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Managing Environmentally Conscious in Designing Closed-loop Supply Chain for the Paper Industry

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ABSTRACT

High amounts of waste paper are disposed of every year in Iran posing the health hazard and environmental damages instead of being recovered. Collection, recovery and proper disposal of waste paper without damaging the environment need to design an efficient closed-loop supply chain network. The main objective of this paper is introducing a bi-objective, multi-echelon, multi-product and single-period logistics network design model in the paper industry while taking into the environmental issues. Alternative recovery options such as recycling with technology selection and energy recovery are considered simultaneously in this model. A life cycle assessment method ISO is utilized for quantifying the environmental impact along the closed-loop supply chain. The model is applied to an illustrative case study of the paper industry in East Azerbaijan of Iran and fuzzy goal programming method is used for solving the proposed bi-objective network optimization model. Also, sensitivity analysis of the proposed model is performed designing different scenarios.

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1. INTRODUCTION

The consumption of paper in Iran is estimated 1/5-2 million tons, 70% of which is imported. The value of imported paper in 2010 totaled 1240469 tons amounting to 1/353 billion dollars. At least 26 million trees would be needed to supply 1/5 million tons of paper [1]. However, a large proportion of waste paper is discarded every year via the non-normative methods which are not friendly to the environment; several recovery alternatives have become crucial for the paper industry of Iran. Furthermore, managing waste paper effectively and balancing the forward and reverse flows are challenging tasks in the paper industry. Thus, designing an ecologically and economically optimized closed-loop supply chain (CLSC) network is crucial for paper manufactures so as to accomplish their sustainable development.

In this paper, we examine alternative recovery options such as recycling with technology selection and energy recovery in paper industry simultaneously to recover the value in the waste paper and coordinate the integrated paper management system. Our model aims to minimize both the total CLSC cost and the total environmental impact along the CLSC. Most of the available papers in the literature which investigate the optimal paper supply chain configuration are only cost or profit oriented. There is a lack in addressing the environmental issues in paper network modeling based on life cycle assessment analysis. For instance, Fleischmann et al. [2] introduced a generic facility location model and analyzed the design of a logistics network for a European paper producer. A mixed integer goal programming model to assist in the proper management of a paper recycling logistics system proposed by Pati et al. [3]. They investigated maximization of the product quality improvement, environmental benefits, and minimization of the reverse logistics costs. Kara and Onut [4] proposed a two-stage stochastic revenue-maximization model to determine a long-term strategy under uncertainty, for a large-scale real-world paper recycling company. Schwiger and

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Sahamie [5] designed a paper recycling network and modeled the problem as a combined continuous and discrete facility location problem and solved it using a hybrid tabu search algorithm. Zhou and Zhou [6] analyzed the characteristics of office paper reverse logistic and formulated a nonlinear integer programming model in order to determine the locations and numbers of recycling stations and plants. Furthermore, only recycling is an option for the recovery of paper in the context of literature, whereas energy recovery can be another alternative. For example, Incineration of waste paper with the production of steam for heating or electric power production is one method of energy recovery.

Since the lack of environmental considerations in paper network modeling, we apply a life cycle assessment method ISO to quantify the environmental impact along the CLSC. It was emphasized that a life cycle assessment method ISO is more advantageous than other methods since it adopts a systematic way to perform the subjective procedure for assigning and scoring of the relative importance to different impact categories. Furthermore, this method yields the assessment of environmental impact related to a product by using a single indicator [7].

The main objective of this paper is introducing a bi-objective, multi-echelon, multi-product and single-period CLSC network design in the paper industry while taking into the environmental issues. Also, Alternative recovery options such as recycling and energy recovery are considered in this model. Furthermore, the proposed model is applied to an illustrative example designed utilizing real data of the paper industry in East Azerbaijan of Iran and fuzzy goal programming (FGP) method is used for solving the proposed bi-objective network optimization model. Finally, sensitivity analysis of the proposed model is performed designing different scenarios. End users of this study can be the managers of the paper industry, the logistics service providers and the government. The reminder of this paper is organized as follows. Section 2 contains a review of related work. In section 3, details of the problem with the model formulation, assumptions and parameters are described. In section 4, a case study from paper industry located in East Azerbaijan of Iran is considered in order to study the validity and practicality of the proposed model. Sensitivity analysis of the key parameters of the model is given considering different scenarios in Section 5. In section 6, conclusion and suggestions for future researches are given respectively.

2. LITERATURE REVIEW

Reverse logistics concerns “the logistics activities all the way from used products no longer required by the user to products again usable in a market” as defined by Fleischmann et al. [8]. Uster et al. [9] emphasized that reverse flow networks which are independent of the forward flows will cause an increase in infrastructure costs and potential profit decrease related to the different recovery. Indeed CLSC research has evolved significantly and many papers have been published in several reviews. A description of the main type of modeling techniques and topics in CLSC research are introduced by Ilgin and Gupta [10]. Du and Evans [11] introduced a bi-objective optimization model which minimizes overall costs and total tardiness for a reverse logistic network for repair services. They used a hybrid solution algorithm containing scatter search, the dual simplex, and the constraint method for solving the problem. Kannan et al. [12] developed a multi-echelon, multi-period, and multi-product CLSC in lead-acid batteries to determine optimum distribution and inventory level decisions through a heuristics-based genetic algorithm. Akcali and Centinkaya [13] evaluated the work done on CLSC and categorized the research on the basis of deterministic and stochastic modeling approaches. Khajavi et al. [14] proposed a bi-objective mixed-integer programming model to minimize the total costs as well as maximize the responsiveness of the CLSC network and applied branch and bound method to find a global optimum for the proposed model. A multi- objective mixed integer linear programming model under uncertainty for configuring CLSC network and selecting supplier was presented by Amin and Zhang [15]. They examined maximization of the profit, weights of suppliers and minimization of the defect rates and used a fuzzy programming for taking into account the effects of uncertainty. Devika et al. [16] developed a mixed integer linear programming model to design a CLSC network to capture the triple bottom line of the sustainability and considered three novel hybrid meta-heuristic methods to solve. Ahmadi Yazdi and Honarvar [17] proposed a new mixed integer linear programming model for designing integrated forward/reverse logistics based on pricing policy in direct and indirect sales channel using scenario-based stochastic approach. Ghomi-Avili et al. [18] developed a model for the CLSC design with disruption risk. The main purpose was to reduce the supply chain costs due to the location decisions, quantity of products between different levels and lost sale. Furthermore, a two-stage stochastic approach was implemented to tackle uncertainty. Also, recent studies have already been conducted new multi-objective algorithms in the literature [19-21].

Dealing with environmental issues in CLSC has been an area of great concern. The literature on green supply chains is diverse and several approaches have been proposed to assess environmental impact. However, life cycle assessment has been introduced as the most reliable method currently available for measuring and studying the environmental impacts of a product, allowing both prospective and retrospective measurement [22]. Some literature exists where authors apply life cycle assessment methodologies (e.g. eco-indicator 99; IMPACT 2002+) to supply chain design [23, 24]. This paper integrates ISO life cycle assessment methodology, which to the best of our knowledge had never been utilized before in supply chain design models, even though it is used in the literature [25, 26] and by the European Commission as one of the best method one currently available.

3. PROBLEM DEVELOPMENT

3. 1. Problem Description and Assumptions

Paper as a key product requires an optimal CLSC network design. The scheme of the paper CLSC network structure is depicted in Figure 1. In the forward supply chain, different types of new paper are transported to the wholesalers to meet the paper dealers' demands. Furthermore, recycled paper is shipped from recycling facilities to the wholesalers to meet the secondary market requirements. In the reverse chain, collection centers collect waste paper from customer zones and supply it to the centralized collection points, where the sorting for waste paper occurs. Based on the sorting process, the appropriate paper is shipped to the recycling facilities or sold for energy recovery while the contaminated paper is transported to the disposal sites. Incineration of waste paper with the production of steam for heating or electric power production is an accepted method of energy recovery. Waste paper can be categorized into eleven easily identifiable types of paper. Of the eleven components, the newspaper has the highest calorific value while the glossy paper has the lowest calorific value. Cardboard and white office papers are appropriate for recycling while colored office paper and oily papers are suitable for incineration. Furthermore, centralized collection points can be considered as a temporary storage area for the waste paper. Appropriate processing technologies need to be installed at each recycling facility location, depending on the type of the input materials and the requirements for the output materials. The proposed mathematical model will be developed based on the following assumptions: There are two different points for wholesalers to supply demands. One is achieving them from different manufacturers, and the other is acquiring them by recycling from the recycling facilities. Cost parameters at all stages of the CLSC network do not vary. Also, inventory and shortages holding are not authorized. Backordering levels and inventory are not considered in the scope of strategic planning since they are generally taken into account in tactical and/or operational levels of CLSC planning. Transportation lead times between the stages are not mentioned because of the single period consideration which is a basic characteristic of strategic planning problems.

3. 2. Indices and Sets

p	index of paper types, $p \in P$
p'	index of recycled paper types, $p' \in P'$
v	index of virgin pulps, $v \in V$
i	index of new paper manufacturers, $i \in I$
w	index of potential regional wholesalers, $w \in W$
k	index of paper dealers / retailers, $k \in K$
j	index of initial collection centers, $j \in J$
l	index of potential centralized collection points, $l \in L$
r	index of potential recycling facilities, $r \in R$
h	index of potential recycling technologies, $h \in H$
b	index of energy recovery centers, $b \in B$
d	index of disposals sites, $d \in D$
m	index of vendors, $m \in M$

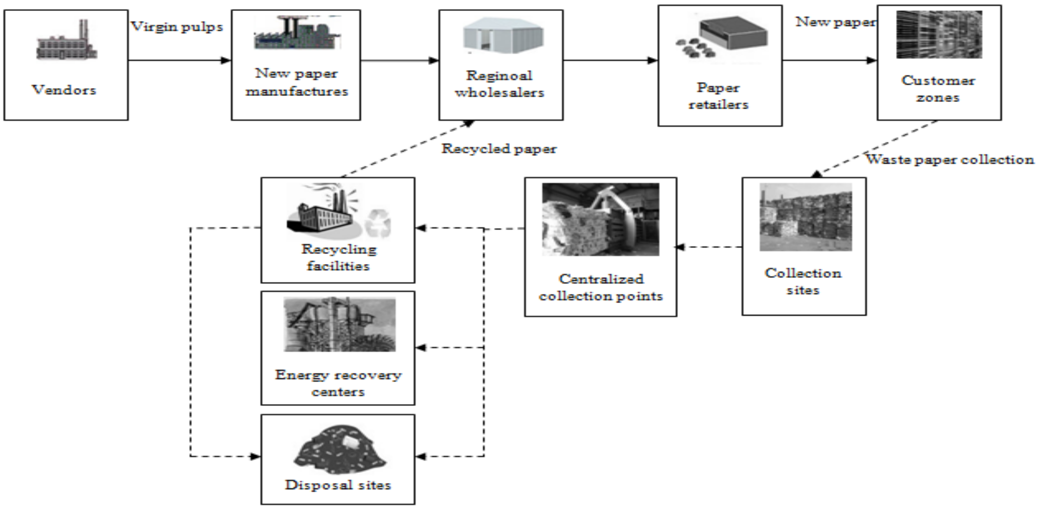

Figure 1. Presentation of the paper CLSC network

3. 3. Model Parameters

f_w	fixed set-up cost of regional wholesaler *w*
f_l	fixed set-up cost of centralized collection point l
f_r	fixed set-up cost of recycling facility *r*
f_{rh}	fixed set-up cost of recycling facility *r* using technology *h*
PRC_p	production cost of paper type *p* in each new paper manufacturer (in terms of monetary unit per kilogram)
TC_p	transportation cost of per kilogram paper type *p* (in terms of monetary unit per kilometer)
PUC_{vmi}	purchasing cost of virgin pulp type *v* from vendor *m* for manufacturer *i* (in terms of monetary unit per kilogram)
RC_{prh}	recycling cost of waste paper type *p* in recycling facility *r* using technology *h* (in terms of monetary unit per kilogram)
CC_{pj}	collection costs of waste paper type *p* through the initial collection center *j* (in terms of monetary unit per kilogram)
SC_{pl}	sorting costs of waste paper type *p* through the centralized collection point *l* (in terms of monetary unit per kilogram)
DIC_p	disposal cost of waste paper type *p* (in terms of monetary unit per kilogram)
DE_{pk}	demand of paper dealer *k* for paper type *p* (in terms of kilogram)
$DE1_{p'k}$	demand of paper dealer *k* for paper type *p'* (in terms of kilogram)
SP_p	sales price of waste paper type *p* to energy recovery center (in terms of monetary unit per kilogram)
RE_{pj}	returned volume of waste paper type *p* to the initial collection center *j* (in terms of kilogram)
a_{lj}	binary parameter which is equal to 1, if the distance between the collection center *j* and the centralized collection point *l* is within the maximum acceptable distance and 0, otherwise
$\varepsilon_p, \theta_p, \tau_p$	fraction of waste paper type *p* shipped from centralized collection point to recycling, energy recovery and disposal sites, respectively noting that $\varepsilon_p + \theta_p + \tau_p = 1$.
σ_p	fraction of waste paper type *p* satisfying the quality specifications for recycling process
Л_{vp}	amount of virgin pulp type *v* to produce paper type *p* (in terms of kilogram)
$Wcapf_w$	capacity of regional wholesaler *w* for forward flows of paper
$Prcap_{pi}$	production capacity of new paper manufacturer *i* for paper type *p*
$Ccapr_l$	capacity of centralized collection point *l* for reverse flow of waste paper
$Recap_{prh}$	recycling capacity of technology *h* at recycling facility *r* for waste paper type *p*
DMAX	maximum allowable distance from a given regional wholesaler to a paper dealer for new paper distribution
DMAX1	maximum allowable distance from a collection center to a centralized collection point for waste paper collection
$Vcap_{vm}$	supply capacity of vendor m for virgin pulp type *v*
$d1_{iw}$	the distance between new paper manufacturer *i* and regional wholesaler *w*
$d2_{wk}$	the distance between regional wholesaler *w* and paper dealer *k*
$d3_{jl}$	the distance between initial collection center *j* and centralized collection point *l*
$d4_{lr}$	the distance between centralized collection point *l* and recycling facility *r*
$d5_{rw}$	the distance between recycling facility *r* and regional wholesaler *w*
$d6_{lb}$	the distance between centralized collection point *l* and energy recovery *b*
$d7_{ld}$	the distance between centralized collection point *l* and disposal site *d*
$d8_{rd}$	the distance between recycling facility *r* and disposal site *d*
EI_v	eco-indicator value of purchasing virgin pulp type *v* from vendors
EIP_{pi}	eco-indicator value of production of paper type p in paper manufacturer *i*
EI_p	eco-indicator value of shipping paper type *p*
$EI1_p$	eco-indicator value of shipping waste paper type *p*
$EI_{p'}$	eco-indicator value of shipping recycled paper type *p'*
EIC_p	eco-indicator value of collecting waste paper type *p* by initial collection centers
EIS_{pl}	eco-indicator value of sorting waste paper type *p* at centralized return point *l*
EIR_{prh}	eco-indicator value of recycling waste paper type *p* at recycling facility *r* with technology *h*
EID_{pd}	eco-indicator value of land filling waste paper type *p* at disposal center *d*
EIE_{pb}	eco-indicator value of incinerating waste paper type *p* in energy recovery center *b*
M	an arbitrary big positive number
N	maximum number of opened centralized collection points

3. 4. Decision Variables

W_w	1, if a regional wholesaler is opened at location *w*; 0, otherwise
L_l	1, if a centralized collection point is opened at location *l*; 0, otherwise
H_{rh}	1, if a technology *h* is activated at recycling location *r*; 0, otherwise
R_r	1, if a recycling facility is opened at location *r*; 0, otherwise
Q_{pi}	production quantity of paper type *p* in paper manufacturer *i* (in terms of kilogram)
$X1_{piwk}$	quantity of paper type *p* shipped to paper dealer *k* from new paper manufacturer *i* via regional wholesaler w (in terms of kilogram)
$X2_{p'rwk}$	quantity of paper type *p'* shipped to paper dealer *k* from recycling facility *r* via regional wholesaler *w* (in terms of kilogram)
$X3_{plb}$	quantity of waste paper type *p* shipped to energy recovery center *b* from centralized collection center

	l (in terms of kilogram)
$X4_{pld}$	quantity of waste paper type p shipped to disposal site d from centralized collection center l (in terms of kilogram)
$X5_{plr}$	quantity of waste paper type p shipped to the recycling facility r from centralized collection center l (in terms of kilogram)
$X6_{prd}$	quantity of waste paper type p shipped to the disposal site d from recycling facility r (in terms of kilogram)
QP_{vmi}	amount of virgin pulp v purchased from vendor m by new paper manufacturer i (in terms of kilogram)
RE_{prh}	recycling quantity of waste paper type p using technology h at recycling facility r (in terms of kilogram)
Y_{wk}	1, if regional wholesaler w serves paper dealer k for meeting its demand in the forward chain; 0, otherwise
$Y1_{jl}$	1, if collection center j is allocated to centralized collection point l; 0, otherwise

3. 5. Objective Functions

As mentioned earlier, two objectives functions are considered in the formulation of the problem which are: (1) minimization of total costs, and (2) minimization of total environmental impacts.

3. 5. 1. First Objective: Minimization of the Total Costs

The first objective function is to minimize the total CLSC costs which is the summation of fixed opening costs (FOC), purchasing costs (PUC), production costs (PC), transportation costs (TC) collection costs (CC), sorting costs (SC), recycling costs (REC), and disposal costs (DC) minus revenue obtained from selling collected waste papers to energy recovery centers. Equation (1) gives the objective function as the sum of its addressed components. Equations (2)-(10) give the details of each component.

$$\begin{aligned} Min\ Z1 = {} & FOC + PUC + PC + TC + CC + SC + REC \\ & + DC - REV \end{aligned} \tag{1}$$

$$FOC = \sum_{w\in W} f_w.W_w + \sum_{l\in L} f_l.L_l + \sum_{r\in R} f_r.R_r + \sum_{r\in R}\sum_{h\in H} f_{rh}.H_{rh} \tag{2}$$

$$PUC = \sum_{v\in V}\sum_{m\in M}\sum_{i\in I} QP_{vmi}.PUC_{vmi} \tag{3}$$

$$PC = \sum_{p\in P}\sum_{i\in I} Q_{pi}.PRC_{pi} \tag{4}$$

$$\begin{aligned} TC = {} & \sum_{p\in P}\sum_{i\in I}\sum_{w\in W}\sum_{k\in K} X1_{piwk}.TC_p.(d1_{iw} + d2_{wk}) + \\ & \sum_{p'\in P'}\sum_{r\in R}\sum_{w\in W}\sum_{k\in K} X2_{p'rwk}TC_p.(d5_{rw} + d2_{wk}) + \\ & \sum_{p\in P}\sum_{l\in L}\sum_{b\in B} X3_{plb}.TC_p.d6_{lb} + \sum_{p\in P}\sum_{l\in L}\sum_{d\in D} X4_{pld}.TC_p.d7_{ld} \\ & + \sum_{p\in P}\sum_{l\in L}\sum_{r\in R} X5_{plr}.TC_p.d4_{lr} + \sum_{p\in P}\sum_{r\in R}\sum_{d\in D} X6_{prd}.TC_p.d8_{rd} \end{aligned} \tag{5}$$

$$CC = \sum_{p\in P}\sum_{j\in J}\sum_{l\in L} Y1_{jl}.RE_{pj}.((TC2_p.d3_{jl}) + CC_{pj}) \tag{6}$$

$$SC = \sum_{p\in P}\sum_{j\in J}\sum_{l\in L} Y1_{jl}.RE_{pj}.SC_{pl} \tag{7}$$

$$REC = \sum_{p\in P}\sum_{r\in R}\sum_{h\in H} RE1_{prh}.RC_{prh} \tag{8}$$

$$DC = \sum_{p\in P}\sum_{l\in L}\sum_{d\in D} X4_{pld}.DIC_P + \sum_{p\in P}\sum_{r\in R}\sum_{d\in D} X6_{prd}.DIC_P \tag{9}$$

$$REV = \sum_{p\in P}\sum_{l\in L}\sum_{b\in B} X3_{plb}.SP_p \tag{10}$$

3. 5. 2. Second Objective: Minimization of the Total Enviromental Impacts

In order to evaluate the potential environmental impacts, life cycle analysis is used for the paper CLSC using the international organization for standardization (ISO) [27-30]. Therefore, the second objective function is to minimize the environmental impacts of the network which is the summation of Eco-indicator score of purchasing (EPU), production (EP), transportation (ET), collection (EC), sorting (ES) and disposal (ED) minus recycling (ERE) and energy recovery (EE) as given by Equations (11)-(19).

$$\begin{aligned} Min\ Z2 = {} & EPU + EP + ET + EC + ES - ERE \\ & - EE + ED \end{aligned} \tag{11}$$

$$EPU = \sum_{v\in V}\sum_{m\in M}\sum_{i\in I} QP_{vmi}.EI_v \tag{12}$$

$$EP = \sum_{p\in P}\sum_{i\in I} Q_{pi}.EIP_{pi} \tag{13}$$

$$\begin{aligned} ET = {} & \sum_{p\in P}\sum_{i\in I}\sum_{w\in W}\sum_{k\in K} X1_{piwk}.(d1_{iw} + d2_{wk}).EI_p + \\ & \sum_{p'\in P'}\sum_{r\in R}\sum_{w\in W}\sum_{k\in K} X2_{p'rwk}.(d5_{rw} + d2_{wk}).EI1_{p'} + \\ & \sum_{p\in P}\sum_{l\in L}\sum_{b\in B} X3_{plb}.d6_{lb}.EI1_p + \sum_{p\in P}\sum_{l\in L}\sum_{d\in D} X4_{pld}.d7_{ld}.EI1_p + \\ & \sum_{p\in P}\sum_{l\in L}\sum_{r\in R} X5_{plr}.d4_{lr}.EI1_p + \sum_{p\in P}\sum_{r\in R}\sum_{d\in D} X6_{prd}.EI1_p.d8_{pd} \end{aligned} \tag{14}$$

$$EC = \sum_{p\in P}\sum_{j\in J}\sum_{l\in L} Y1_{jl}.RE_{pj}.d3_{jl}.EIC_p \tag{15}$$

$$ES = \sum_{p\in P}\sum_{j\in J}\sum_{l\in L} Y1_{jl}.RE_{pj}.EIS_{p} \tag{16}$$

$$ERE = \sum_{p\in P}\sum_{h\in H} RE1_{prh}.EIR_{prh} \tag{17}$$

$$EE = \sum_{p\in P}\sum_{l\in L}\sum_{b\in B} X3_{plb}.EIE_{pb} \tag{18}$$

$$ED = \sum_{p\in P}\sum_{l\in L}\sum_{d\in D} X4_{pld}.EID_{pd} \tag{19}$$

Constraints are given as in Equations (20)-(44).

$$\sum_{k\in K} Y_{wk} \le M.W_{w} \qquad \forall w \tag{20}$$

$$\sum_{w\in W} Y_{wk} = 1 \qquad \forall k \tag{21}$$

$$\sum_{l\in L} L_{l} \le N \tag{22}$$

$$Y1_{jl} \le a_{lj}.L_{l} \qquad \forall j, \forall l \tag{23}$$

$$\sum_{l\in L} Y1_{jl} \ge 1 \qquad \forall j \tag{24}$$

$$\sum_{p\in P}\sum_{p'\in P'}\sum_{k\in K} Y_{wk}.(DE_{pk} + DE1_{p'k}) \le Wcap_{w}.W_{w} \qquad \forall w \tag{25}$$

$$\sum_{i\in I} X1_{piwk} = DE_{pk}.Y_{wk} \qquad \forall p, \forall w, \forall k \tag{26}$$

$$\sum_{r\in R} X2_{p'rwk} = DE1_{p'k}.Y_{wk} \qquad \forall p', \forall w, \forall k \tag{27}$$

$$\sum_{w\in W}\sum_{k\in K} X1_{piwk} \le Q_{pi} \qquad \forall p, \forall i \tag{28}$$

$$Q_{pi} \le Prcap_{pi} \qquad \forall p, \forall i \tag{29}$$

$$d2_{wk}.Y_{wk} \le DMAX \qquad \forall w, \forall \mathrm{k} \tag{30}$$

$$d3_{jl}.Y1_{jl} \le DMAX1 \qquad \forall j, \forall l \tag{31}$$

$$\sum_{j\in J} RE_{pj}.Y1_{jl} \le Ccapr_{l}.L_{l} \qquad \forall p, \forall l \tag{32}$$

$$\sum_{b\in B} X3_{plb} = \varepsilon_{p}.\sum_{j\in J} RE_{pj}.Y1_{jl} \qquad \forall p, \forall l \tag{33}$$

$$\sum_{d\in D} X4_{pld} = \theta_{p}.\sum_{j\in J} RE_{pj}.Y1_{jl} \qquad \forall p, \forall l \tag{34}$$

$$\sum_{r\in R} X5_{plr} = \tau_{p}.\sum_{j\in J} RE_{pj}.Y1_{jl} \qquad \forall p, \forall l \tag{35}$$

$$\sum_{h\in H} RE_{prh} = \sigma_{p}.\sum_{l\in L} X5_{plr} \qquad \forall p, \forall r \tag{36}$$

$$RE_{prh} \le H_{rh}.Recap_{prh} \qquad \forall p, \forall r, \forall h \tag{37}$$

$$\sum_{w\in W}\sum_{k\in K} X2_{p'rwk} \le \sum_{h\in H} RE_{prh} \qquad \forall p', \forall p, \forall \mathrm{r} \tag{38}$$

$$\sum_{d\in D} X6_{prd} = (1-\sigma_{p}).\sum_{l\in L} X5_{plr} \qquad \forall p, \forall r \tag{39}$$

$$\sum_{h\in H} H_{rh} = R_{r} \qquad \forall r \tag{40}$$

$$\sum_{i\in I} QP_{vmi} \le Vcap_{vm} \qquad \forall v, \forall m \tag{41}$$

$$\sum_{m\in M} QP_{vmi} = \sum_{p\in P} Q_{pi}.\pi_{vp} \qquad \forall v, \forall \mathrm{i} \tag{42}$$

$$W_{w}, L_{l}, R_{r}, H_{rh}, Y_{wk}, Y1_{jl} \in (0,1) \tag{43}$$

$$\text{All other varibles are continuous} \ge 0 \tag{44}$$

According to constraint (20), if a regional wholesaler is opened, it may serve to any dealer or retailer. In other words, there may be an outgoing flow (distribution operation) from this wholesaler to the dealers. Constraint (21) ensures that a paper dealer is assigned to a single regional wholesaler for forward flow of newly produced paper. In other words, demands of the paper dealers must be satisfied by a single regional wholesaler. Constraint (22) gives an upper bound for the number of centralized collection points to be opened. Constraint (23) determines which paper returns are covered within the acceptable service distance. Service means the collection of waste papers from the initial collection centers. Constraint (24) guarantees that a paper collection center may be assigned to at least a single centralized collection point for waste paper returns. Constraint (25) limits the amount of newly produced and recycled paper shipped through the regional wholesaler to its capacity of performing forward flows. Constraints (26) and (27) ensure that the demands of paper dealers for newly produced and recycled paper to be satisfied. Constraint (28) guarantees that the outgoing flows from a new paper manufacturer cannot exceed the production quantity at that manufacturer. Constraint (29) ensures that the production quantity of each paper type not to exceed the production capacity of the new paper manufacturers. Constraint (30) guarantees that each regional wholesaler to be located within acceptable proximity of paper dealers. Constraint (31) makes sure that each collection center to be located within acceptable proximity of centralized collection point. Capacities of centralized collection center are restricted by Constraint (32). Constraints (33) to (35) ensure that the sum of the waste paper taken from a centralized collection point for energy recovery centers, disposal sites and recycling facilities do not exceed the amount of waste paper available at the centralized collection center. Constraint (36) represents that the input rate of waste paper is satisfied by the quality specifications for recycling process. According to constraint (37), the recycling quantity of each paper type not to be over the recycling capacity of the different technologies of recycling center. Constraint (38) guarantees that the outgoing flows from a recycling center cannot exceed the recycling quantity at each recycling center. Constraint (39) represents the flow of non-recyclable waste paper from recycling facilities to disposal centers. Constraint (40) guarantees that each opened facility location has exactly one technology in use at each time. Constraint (41) gives the capacity constraint for vendors. Constraint (42) gives the authorized share of virgin pulp in order to satisfy quality conditions for paper types. Constraint (43) represents the binary variables such as opening decisions for the facilities (regional wholesalers, centralized collection points and recycling facilities) and activating decisions for the technologies at recycling facilities; assignment decisions for allocating paper dealers to the regional wholesalers and collection centers to the centralized collection points. Constraint (44) ensures the non-negativity of other variables.

4. MODEL IMPLEMENTATION

In order to observe the performance of the proposed model, a case study whose data originated from the paper industry in East Azerbaijan of Iran is studied. The CLSC network involves two paper plants, three vendors to supply virgin pulps, four potential regional wholesalers, twenty paper dealers, five initial collection centers, four potential sites for centralized return points, two potential sites for paper recycling facilities, two potential recycling technologies, one energy recovery center and six sites for disposal. Four types of papers including glossy, printing and writing, kraft, and fluting, together with four types of virgin pulps and two types of recycled papers are considered. The values of parameters can be provided upon request. We have solved the problem using the CPLEX solver of GAMS commercial software version 24.1.3. Table 1 illustrates the results for solving each objective separately. In this way, nadir and optimal solutions to form fuzzy membership functions are obtained separately [31].

The solution of FGP on case study yields the total cost of 8.41 E9 and the total environmental score of 4.85 E10. It is assumed that the DM is satisfied at the end of iteration 3 with α_1=0.865 and α_2=0.772. With this solution, three of the regional wholesalers, two of the centralized collection points and one of the paper recycling facilities with one type of technologies is opened.

5. SENSITIVITY ANALYSIS

In order to analyze the sensitivity of decision parameters regarding collection-recovery system to variation of each fuzzy goal, the proposed fuzzy bi-objective problem is resolved with different scenarios. In scenarios 1-3, the variations of each fuzzy goal are analyzed by changing recycling capacity of different technologies at recycling facilities.

Evaluating the sensitivity by changing selling price of waste paper to energy recovery center is performed in scenarios 4-6. In scenarios 7-9, rates of the disposition of waste paper are examined. Sensitivity analysis is applied to scenarios using the data given in Table 2.

Different upper and lower bounds are obtained for each scenario while considering each scenario. For this reason, boundary values of the fuzzy goals vary and membership functions should be revised for each scenario. Results of scenario analysis for simultaneous consideration of fuzzy objectives after two iterations are given by Figure 2.

TABLE 1. Results from solving each single objective model

Goals	Total costs	Total environmental scores
Total number of variables	1380	1380
Total number of constraints	843	843
Total number of iterations	130	147
Solving time (second)	0.124	0.187
Total costs	7.35E9 Rial (optimal)	9.81E9Rial (nadir)
Total environmental scores	5.95E10 milli-point (nadir)	3.97E10 milli-point (optimal)
Number of opened paper recycling facilities	1	1
Number of opened regional wholesalers	3	4
Number of opened centralized return points	2	3
Number of activated technologies	1	1

TABLE 2. Application data of different scenarios

Scenario	Item Recap$_{prh}$ (%)	Scenario	Item SP$_p$ (%)	Scenario	Item τ_p (%)
Scenario 1	-25	Scenario 4	-50	Scenario 7	20
Scenario 2	+25	Scenario 5	+20	Scenario 8	40
Scenario 3	+50	Scenario 6	+50	Scenario 9	60

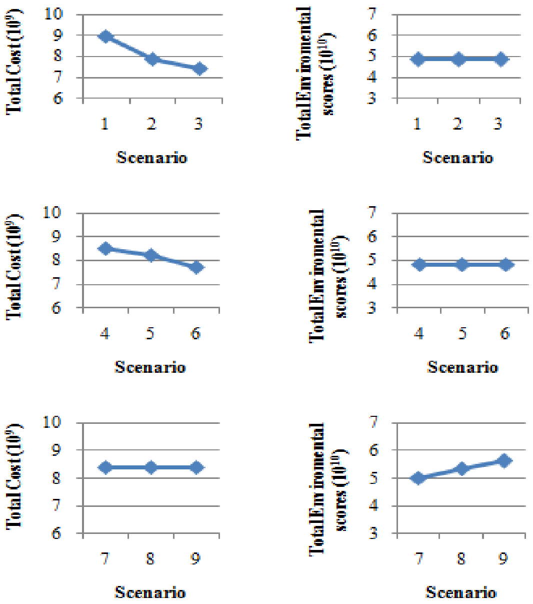

Figure 2. Evaluating scenarios considering two fuzzy goals simultaneously

In scenarios 1-3, different recycling capacities of technologies are taken into account. It is clearly understood from Figure 2 that higher recycling capacities provide lower costs and equal environmental scores considering two fuzzy goals simultaneously. In scenarios 4-6, the effects of the increasing selling price of waste paper to energy recovery center are examined. According to Figure 2, when the selling price of waste paper increases, the total costs will decrease. Moreover, total environmental scores will not improve due to increasing the selling price of waste paper. Scenarios 7-9 show that the rate of disposition has an important impact on the total environmental scores. According to Figure 2, when the rate of disposition increases, the total environmental scores increase. On the other hand, increasing the rate of disposition to a specified level does not significantly affect the total cost as can be seen in Figure 2.

6. CONCLUSION AND FUTURE RESEARCH

In this paper, a bi-objective, multi-product, multi-echelon and single-period environmentally logistics network design model is developed for a paper CLSC chain while taking account of alternative recovery options such as recycling and energy recovery simultaneously. The model is applied to an illustrative case study of the paper industry in East Azerbaijan of Iran and FGP method is used for solving the proposed bi-objective network optimization model.

From the case study, we can conclude that the proposed model improves two objectives of proposed model and offers important managerial insights. DMs should increase the recycling capacities of technologies and selling price of waste paper to energy recovery center in order to decrease cost. They may decrease the rate of disposition in order to decrease environmental scores.

The total assessment of total environmental issues is challenging tasks in deterministic environments. Furthermore, some information may be unobtainable or incomplete for the environmental impact parameters. Thus, these parameters should also be proposed as fuzzy in future researches. Besides these environmental parameters, uncertainties related to the demand of new and recycled papers, return quantities of waste papers, return rates and capacities of facilities may be overcome by employing fuzzy mathematical programming approaches in the future studies.

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Managing Environmentally Conscious in Designing Closed-loop Supply Chain for the Paper Industry

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چکیده

هر ساله میزان زیادی کاغذ باطله در ایران به جای بازیافت دفع می شوند که به سلامتی انسان و محیط زیست آسیب می رسانند. جمع آوری، بهبود و دفع صحیح کاغذهای باطله بدون آسیب به محیط زیست نیازمند طراحی شبکه زنجیره تامین حلقه بسته موثر می باشد. هدف این مقاله ارائه مدل طراحی شبکه لجستیک دو هدفه، چندسطحی، چندمحصولی و تک پریودی برای صنعت کاغذ با در نظر گرفتن مسائل محیطی است. گزینه های استفاده مجدد از کاغذهای باطله نظیر بازیافت با انتخاب تکنولوژِی و بهبود انرژی به طور همزمان در این مدل در نظر گرفته شده اند. روش ارزیابی چرخه زندگی ایزو برای کمی کردن اثرات محیطی در زنجیره تامین حلقه بسته به کار رفته است. مدل مفروض در صنعت کاغذ استان آذربایجان شرقی ایران مورد بررسی قرار گرفته و از روش برنامه ریزی آرمانی فازی برای حل آن استفاده شده است. همچنین، تحلیل حساسیت مدل مفروض با در نظر گرفتن سناریوهای محتلف انجام شده است.

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