{ipmt} n_{ipmt} + \sum_{m} \sum_{l} \sum_{t} sm_{m} x_{m} + \sum_{t} \sum_{d} \sum_{t} sm_{t} x_{t} + \sum_{p} \sum_{t} sp_{ipmt} n_{ipmt} \\
&+ \sum_{j} \sum_{m} \sum_{l} \sum_{t} h_{jct} h_{jct} + \sum_{j} \sum_{s} \sum_{l} \sum_{t} q_{ji} \sum_{c} \sum_{t} h_{jct} + \sum_{j} \sum_{s} \sum_{l} \sum_{t} l_{isrt} l_{isrt} + \\
&\sum_{j} \sum_{r} \sum_{s} \sum_{t} \sum_{l} m_{irpt} m_{irpt} + \sum_{i} \sum_{p} \sum_{r} \sum_{t} m_{irpt}
\end{align*}
\]

Total generated pollution: equation [15] imply the total CO₂ equivalent emission generated by transportation between facilities in the CLCS

\[
\min z_{3} = \sum_{i} \sum_{m} \sum_{k} \sum_{t} ph_{ikmt} s_{ikmt} + \sum_{i} \sum_{m} \sum_{d} \sum_{t} pf_{jmdt} f_{jmdt} + \sum_{i} \sum_{j} \sum_{d} \sum_{t} pe_{jdt} e_{jdt} \\
+ \sum_{j} \sum_{c} \sum_{s} \sum_{t} ph_{jct} h_{jct} + \sum_{j} \sum_{s} \sum_{l} \sum_{t} pl_{isrt} l_{isrt} + \sum_{i} \sum_{r} \sum_{t} \sum_{l} pm_{irpt} m_{irpt} \\
+ \sum_{i} \sum_{p} \sum_{m} \sum_{t} pm_{ipmt} n_{ipmt}
\]

Constraints:
Suppliers score constraints:
Constraints [16] [17] ensure that if the purchasing amount was more than a predetermine amount the second level performance included in calculation and otherwise the first level performance score considered. constraint [18] implies that only one performance level score can included and constraint [19] [20] imply that if supplier k selected its performance score can included.

\[
\sum_{i,m,t} s_{ikmt} \geq b - M * y_{1kl} \quad \forall k,l
\]

\[
\sum_{i,m,t} s_{ikmt} \leq b + M * y_{2kl} \quad \forall k,l
\]

\[
y_{1kl} + y_{2kl} = 1 \quad \forall k,l
\]

\[
y_{1kl} \leq x_{k} \quad \forall k,l
\]

\[
y_{2kl} \leq x_{k} \quad \forall k,l
\]

Possibility Constraints:
All relevant possibility constraints [21] - [31] are summarizes as follows:
If a facility located in candidate location, it is possible to send to and receive from it. Constraint 32 implies that if supplier $k$ selected it is possible to purchase from it.

\[
\sum_{j,t,d} f_{jmdt} \leq M \times x_{m} \quad \forall m
\]  
(21)

\[
\sum_{i,p,t} n_{ipmt} \leq M \times x_{m} \quad \forall m
\]  
(22)

\[
\sum_{i,k,t} s_{ikmt} \leq M \times x_{m} \quad \forall m
\]  
(23)

\[
\sum_{c,t,j} e_{jdtc} \leq M \times x_{d} \quad \forall d
\]  
(24)

\[
\sum_{j,t,m} f_{jmdt} \leq M \times x_{d} \quad \forall d
\]  
(25)

\[
\sum_{i,r,t} l_{isrt} \leq M \times x_{s} \quad \forall s
\]  
(26)

\[
\sum_{j,r,t} m_{irpt} \leq M \times x_{r} \quad \forall r
\]  
(27)

\[
\sum_{i,m,t} n_{ipmt} \leq M \times x_{p} \quad \forall p
\]  
(28)

\[
\sum_{i,r,t} m_{iprt} \leq M \times x_{p} \quad \forall p
\]  
(29)

\[
\sum_{i,m,t} s_{ikmt} \leq M \times x_{k} \quad \forall k
\]  
(30)

Flow balance constraints:

Constraint 33 shows the flow balance at manufacturers. Constraint 34 ensures that the total product sent to distributors is equal to the manufactured products. Constraint 35 guarantees the flow balance at distributor. Constraints 36, 37 defines the flow balance at retailers. Constraints 38, 39 ensure the flow balance at disassembly sites. Constraint 40 considers the flow balance at refurbishing sites. Constraint 41 ensures the flow balance at part inventories.

\[
\sum_{j} q_{ij} o_{jm} = \sum_{k,t} s_{ikmt} + \sum_{p,t} n_{ipmt} \quad \forall m, i
\]  
(33)

\[
o_{jm} = \sum_{d,t} f_{jmdt} \quad \forall m, j
\]  
(34)

\[
\sum_{m,t} f_{jmdt} = \sum_{c,t} e_{jdtc} \quad \forall d, j
\]  
(35)

\[
x_{jc} = \sum_{d,t} e_{jdtc} \quad \forall c, j
\]  
(36)

\[
e_{j} x_{jc} = \sum_{s,t} h_{jcs} \quad \forall c, j
\]  
(37)
MULTI-OBJECTIVE INTEGRATED MODEL IN CLSC

\[ t_{is} = \sum_{c,j,t} h_{jcst} q_{ij} \quad \forall c, i \quad (38) \]
\[ t_{is} = w_{it} t_{is} + \sum_{r,t} l_{isrt} \quad \forall i, s \quad (39) \]
\[ \sum_{s,t} l_{isrt} = \sum_{p,t} m_{irpt} \quad \forall i, r \quad (40) \]
\[ \sum_{r,t} m_{irpt} = \sum_{m,t} n_{ipmt} \quad \forall p, i \quad (41) \]

Capacity constraints:
All relevant capacity constraints are summarized as follows.
Constraints [42-46] are capacity constraints on manufacturers, distributors, disassemble sites, refurbishing sites and part inventory.

\[ \sum_{j} a_{jm} \leq cm_{m} x_{m} \quad \forall m \quad (42) \]
\[ \sum_{m,t} f_{jmdt} \leq cd_{j} x_{d} \quad \forall d, j \quad (43) \]
\[ \sum_{j} q_{ij} \times \sum_{c,t} h_{jcst} \leq cs_{i} x_{s} \quad \forall s, i \quad (44) \]
\[ \sum_{i,s,t} l_{isrt} \leq cr_{r} x_{r} \quad \forall r \quad (45) \]
\[ \sum_{r,t} m_{irpt} \leq cp_{p} x_{p} \quad \forall p, i \quad (46) \]

Set up constrains:
Constraint [47] implies that manufacturer \( m \) can set up to product \( j \) if a manufacturer is located in location \( m \). Constraint [48] shows that refurbishing site \( r \) can set up to part \( i \) if a refurbishing site is located in location \( r \). Constraint [49] defines that product \( j \) can produced in manufacturer \( m \) if it sets up to this product.

\[ sm_{xj} \leq x_{m} \quad \forall m, j \quad (47) \]
\[ sr_{x} \leq x_{r} \quad \forall r \quad (48) \]
\[ o_{j,m} \leq M \times sm_{xj,m} \quad \forall m, j \quad (49) \]

Budget constraint:
Constraint [50] insures that the total fixed opening costs of facilities are not more a certain limit.

\[ \sum_{m} f_{m} x_{m} + \sum_{d} f_{d} x_{d} + \sum_{s} f_{s} x_{s} + \sum_{r} f_{r} x_{r} + \sum_{p} f_{p} x_{p} \leq bug \quad (50) \]

Decision variables constraints:
The following constraints are related to the binary and non-negativity restrictions on the corresponding decision variables:

\[ s_{ikmt}, f_{jmdt}, e_{jct} h_{jcst}, l_{isrt}, m_{irpt}, n_{ipmt}, a_{jm}, t_{is}, x_{jc} \geq 0 \quad (51) \]
\[ x_{m}, x_{d}, x_{s}, x_{r}, x_{p}, x_{k}, sm_{xj}, sr_{x}, y_{1,kl}, y_{2,kl} \in \{0, 1\} \quad (52) \]
5. The solution method.

5.1. Model linearization. The proposed model in the previous section is a multi-objective mixed integer nonlinear model with one nonlinear objective function and two linear objective function and $6K + 5L + 8M + 4D + 5S + 5R + 4P + 3C + 7I + 7J + 1$ linear constraints. It also contains $2M + D + S + 2R + 3K + 2L + I + J$ binary and $4M + 2D + 3S + 2R + K + 5I + 5J$ continuous variables, respectively.

This model is seriously nonlinear due to the integral of cumulative distribution function in objective function. According to the type of distribution function of the markets, the form of this term can be different and for some cases, such as a normal distribution, calculating the amount of this term is not straightforward and it cannot be a closed form. Therefore, we need to use a numerical technique to figure out the form of this function and we used a piecewise linear transformation which breaks the range of this nonlinear function into several intervals and substituted the convex function with straight lines (with a unique constant and coefficient) in each interval. Such linearization is used in [5]. For the normal distribution function, the approximations used can be seen in figure [3].

This approximation converts our nonlinear model into a linear one and we reached an optimal solution for the linearized model. Since the nonlinear model is convex, we have reached a solution that is close to the global optimum, but an error already exists. By increasing the number of intervals, the error decreases. We considered several intervals for product $j$ in retailer $c$ and defined one index and one binary variable for interval selection.
After defining the above notations, the model is linearized as follows:

\[
\max z_1 = \sum_{k} \sum_{l} y_{kl} * a_{1kl} + y_{2kl} * a_{2kl}
\]

\[
\max z_2 = \left( \sum_{j} \sum_{c} \left((s_{jc} + sc_{jc})x_{jc} + (sv_{jc} - s_{jc} - sc_{jc}) \cdot \int_{0}^{x_{jc}} F(D_{jc})dD_{jc}\right)ight)
\]

\[
- \sum_{i} \sum_{j} \sum_{m} \sum_{t} \sum_{s} p_{ikmt}s_{ikmt} + \sum_{j} \sum_{m} \sum_{t} \sum_{s} p_{fjmt}f_{jtmt} + \sum_{j} \sum_{m} \sum_{t} \sum_{s} p_{njmt}n_{ijmt}
\]

\[
\min z_3 = \sum_{i} \sum_{j} \sum_{m} \sum_{t} \sum_{s} p_{ikmt}s_{ikmt} + \sum_{j} \sum_{m} \sum_{t} \sum_{s} p_{fjmt}f_{jtmt} + \sum_{j} \sum_{m} \sum_{t} \sum_{s} p_{njmt}n_{ijmt}
\]

s.t. (16)-(52)

\[
\sum_{n_{c}^j} y_{n_{c}^j} = 1 \quad (53)
\]
\[
x_{n_{c}^j} \leq upper_{n_{c}^j} \cdot y_{n_{c}^j} \quad \forall n_{c}^j \quad (54)
\]
\[
x_{n_{c}^j} \geq lower_{n_{c}^j} \cdot y_{n_{c}^j} \quad \forall n_{c}^j \quad (55)
\]
\[
\sum_{n_{c}^j} x_{n_{c}^j} = x_{j,c} \quad \forall c,j \quad (56)
\]
\[
y_{n_{c}^j} \in \{0,1\} \quad (57)
\]
\[
x_{n_{c}^j} \geq 0 \quad (58)
\]

Constraint [53] insures that only one interval selected for product j in retailer c. Constraints [54, 55] determine boundaries for every interval. Constraint [56] implies that the amount of product j sent to the retailer c is equal to the summation amount of product j flows to retailer c in all intervals. Constraints [57, 58] are related
to the binary and non-negativity restrictions on the linearization decision variables. Moreover, other constraints are explained as before.

5.2. Multi-objective methodology. For solving the proposed multi-objective model, the compromise programming method is adopted. This method is one of the multi-objective techniques with priori articulation of DMs preference information and is one-stage technique, unlike interactive multi-objective approaches; hence, it will be computationally faster than others.

The aim is to minimize a function that is a measure of closeness of the decision to the ideal vector. A possible measure of closeness to the ideal solution is a family of Lp-metrics. Equation (59) shows the formula where \( Y \) is the number of objectives. Decision makers determine the importance of objective functions. FAHP can be helpful in this matter. For more details about FAHP, you can refer to and .

The new objective function is constructed which is shown in equation (60). Where \( Zy+ \) and \( Zy− \) are the best and the worst solutions \((y = 1, 2, 3)\) of single objective functions subject to models constraint. For the first and second objective function that must be maximized, \( Zy+ \) is the maximum value of objective function and \( Zy− \) is the minimum value of objective function subject to the model constraints. For the third objective function that must be minimized, \( Zy+ \) is the minimum value of objective function and \( Zy− \) is the maximum value of objective function subject to model constraints. Generally, \( p \) is 1 or 2 but, other values of \( p \) also can be used.

\[
l_p = \left[ \sum_{y=1}^{Y} w_y^p \left( \frac{z_{y} - z_{y}^{-}}{z_{y}^{-} - z_{y}^{+}} \right)^p \right]^{1/p}
\]

\[
\min z = \left[ w_1^p \left( \frac{z_1 - z_1^{-}}{z_1^{-} - z_1^{+}} \right)^p + w_2^p \left( \frac{z_2 - z_2^{-}}{z_2^{-} - z_2^{+}} \right)^p + w_3^p \left( \frac{z_3 - z_3^{-}}{z_3^{-} - z_3^{+}} \right)^p \right]^{1/p}
\]  

(59)  

(60)

Finally, the mixed-integer linear programming model with new objective function can be solved.

6. Numerical example. In this section, a numerical example is presented to show the proposed model. Suppose that a computer vendor assembles and sells 3 models of computer. In addition there are 3 market and for each market one retailer. This numerical example is taken of a computer vendor supply chain that its parts can be cleaned and refurbished and used in new manufacturing cycle. This model is the best to show the computer vendor supply chain.

We have 3 potential locations for each facility (manufacturer, distributor, disassembly site, refurbishing site and part inventory). The maximum budget for opening the facilities is 30,000 monetary unit. Defective rate for all products is 10% and useless rate for all parts is 15%. We suppose that Transportation costs between candidate locations in each kilometer have uniform distribution function between 10 and 60 and the pollution amounts in each kilometer have uniform distribution function between 3 and 10 and the operational costs in all facilities have uniform distribution function between 1 and 5 and set up costs in manufacturer and refurbishing site have uniform distribution function between 2 and 3 and the fixed costs for all facilities have uniform distribution function between 1000 and 4000. Maximum capacity of all facilities have uniform distribution function between 1000 and 4000. Part requirement to produce the product have uniform distribution function between 2 and 5.
In the first phase, manager of company forms a decision making group which is composed of 3 decision makers. The members of group determine the importance of categories and criteria, which are obtained by linguistic variables and TFNs. The results are written in table 1 and 2. In the next step, each supplier is assessed according to the criteria in the two performance levels. The process is repeated for other suppliers. Then, the weights of categories are multiplied by weights of criteria and aggregated weights. Therefore, final scores can be calculated. Table 4 shows the results for supplier 1 in two performance levels. The process is repeated for other suppliers. Table 5 shows the score of suppliers in each criterion in two performance levels. The predetermine amount for upgrading supplier 5 is 10000 unit and for other suppliers is 9000 unit.

In the second phase, the CLSC network is examined by using multi-objective MILP. We assumed that the demand have a normal distribution. Its mean and variance affect in the shape of integral of cumulative distribution function that is presented in equation 8. In this paper, GAMS is utilized to solve the model. The decision-making group determines the importance of objective functions as \( w_1 = 0.2, w_2 = 0.5 \), and \( w_3 = 0.3 \). The problem is solved for \( p = 1 \). The results of solving multi-objective functions problem consist of facility locations and flow amount in the network is shown in the figure 4. In this paper, due to the large scale of problem and having a good figure of our solution, a new method is used to display the result. In this method, a schematic model of supply chain network is drawn. The flow of products and parts are expressed by the numbers that written on the filed arcs. Each color is applied to a part or a product. Two types of vehicles are utilized in this supply chain. In the schematic model, the ICE is shown as dash-lines and HM is shown as solid-lines. All potential suppliers have
Table 3. Assessment supplier 1 in two performance levels

| Criteria                   | SUPPLIER 1 IN LEVEL 1 | SUPPLIER 1 IN LEVEL 2 |
|----------------------------|------------------------|-----------------------|
|                            | DM1 DM2 DM3 ASSESSMENT | DM1 DM2 DM3 ASSESSMENT |
| SUPPLIER 1 IN LEVEL 1      |                        | SUPPLIER 1 IN LEVEL 2 |
| Delivery (Lead time)       | VH H MH (7.8,6.6,9.66)  | VH VH H (8.3,3,9.66,10) |
| Defect rate                | MH M ML (3.5,7)         | H MH M (5.7,8,66)     |
| Financial position         | MH M M (3.66,5.66,7.66) | MH MH M (4.33,6.33,8.33) |
| Training                   | H MH H (6.33,8,3,9.66)  | H H VH (7.6,9,3,3,10) |
| Number of personnel        | VH H MH (7.8,6,9.66)    | VH VH H (8.3,3,9.66,10) |
| Number of personnel        | MH M MH (4.33,6.33,8.33) | H MH H (6.3,3,8,9.66) |
| Green packaging            | M MH M (3.66,5.66,7.66) | MH H MH (5.6,6,6,9.33) |
| Process flexibility        | M MH MH (4.33,6.33,8.33) | MH H H (6.3,3,8,9.66) |
| Process safety             | MH H H (6.33,8,3,9.66)  | H VH VH (8.3,3,9.66,10) |

Table 4. Final score for supplier 1 in two performance levels

| Criteria                   | Final score 1 | Final score 2 | a1l1 | a1l2 |
|----------------------------|---------------|---------------|------|------|
| Delivery (Lead time)       | (213,41,473,49,739,95) | (248,462,33,760) | 411.6 | 490.1 |
| Defect rate                | (39,52,160,17,410,72) | (64,8,219,52,496,73) | 203.3 | 260.3 |
| Financial position         | (58,202,78,488,76) | (66,56,222,26,523,56) | 249.8 | 270.3 |
| Training                   | (250,79,552,57,870,63) | (297,92,607,84,892,8) | 557.9 | 599.5 |
| Number of personnel        | (277,34,574,46,870,63) | (325,36,627,45,892,8) | 574.1 | 615.1 |
| Reusable                   | (121,39,328,1,630,8) | (172,36,432,26,729,6) | 360 | 444.7 |
| Green packaging            | (117,64,328,1,630,8) | (183,445,28,771,9) | 358.8 | 466.7 |
| Process flexibility        | (55,72,197,56,479,4) | (81,64,260,28,554,49) | 244.2 | 298.7 |
| Process safety             | (97,52,292,82,605,56) | (128,484,292,82,630,8) | 331.9 | 350.6 |

been selected. Supplier 4 is in the second performance level and other suppliers are in first performance level. Manufacturer 3 sets up to product 1 and manufacturer 1 is sets up to the products 2 and 3.

7. Conclusions and future direction. In this paper, we presented an integrated mathematical model for supplier selection, order allocation, transportation vehicle selection and closed-loop network configuration, by consideration the demand uncertainty. Extra and shortage costs that are important to provide a predetermined service level for customers, considered in this paper. In addition, each supplier have
two performance levels as a novel innovation. Considering two kind of transportation vehicle (normal and green one) between every facility is another innovation in this paper.

In the first phase, fuzzy sets theory is used to overcome the uncertainty in assessment of eligible suppliers. Therefore, the score of suppliers in two performance
levels can be calculated. Then, we designed a nonlinear multi-objective mixed integer model to optimize the supply chain network. In order to solve the model we linearized it via a piecewise linear approximation conversion. A numerical example is performed to analyze and validate the model, also GAMS is utilized to solve the proposed model.

In this paper, we consider the demand uncertain and other parameters supposed certain. In the real world this parameters may be not crisp. Robust optimization is useful to tackle these uncertainties. In addition, this model is written only for one period, consideration of several periods may cause better solution, which needs to consider holding cost and purchasing and selling price in each period.

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Appendix. the profit of the products in retailers’ equation summarization As mentioned in equation \[\text{(7)}\]

\[
\text{Profit of product } j \text{ in retailer } c = s_{jc}(x_{jc} \land D_{jc}) + sv_{jc}(x_{jc} - D_{jc})^+ - sc_{jc}(D_{jc} - x_{jc})^+
\]

That by using the following equations \[\text{(8)}\]

\[
(x \land D) = x - (x - D)^+
\]

\[
(x - D)^+ = \int_0^x F(D) \, dD
\]

\[
(x - D)^+ - (D - x)^+ = x - E(D)
\]

can simplify as:

\[
\text{Profit of product } j \text{ in retailer } c
\]

\[
= s_{jc}(x_{jc} \land D_{jc}) + sv_{jc}(x_{jc} - D_{jc})^+ - sc_{jc}(D_{jc} - x_{jc})^+
\]

\[
= s_{jc}(x_{jc} - (x_{jc} - D_{jc})^+) + sv_{jc}(x_{jc} - D_{jc})^+ - sc_{jc}(D_{jc} - x_{jc})^+
\]

\[
= s_{jc}x_{jc} + (x_{jc} - D_{jc})^+(-s_{jc} + sv_{jc}) + (D_{jc} - x_{jc})^+(-sc_{jc})
\]

\[
= s_{jc}x_{jc} + (x_{jc} - D_{jc})^+(-s_{jc} + sv_{jc}) + ((x_{jc} - D_{jc})^+ - (x_{jc} - E(D_{jc})))(-sc_{jc})
\]

\[
= (s_{jc} + sc_{jc})x_{jc} + (x_{jc} - D_{jc})^+(sv_{jc} - sc_{jc} - sc_{jc}) - E(D_{jc})sc_{jc}
\]

\[
= (s_{jc} + sc_{jc})x_{jc} + (sv_{jc} - sc_{jc} - sc_{jc}) \int_0^{x_{jc}} F(D_{jc}) dD_{jc} - E(D_{jc})sc_{jc}
\]

\[
\text{(65)}
\]

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