Sustainable Closed-Loop Supply Chain Network Design with Joint Economic Lot Sizing Problem

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Abstract: In the fashion of sustainable development and a friendly environment, the traditional supply chain, specifically network design, is no longer sufficient for sustainability needs. With the increasing demand for them and toward a holistic model in a sustainable closed-loop supply chain (SCLSC),we proposed the network design and joint economic lot-sizing problems (JELS). The new problem is modeled as a mixed-integer multi-objective problem, considering the three factors of sustainability: maximizing total profit, minimizing the total amount of CO_2emissions, and maximizing social job opportunities. In orderto achieve optimal decisions of facility location, amount flow, cycle time, and the number of shipments delivered in each inventory. The experiment analysis usedfiveperformanceindicatorscomparedtothenon-dominatedsortinggenetic algorithm-II. Finally, the results show that the proposed model of SCLSC network design with JELS is reaching a more accurate and better decision in all three aspects of sustainability.
Keywords: Sustainable Supply Chain Management; Supply Chain Network Design; Closed-Loop Supply Chain; Joint Economic Lot Sizing; Lot Sizing; Sustainable Closed-loop Supply Chain.

1 Introduction

One of the most complex strategic decision problems in any supply chain is its network designproblem[1].Thiscomplexityisbecause,inthisproblem,weshoulddeterminethe optimal long-term planning for the whole supply chain by giving the number, capacity, location, type, and more configuration parameters for each facility. These decisions, in return,willaffecttheprofit,operationcost,riskresistance,andotherproductsofthesupply chain. Furthermore, the dramatic increase in the number of industries and globalization consuming our planet's limited resources lead to increased environmental pollution and social problems. These problems make the countries concerned about those problems worldwide [2, 3, 4]. And because of its continuous influences, the enterprises have been forcedtoconsiderthemtogetherwitheconomicperformance,whichleadstoadaptingtheir operation mode from traditional supply chain network (SCND) to green or sustainable supply chain network design (GSCND or SSCND).

The sustainable development definition is "to meet the current requirements without compressingtheabilityoffuturegenerationstomeettheirownneeds"[1].Thisdefinition interpretsthetriplebottomlineconceptforsustainabilitywhichconsistsofpeople–which represents the social issues (Soc.), planet - which means the environmental issues (Env.), and profit - which represents the economic issues (Eco.) [5]. Moreover, [6, 7] illustrated that there is still a gap in the area of supply chain network design (SCND).

Mainly,theclosed-loopsupplychain(CLSC)networkdesignproblemsconsistoftwo parts;thesepartsaresolvedsimultaneously,forwardlogistics(FL)andreverselogistics

(RL) for every echelon in the network. In FL, the flow of materials and information movesfromsuppliers,manufacturers,distributioncenters,andretailersuntilreachingfinal customers. However, in RL, the flow of materials (mainly the returned materials) and information move from customers returned to collection and recovery centers or disposal centers [8]. One of the significant trends in CLSC design problems is sustainable CLSC design problems [9]. They are concerned with solving economic, environmental, and social factors to simultaneously construct a more effective long-term network plan for both FL and RL.

To seek global optimization for network design problems considering, one of the factors that affect the SCND as same as SSCND is inventory decisions [10]. Their costs andreplenishmentdecisionsdirectlyaffecttheeconomicpartbyaddinginventorycostsas well as the environmental part by transportation emissions and the social part by creating anemployeejobopportunity.Inthepreviousresearch,lot-sizemodelsareconcernedwith coordinationbetweenbuyerandvendorininventoryreplenishmentdecisions,calledjoint economic lot size (JELS) models. These models minimize the total cost by determining inventory decisions like order, production, and shipment quantities.

SincemostSCND,SSCND,CLSCdesigns,andJELSproblemsareclassifiedas NP-hard problems [11], achieving the expected performance is quite challenging. Many techniques are used to solve these problems, like stochastic programming, heuristic techniques,fuzzy-basedapproaches,Bayesiannetwork,etc.[12].Ideally,thebeststrategy to achieve a sustainable supply chain is to construct it as a closed loop. This construction causesamorefriendlyenvironment(reducingwasteandgasemissions)withmoreefficient economicfactors[13,14,12].Accordingly,thissectionprovidestheliteraturebackground in two areas: sustainable CLSC network design and closed-loop JELS.

Firstly, in the SCLSC network design problem, much recent research dealt with only one sustainable factor. In contrast, a few works have considered the mixed objectives [6, 15, 16], whichwewillfocusonthistopichere.Wecancategorizethemassustainabilityconcerns (Eco.,Env.,Soc.),JELS’sdecision,andfacilitylocation’sdecision(LD),asshowninTable 1.

[17]studiedthedesignofsustainableCLSCbysolvingasingleobjectivetominimize thetotalsupplychaincostsandthetotalCO_2emissionstofindthebestamountsofproducts based on the network. They solved their model by simulation method. Furthermore, they did not consider the location decisions in their model. In contrast, [18] considered the location decisions for facilities were to establish it or not, in addition to the inventory decisionaboutthebestordersize,astheproductamountflowintheirCLSC.Theirmodel alsoasingleobjectiveminimizationfortotalcostandgasemission,butthegaswascarbon footprint in this research. Therefore, they solve the problem using AMPL for CPLEX. Later, some researchers studied the models for network design CLSC to determine the product flow and facility locations

with the same idea as the previously reviewed models with a single-objective minimization of total cost and total emission. However, those researchers solved them as a bi-objective model using Fuzzy Programming like [19] and [20].

SomeotherstudiesworkontheCLSCnetworkdesignforeconomicandsocialfactors onlylikein[22]'spaper.Theydeterminedproductflow,facilitylocation,operationssystem,

Table1 Literatureworkclassification

Citation	Eco.	Env.	Soc.	JELS	LD
[17]	•	•			
[18]	•	•			•
[6]	•	•	•		•
[19]	•	•			•
[16]	•	•	•		•
[20]	•	•			•
[15]	•	•	•		
[21]	•	•	•		•
[22]	•		•		•
[9]	•	•	•		•
Ourwork	•	•	•	•	•

and transportation between facilities to minimize the total cost and maximize customersatisfaction. The model was solved by two heuristic algorithms NSGA-II and MOSA.

Furthermore, much research investigated the three sustainability factors in CLSC network design. [15] studied the three sustainable objectives minimizing the total cost, minimizing environmental factors, and maximizing the social aspects to find the best productsflow.Themodelissolvedbynetworkoptimization.Additionally,[9]introduced and solved the model of the three factors of sustainability: minimizing the total cost, minimizingtheCO_2emissions,andmaximizingthesocialfactors.Toindicatethelocation, amountofproductionflow,andtechnologyuseddecisionswiththreedifferentdistribution types: regular delivery, direct shipment, and direct delivery. They solved their model by proposing a Hybrid Genetic Algorithm (pro-HGA) and comparing it with the Genetic AlgorithmandHybridGeneticAlgorithm(HGA)proposedby[23]and[24]basedonthe Genetic Algorithm (GA) and the Tabu Search (TS).

On another hand, the area of solving the JELS problem in CLSC is considered one of thehottopics[25,26,27].ManyresearchersdealtwiththeCLSCfortheone-two-and-three echelon with different production sequences. According to [26] and specifically in the classification of the relevant literature table, about 75% of their citations were done for less than four echelons, while about 21% of work was done for the four echelons (eleven citationsforthesingleechelonfrom1967until2020,twelvecitationsforthetwoechelons from 2009 until 2019, and two citations for the three echelons, seven citations for thefour echelon, and one citation for the five echelons). Thus, we focus on the four echelons CLSC introduced by [28]. Their model studied the integrated concerns of the supplier, manufacturer,retailer,andthirdpartyrecycledealerforbothcentralizedanddecentralized decisions. The model considers (1,1) policy that is one manufacturing cycle and one remanufacturingcycle.Hence,[29]extendedtheworkdoneonthisstudybystudying(M, 1) and (1, P) policies. Where [30] studied the (M, R) policy under deterioration, [31] did thesamebutunderimperfectmanufacturingassumptionthatgeneratedfromthequalityof thereturneditemsandcompareditwith(1,1)policy.Incontrast,[26]dealtwithsustainable industriesingeneralandstudiedtheindustryparticularlybyaddingrecycledproducts.Itsmodelconsi deredfiveechelonCLSCandsimultaneousproductionsequences.

In this paper, toward generating a holistic model for SCLSC to solve network design and JELS simultaneously, we proposed an integrated model from [9] for network design SCLSC with [28] model for JELS in CLSC. First, the conceptual model and problem description are introduced; the model assumptions, notations, and the mathematical model are described inSection2.Furthermore,Section3illustratestheexperiment.Then,wepresenttheresults and the discussion in Section 4.Finally, the conclusion and future work are discussed in Section 5.

2 ProblemDescriptionandMathematicalModel

The proposed SCLSC network-inventory problem is shown in Figure 1. It is based onthe model described by [28]. The raw material flows from the suppliers – specifically the materialinventory–tothemanufacturerandthefinalproductsstoredinthemanufacturer's finishedgoodinventory.Thentransferredtotheretailerinventorytobesoldtocustomers. Somereturnstothethird-party/collectionstoresincollectorinventoryandtransferred to the manufacturer to recycle them. Those are stored in the manufacturer used product inventory to reproduce again and so on.

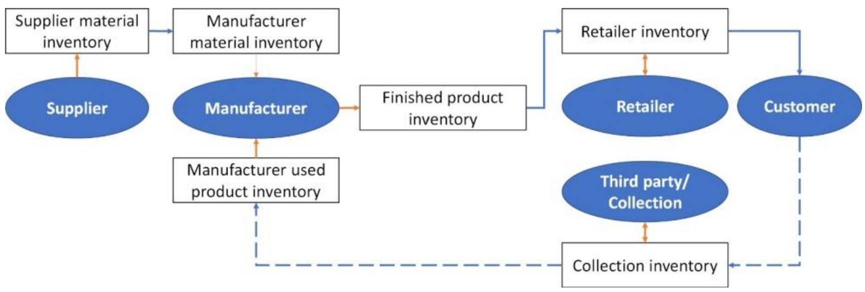

Figure1 Supply Chain Network

By considering the described network, what is the best facility locations for every facility in our network (suppliers, manufacturer, retailer, and third party)? And, what is the best technology to be used at the chosen manufacturer? Furthermore, what is the best time for the retailer ordering cycle? Finally, what is the best number of delivers per each facility cycletimeinbothforwardandbackwardflows?Thosequestionsshapethemainproblem of this paper.

2.1 Assumptionsandnotations

Themathematicalmodelsinthisanalysishavethefollowingassumptions:

- Aninfiniteplanninghorizon.
- Nodeterioration.
- Nostockshortages.
- Themulti-echeloninventorysystemcontainsasingleitem.
- Nospace,capacity,orcapitalconstraints.
- Noquantitydiscounts.
- Themanufacturingandremanufacturingratesandleadtimesareconstant.
- The product’s annual demand rate and the annual return rate are constant, and the annual return rate is less than the annual demand rate.
- Thenumberofdeliverieswithinthemanufacturingcycleisaninteger.
- Thesetupcostperrunandtheannualholdingcostfractionareknownandconstant.
- To meet the retailer demand, remanufactured products are available before the manufactured products.
- Theremanufacturedproductsarecomparabletonewlymanufacturedproducts.
- Singlesuppliers,singlemanufacturers,singleretailers,andsinglethirdpartiesinthe closed-loop supply chain.
- Themulti-echeloninventorysystemisconsidered.
- The unit transportation costsamongthe manufacturer, the DC, theretailer, the customer, the collection center, the recovery center, and the disposal center are different from each other in value and known beforehand.
- The unit amount of CO_2emitted during transportation at each stage, and those emittedduringmanufactureandrecoveryatthemanufacturerandtherecoverycenter, respectively, are different from each other in value and known beforehand.
- TheproposedSCLSCdesignproblemisinasteady-statesituation.
- Thevehiclecapacityisconstantforallechelonsandknownbeforehand.
- Themodelannotationsarerepresentedbytheindexsets,theechelonparameters, general parameters (parameters appeared in all echelons), and the decision variables.

Sets:

s	setofsuppliers:$s \in \{1,2,...,S\}$
m	setofmanufacturers:$m \in \{1,2, ,M\}$
c	setofcustomers:$c \in \{1,2,...,U\}$
d	setofthirdparties:$d \in \{1,2,..,\partial\}$
r	setofpotentialretailers:$r \in \{1,2,.,R\}$

Supplier'sParameters:

F_{so} Fixedcosttosupplierperorder

H_s Materialinventoryholdingcosttosupplier,inpercentageper year per dollar

P_s Supplierpurchaseunitprice

F_s Fixed supplier cost to process manufacturer orders of any size

TP_s Totalsupplierprofitperunittime

d_{sm} Distancefromthesupplierstomanufacturerm,where$s$ $\{1,2,...S\}$and$m$ $\{1,2,...M\}$

θ_{sm} Thecostofshippingoneunitfromsupplierstomanufacturer m,where$s$ $\{1,2,...S\}$and$m$ $\{1,2,...M\}$

e_s Thefixedcontractcostforsuppliers,where$s$ $\{1,2,... S\}$

GeneralParameters:

vc Thecapacitythatcanbeshippedinavehicle

d_{cd} Distancefromcustomerctothirdpartyd,where$d$ $\{1,2,...\partial\}$ and$c$ $\{1,2,...U\}$

θ_{cd} Thecostofshippingoneunitfromcustomerctothirdpartyd,where d $\{1,2,...\partial\}$and$c$ $\{1,2,...U\}$

ParametersRetailers:

D Demandannualrate

O_r Ordercosttotheretailer

H_r Inventoryholdingcosttoretailerinannualpercentageperdollar

P_c Retailprice

P_r Wholesaleprice

TP_r Totalretailerprofitperunittime

d_{rc} Distancefromretailer$r$tocustomer$c$,where$r$ $\{1,2,...R\}$ and$c$ $\{1,2,...U\}$

θ_{rc} Thecostofshippingoneunitfromretailer$r$tocustomer$c$, where r $\{1,2,...R\}$and$c$ $\{1,2,...U\}$

e_r Thefixedcontractcostforretailer$r$,where$r$ $\{1,2,...R\}$

Manufacturer'sParameters:

A_M Setupcostpermanufacturingrun

A_R Setupcostperremanufacturingrun

O_{Mw} Orderingcostforthemanufacturermaterialwarehouse

O_{Rw} Orderingcostforthemanufacturerusedproductwarehouse

H_M FinishedProductinventoryholdingcostpercentageperyearperdollar to the manufacturer

H_{Mw} Rawmaterialinventoryholdingcostpercentageperyearperdollarfor the manufacturer warehouse

H_{Rw} Usedproductinventoryholdingcostpercentageperyearperdollarfor the manufacturer warehouse

P_M Manufacturerunitpurchasepricefromthesupplier

P_R Manufacturerunitpurchasepricefromthethirdparty

T_{R1} Manufacturer reproduction period in each remanufacturing cycle T_{R2}

Manufacturernon-productionperiodineachremanufacturingcycle T_{M1}

Manufacturer production period in each manufacturing cycle

T_{M2} Manufacturernon-productionperiodineachmanufacturingcycle

F_m Fixedcosttothemanufacturerforprocessingbuyerordersofanysize

P Annualmanufacturerproductionrate(P>D)

B Annualmanufacturerreproductionrate(β>D)

I Number of deliveries per remanufacturing/manufacturing cycle time from the manufacturer to the retailer, $I = k_M + k_R$, where I is a positive integer

TP_m Totalmanufacturerprofitperunittime

wc Wightallocatedtothecreatedjobopportunity

wl Wightallocatedtothenumberoflostdaysduetodamagetowork

wu Wightallocatedtounemployment

se_m Number of job opportunities created due to the use of technology t at manufacturer m

sl_m Numberoflostdaysduetodamageofworkcausedbytheuseof technology t at manufacturer m

CO_2V AmountofCO2emitted fromavehicleper km

CO_2M UnitamountofCO2emittedduringtheproductionprocessat manufacturer m

CO_2R UnitamountofCO2emittedduringreproductionprocessat manufacturer m

d_{mr} Distance from manufacturer m to retailer r, where r {1,2,...R}and$m$ {1,2, ...M}

θ_{mr} Thecostofshippingoneunitfrommanufacturer$m$toretailer$r$,where r{1,2,...R}and$m${1,2,...M}

e_m Fixedlocationcostformanufacturer$m$,where$m${1,2, M}

Thirdparty'sParameters:

C Annualreturnrate

A_d Setupcostperrunforthethirdparty

H_d Usedproductinventoryholdingcostpercentageperyearperdollar to the third party

P_d Third-partycollectingunitcostfromtheconsumer

F_d Fixedthirdpartycosttoprocessmanufacturerordersofanysize

TP_d Totalthird-partyprofitperunittime

d_{dm} Distancefromthirdpartydtomanufacturer$m$,where$d$ $\{1,2,...\partial\}$and$m$ $\{1,2,...M\}$

θ_{dm} Thecostofshippingoneunitfromthirdpartydtomanufacturer$m$, where$d$ $\{1,2,...\partial\}$and$m$ $\{1,2,...M\}$

e_d Thefixedcontractcostforthirdparty$d$,where$d$ $\{1,2,...\partial\}$

ObjectiveNotations:

F_{eco} Jointprofitperunittimeforthewholesystemrepresentsthe economic objective

F_{soc} Socialobjectives

F_{env}Environmentalobjectives TTCTotaltransportationcosts TFCTotalfixedlocationcosts

TCPThe total amount of CO_2emitted during the production and reproduction process

TCTThetotalamountofCO_2emittedduringthetransportation process

DecisionVariables:

T_r Retailerorderingcycletime

k_M Numberofdeliveriespermanufacturingcycletimefromthe manufacturer to the retailer

k_R Numberofdeliveriesperremanufacturingcycletimefromthe manufacturer to the retailer

k_s NumberofdeliveriesperT_{M1}fromthesuppliertothe manufacturer

k_d NumberofdeliveriesperT_{R1}fromthethirdpartytothemanufacturer

x_m Themanufacturerisopenedtakevalue1ifnottakezero$m$ $\{1,2,3,...M\}$

x_r Theretailerischosentotakevalue1ifnottakevaluezero$r$ $\{1,2,3,...R\}$

x_s Ifthesupplierischosentakevalue1,zerootherwise$s$ $\{1,2,3,...S\}$

x_d Ifthethirdpartyischosentakevalue1,zerootherwise$d$ $\{1,2,3,...\partial\}$

t_m Takesthevalue1iftechnologytisusedatmanufacturer$m$and0 otherwise

2.2 *Model-1:SustainableCLSCnetworkdesignandjointeconomiclotsizing*

Totalretailerprofit(Eq.1)iscalculatedas;retailprice*ademand-(totalretailercost);the total retailer cost is calculated as; fixed cost + holding cost * wholesale price * inventory level + wholesale price * demand. Thus;

$$TP_r(T_r) = P_c D - \left[\frac{O_r}{T_r} + \frac{H_r P_r D T_r}{2} + P_r D\right] \quad (1)$$

Total manufacturer profit (Eq.2) consists of the wholesale price minus the total costs of the manufacturer, used product warehouse, and material warehouse. Total costs of return/used product consist of ordering cost for used products + holding cost for used productsinventory*manufacturerunitpurchasefromthethirdparty*numberorproducts in inventory + purchasing cost = (manufacturer unit purchase from the third party * demand). Where the total costs of material/raw material inventory consist of ordering cost for material warehouse+holdingcost=(materialinventoryholdingcost*manufacturerunitpurchase pricefromsupplier*quantity)+purchasingcost=(numberofdeliveriespermanufacturing cycle time from manufacturer to retailer * purchase price * Demand); thus;

$$TP_m(k_s, k_d, k_R, k_M, T_r) = P_r D - \frac{A_R + A_M + (k_R + k_s)F_m + k_d O_{Rw} + k_s O_{Mw}}{(k_R + k_s)T_r} - \frac{H_M(k_R P_R + k_M P_M)}{k_R + k_m} * \left[\frac{T_r D(2D + k_R \beta - k_R D)k_R}{2\beta(k_R + k_M)} + \frac{T_r D(2D + k_M P - k_M D)k_M}{2P(k_R + k_M)} - \frac{T_r D}{2}\right] - \frac{H_{Rw} P_R D^2 k_R^2 T_r}{2k_d(k_R + k_M)\beta} - \frac{H_{Mw} P_M D^2 k_M^2 T_r}{2k_s(k_R + k_M)P} - \frac{(k_R P_R + k_M P_M)D}{k_R + k_M} \quad (2)$$

The total third-party profit (Eq.3) shown below is calculated as manufacturer unit purchase price from third-party minus (setup cost plus fixed cost-plus holding cost plus collecting cost).

$$TP_d(k_d, k_R, k_M, T_r) = \frac{(P_R - P_d)Dk_R}{k_R + k_M} - \frac{A_d + k_d F_d}{(k_R + k_M)T_r} - \frac{H_d P_d T_r\left[\left(D^2 k_R^2 - 2Ck_R D(k_R + k_M)\right)(k_d - 1) + C\beta k_d (k_R + k_M)^2\right]}{2(k_R + k_M)\beta k_d} \quad (1)$$

Totalsupplierprofit(Eq.4)iscalculatedasthemanufacturerunitpurchasepricefrom the supplier (The fixed cost to supplier per order plus the number of deliveries multiplied by the fixed supplier cost of any order size) plus holding cost-plus purchase price.

$$TP_s(k_s, k_R, k_M, T_r) = \frac{(P_M - P_s)Dk_M}{k_R + k_M} + \frac{F_{so} + k_s F_s}{(k_R + k_M)T_r} + \frac{H_s P_s D^2 k_M^2 T_r}{2P(k_R + k_M)}\left(1 - \frac{1}{k_s}\right) \quad (2)$$

The total amount of CO_2emitted during production and recovery processes (Eq.5) is equaltothecapacityoftheselectedmanufacturermmultipliedbytheunitamountofCO_2emitted during the production process at the manufacturer.

$$TCP(x_m) = \sum_m^M [Px_m CO2_M + \beta x_m CO2_R] \quad (3)$$

The total amount of CO_2emitted during transportation processes (Eq.6) equals the amount of CO_2ejected from a vehicle multiplied by the summation of distances from different selected facilities.

$$TCT(x_m, x_r, x_d, x_s) = CO2V \left[\sum_s^S \sum_m^M \left(d_{sm} x_s x_m \frac{Dk_M}{(k_R+k_M)vc} \right) + \sum_m^M \sum_r^R \left(d_{mr} x_m x_r \frac{D}{vc} \right) + \sum_r^R \sum_c^U \left(d_{rc} x_r \frac{D}{vc} \right) + \sum_c^U \sum_d^\partial \left(d_{cd} x_d \frac{Dk_R}{(k_R+k_M)vc} \right) + \sum_d^\partial \sum_m^M \left(d_{dm} x_d x_m \frac{Dk_M}{(k_R+k_M)vc} \right) \right] \quad (4)$$

Total annual transportation cost (Eq.7) equals the summation of yearly transportation cost multiplied by the distances between selected facilities.

$$\mathrm{TTC}(x_s, x_m, x_r, x_d) = \sum_s^S \sum_m^M \left(\theta_{sm} x_s x_m \frac{Dk_M}{(k_R+k_M)} \right) + \sum_m^M \sum_r^R (\theta_{mr} x_r x_m D) + \sum_r^R \sum_c^U (\theta_{rc} x_r D) + \sum_c^U \sum_d^\partial \left(\theta_{cd} x_d \frac{Dk_R}{(k_R+k_M)} \right) + \sum_d^\partial \sum_m^M \left(\theta_{dm} x_d x_m \frac{Dk_M}{(k_R+k_M)} \right) \quad (5)$$

TotalFixedassociationCosts(Eq.8)equalfixedcostsforselectingthisfacility.

$$\mathrm{TFC}(x_r, x_m, x_s, x_r) = \sum_r^R e_r x_r + \sum_m^M e_m x_m + \sum_s^S e_s x_s + \sum_d^\partial e_d x_d \quad (6)$$

The first objective (Eq.9) is to maximize the total profit for retailers, manufacturers, third-party, and suppliers minus (the total fixed association costs plus total annual transportationcosts).Thesecondobjective(Eq.10)istomaximizethesocialfactor,which is equal to the weight allocated to the created job opportunity at the manufacturer minus theweightallocatedtoalostdaycausedbyworker'sdamage*numberoflostdayscaused by worker's damage at the manufacturer) minus (weight allocated to unemployment * amountofunemploymentatthemanufacturer).Thethirdobjective(Eq.11)istominimize theenvironmentalfactorthatisequaltothetotalamountofCO_2emittedduringproduction andrecoveryprocesses(TCP)plusthetotalamountofCO_2emittedduringtransportation processes (TCT).

Finally,themodel'sconstraints(Eq.12-16)aretheratioofthenumberofdeliveriesper manufacturercycletimeoverthenumberofdeliveriesperretailercycletime,equaltothe (demand minus annual return rate) over yearly return rate. The number of deliveries per manufacturercycletimeandthenumberofdeliveriesperretailercycletimeisequaltothe number of deliveries per re-manufacturer/manufacturer cycle time. The logic constraints and only one facility should be selected per echelon.

$$Max. \quad F_{eco}\,(k_R, k_M, T_r, k_s, x_s, x_m, x_r, x_d) = TP_r + TP_m + TP_s + TP_d - (TFC + TTC) \tag{7}$$

$$Max. \quad F_{soc}(x_m,\ t_m) = wc * \sum_{m}^{M}(se_m * x_m * t_m) \ - wl * \sum_{m}^{M}(sl_m * x_m * t_m) \ - wu \ * \sum_{m}^{M}(su_m * x_m) \tag{8}$$

$$Min. \quad F_{env}(x_m, x_r, x_d, x_s) = TCP + TCT \tag{9}$$

Subject to:

$$\frac{k_M}{k_R} = \frac{D - C}{C} \tag{10}$$

$$k_R + k_M = I \tag{11}$$

$$T_r \geq 0 \tag{12}$$

$$k_s, k_d, I = 1,2,3, \dots \tag{13}$$

$$\sum_{s=1}^{S} x_s = \ 1,\ \sum_{m=1}^{M} x_m = 1,\ \sum_{p=1}^{\delta} x_p = \ 1,\ and\ \sum_{r=1}^{R} x_r = \ 1 \tag{14}$$

2.3 Model-2:JointeconomiclotsizingforCLSC

Wereintroducethepreviousworkdoneby[28]preciselytheJELSconceptinournetwork forthecomparisonresponses.Themodelheredeterminestheretailercycletimeand the number of delivers per facility cycle time in each flow. The only objective here is maximizing the total profit, representing only the economic factor as in reference work [28].

Toconvertthepreviousworkdoneby[28]tobemulti-objective,weputthesocialand environmentalobjectivesequaltozerotosolvethismodelbyNSGA-II.Thesecondchange is removing the additional costs for the location decisions (TFC and TTC) to remove the impact of choosing the facility location. The objectives will be Eq.(17-19).

$$Max.F_{eco}(k_R,k_M,T_r,k_s)=TP_r+TP_m+TP_s+TP_d \quad (17)$$

$$Max.F_{soc}(x_m,t_m)=0 \quad (18)$$

$$Min.F_{env}(x_m,x_r,x_d,x_s)=0 \quad (19)$$

3 Experiments

Thispaperusesthepreviousdatageneratedby[28,9]–asshowninTable2–andapplies thesedatamainlyonthreescales:small,medium,andsignificantineverymodel–shown in Table3.Furthermore,we usednon-dominatedsortinggeneticalgorithm-II (NSGA-II) [32]becausethisalgorithmisthemostalgorithmusedtosolvethiskindofprobleminthe literature.Finally,wetrysixdifferentalgorithmparametersshowninTable4becausewe seek to find the best solutions for these problems.

Tooverlaptherandomness,weruneverycaseforeveryscaleof30runswiththesame parameters and evaluate the output by computing the non-dominated sorting to find the first front for these 30 runs. All runs were done using Julia Language in Intel® Core™i7CPUQ720@1.60GHzand16GBRAM.Moreover,differentperformancemetricsare calculated for the proposed model to evaluate the algorithm.

Table2 ParametersSetting

Value	Parameter	Value	Parameter	Value	Parameter	Value	Parameter	Value	Parameter
2000	D	770	C	2000	AM	0.25	HMw	U[90,100]	sem
100	Or	250	Ad	2500	AR	0.25	HRw	U[20,30]	slm
0.3	Hr	0.35	Hd	350	OMw	115	PM	150	vc
175	Pc	70	Pd	350	ORw	110	PR	0.3	Hs
150	Pr	150	Fd	0.2	HM	350	Fm	90	Ps
5000	P	U[15,20]	sum	150	Fs	U(75,950)	dcd	U(1,5)	θcd
4000	B	3	$CO2V$	U(75,950)	drc	U(75,950)	ddm	U(1,5)	θmr
0.15	wc	0.5	$CO2M$	U(10,50)	θrc	U(1,5)	θdm	U(1000,5000)	em
0.15	wl	0.3	$CO2R$	U(100,500)	er	U(100,500)	ed	U(1,5)	θsm
0.1	wu	200	Fso	U(75,9	dmr	U(75,9	dsm	U(100,5	es

5	50)	50)	00)

Table3 Scalesetting Scales Supplier

ManufacturerRetailersCustomersThird- Numbers (Snum)

(Mnum)

(Rnum)

(Unum)

party

of Decision

					(Dnum)	Variables (dv_size)
1	3	3	3	2	2	19
2	30	30	30	15	15	140
3	60	60	60	30	30	275

Table4 Casessetting

Cases	popSize	iter_num	pCross	pMut
1	80	800	0.25	0.1
2	100	1000	0.5	0.2
3	120	1200	0.75	0.3
4	60	800	0.25	0.1
5	140	1200	0.75	0.3
6	140	1200	0.25	0.1

Theperformancemetricsusedhereare(1)theerrorratio(ER)forassessingthenumber ofPareto-optimalsolutionsinthesetwherethelowervalueisthebest,(2)Thegenerational distance (GD) for measuring the closeness of the solutions to the true Pareto-front, the lowervalueisthebest,(3)theuniformdistribution(UD)forfocusingonthedistributionof thesolutions,(4)themaximumspread(MS)concerningthespreadofthesolutionsalarge value is the best, and (5). The maximum value is the best for the hyper area ratio (HAR), whichconsidersclosenessanddiversitytogether.Formoreinformation,youcanread[33].

4 ResultsandDiscussions

Inthissection,weprovide–first–thecomparisonbetweenthetwomodels–second–the performanceofNSGA-IIinsolvingtheproposedmodelonthedifferentscalesandcases. The comparison was made for the first-front solutions. This first front is interpreted from thenon-dominatedsortingalgorithmforallfirstfrontsofthelastiterationforeveryrunof 30 runs.

The results of the final objectives are represented in Table 5; Comparing the profit objective, Model-2 is generally better than Model-1 since it is mainly concerned with onlythisobjective,soitmakessensetogettheseresults.However,theModel-1achieves better profit in some cases (Scale 1: Cases 3 and 6, Scale 2: Cases 1 and 5), whichshownintheitalicformatinTable5.Also,Model-1richesthebestprofitforallruns which is 127,336.23□10,000 which indicates that our proposed model for integrating JELSandSCLSCnetworkthedesignmakesabetterdecisionnotonlyforthesocialand environmentalissuesbutalsoforeconomic(profit).

TheresultsofModel-1showthatthealgorithmrichestothemaximumsocialvalueon all scales. The best environment objective values have been reached two times in Scale 1 andScale2.Theworstenvironmentvalueis0.49%morethanthebestsolutiononScale1, 18.7%onScale2,and3.15%onScale3.So,ingeneral,wecanconcludethattheNSGA-II algorithm can solve this model effectively.

Table5 Runsresults

Model-1

Scale	**1**			**2**			**3**		
Case	**Profit* 10,000**	**Social**	**Environment**	**Profit* 10,000**	**Social**	**Environment**	**Profit* 10,000**	**Social**	**Environment**
1	10,945.61	7.89	35,408.33	*8,891.38*	9.19	248,140.35	35.42	9.03	551,293.22
2	2,886.81	7.89	35,275.80	946.77	9.19	203,446.17	41.62	9.03	542,935.28
3	*127,336.23*	7.89	35,408.33	10,844.89	9.19	203,951.40	10.65	9.03	541,661.46

4	1,688.94	7.89	35,447.93	73.86	9.19	248,978.37	2.33	9.03	551,477.13
5	16,634.34	7.89	35,275.80	*8,398.87*	9.19	202,403.53	1,993.06	9.03	545,553.46
6	*43,391.44*	7.89	35,305.57	2,565.07	9.19	202,403.53	21.4	9.03	559,294.12
Model-2Scale	**1**			**2**			**3**		
Case	**Profit* 10,000**	**Social**	**Environment**	**Profit* 10,000**	**Social**	**Environment**	**Profit* 10,000**	**Social**	**Environment**
1	11,210.30	0	0	5,388.38	0	0	3,483.38	0	0
2	20,045.10	0	0	7,300.61	0	0	109,007.00	0	0
3	94,722.90	0	0	34,071.99	0	0	75,139.50	0	0
4	2,093.93	0	0	3,469.49	0	0	823.5	0	0
5	34,010.00	0	0	2,975.91	0	0	66,354.30	0	0
6	984.4	0	0	71,814.30	0	0	118,465.00	0	0

The performance impacts illustrated in Table 5 and Figures 2, 3, and 4 represent each problemscaleonthefirstproposedmodel;notethat;allofthemaremodifiedbyremoving

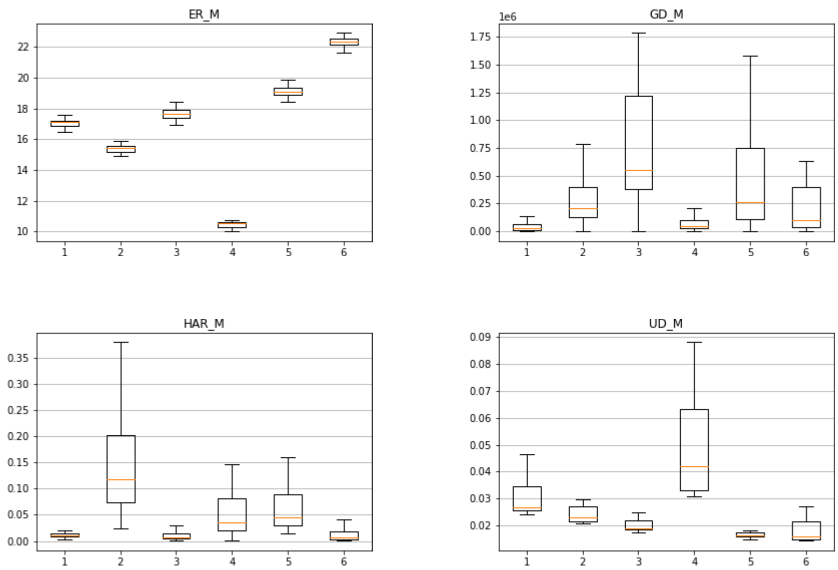

Figure2 Scale-1performanceindicators

theoutliers.

For the first scale, the small one (Figure 2), case 4 is the best performance for the Pareto optimal solutions (ER), the solution distributions (UD), and the second-best forthe closeness (GD) of the solutions but not the diversity. The best performance for both closenessanddiversity(HAR)iscase2.Furthermore,thespreadmetric(MS)hasnovalues forthisscalebecausethesocialobjective'svaluesarethesameinallfrontsolutions,sothis metric cannot be evaluated. In contrast, the worst cases are 6 for ER and 3 for GD. Also, case 3 is the second-worst for HAR and UD.

On the second scale, Figure 3, case 3 is the best case for reaching the minimum ER. Case 5 has the best observations for the closeness of solutions (GD) and the second-best iscase3ifweconsidertheminimumandthemostobservationsvaluesfrom25%up to75%.Whilecase4;achievesthebestperformancefor distribution(UD);inaddition to both closeness and diversity (HAR). However, it's hard to define the best spread case precisely;also,wecanarguethatthebestcasehereiscase3becauseithas25%upto75% ofobservationshigherthantheremainingcases.Asaresult;wecanconcludethatcase3is thebestERandMSandthesecond-bestforGD,whilecase4isthebestintheremaining indicators. The worst cases are case 6 for ER, case 2 for GD, cases 1, 3, and 5 for HAR, case 3 for UD, and case 4 for MS.

For the last scale in Figure 4, the best case for ER and HAR is case 3. Case 6 is the best for GD followed by case 3. While case-4 is the best case for UD. Case 5 is the best forMSfollowedbycase3.Hence,case3isthebestParetofrontsolutions,closeness,and diversity; it comes in second place after case 5 for solutions spread. Case 6 is the best for closeness but not for diversity. So case 3 is considered the best case on the scale-3.

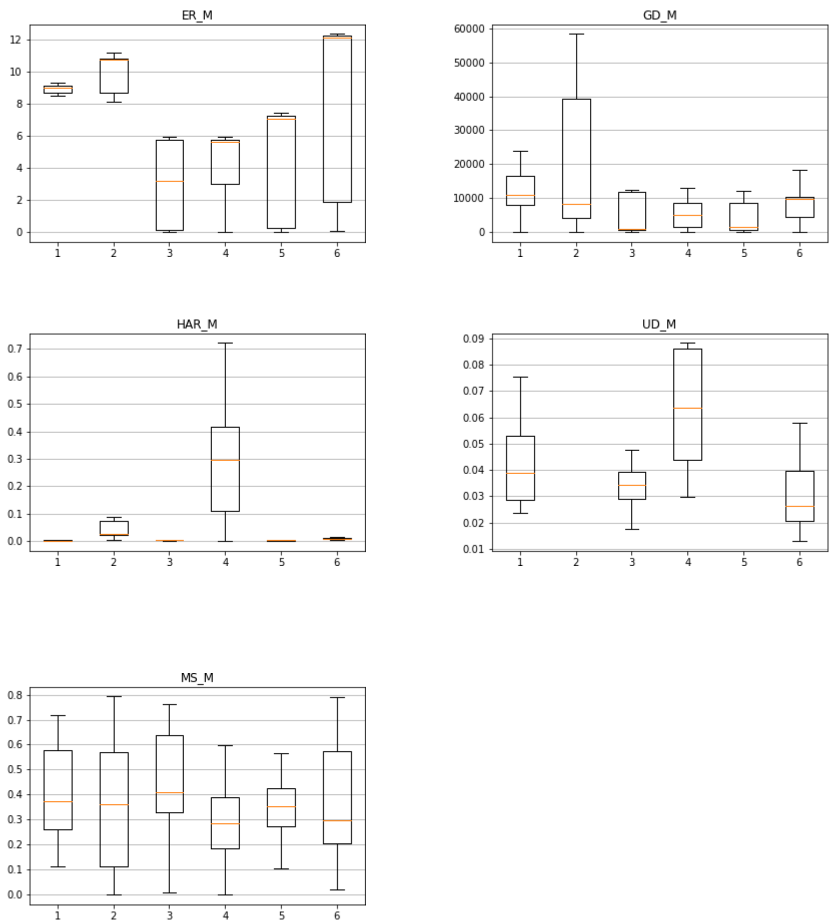

Figure3 Scale-2performanceindicators

Inconclusion,asrepresentedinTable6,thebestcaseforthemostperformancemetrics iscase4concerningscale-1andsomeoftheperformancemetricsforscales2and3.While case 3 is the best for remaining scales in most performance metrics. So, we can conclude that the medium "*popSize*" with high "*iter_num*" and maximum "*pCross*" and "*pMute*" is needed for medium and large-scale problems, while the small "*pCross*" and "*pMute*" with minimum"*popSize*"and"*iter_num*"arethebestperformanceforsmallscaleproblem.

Table6 Summaryofperformanceconclusions

Scale	ER	GD	HAR	UD	MS
1	Case4	Case4	Case2	Case4	
2	Case3 3	Case5then	Case4	Case4	Case3
3	Case3	Case6then	Case3	Case4 Case5then3	

3

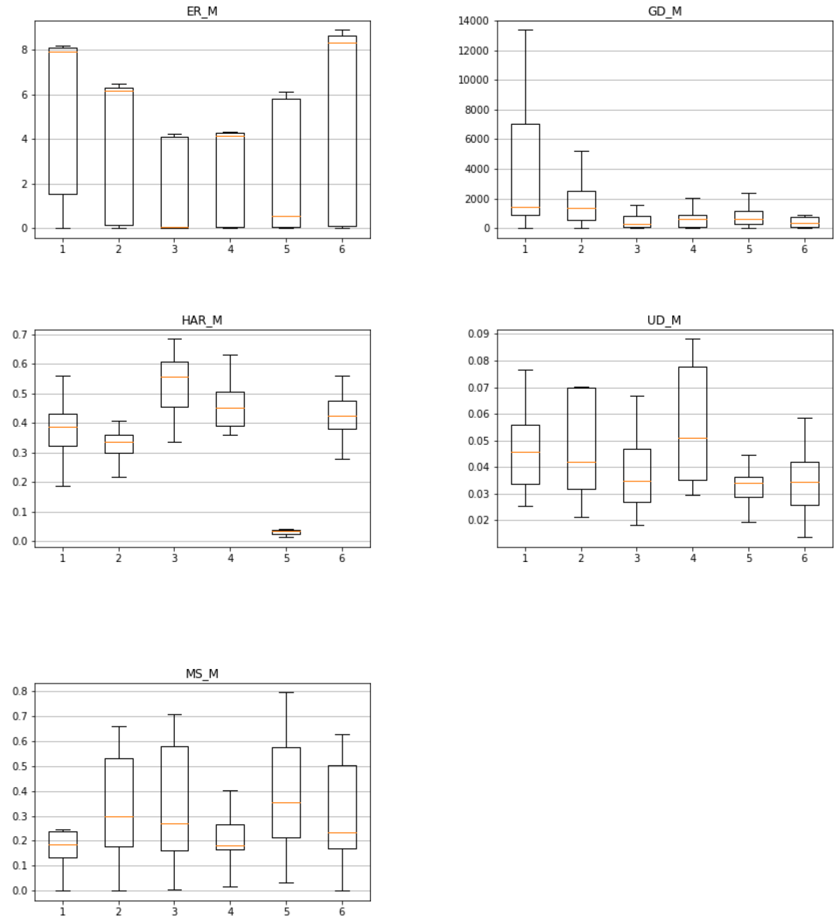

Figure4 Scale-3performanceindicators

5 Conclusionandfuturework

In this paper, we proposed and solved the integrated model of joint economic lot-sizing problem with network design problem; we solved the problem under the three sustainability objectives for the closed-loop supply chain. The first objective is maximizing the total profit;thesecondismaximizingthesocialimpact,whilethethirdobjectiveminimizesthe environmental impact caused by transportation.

The problem was designed considering the network location for one supplier, one manufacturer,oneretailer,onecustomerzone,andone-thirdparty,inadditiontoselecting thetechnologyusedinthemanufacturer,thebasiccycletime,andthenumberofdeliveries pereveryecheloncycletime.Theproblemwasformulatedasamulti-objectivemixednon-linearprogrammingmodelandsolvedusingtheNSGA-II.Tocomparetheperformanceof theproposedmodel,weconsideranothermodel(Model2),whichrepresentsthelot-sizing problem for CLSC on our network.

Everymodelistestedforthreescales(small,medium,andlarge)infivecasesbasedon algorithmparametersettings.Theresultsshowthatconsideringthelotsizingandnetwork designdecisionssimultaneouslyleadstobetterdecisionsthanconsideringthemseparately. Furtheranalysisisdoneforalgorithmperformanceusedtosolvetheproposedmodel.This analysiswasdoneforfiveindicatorswhicharethenumberofParetofrontsolutions(ER) solution closeness to the true Pareto front (GD) diversity with closeness (HAR) solution spread(MS),anddistribution(UD).Theresultsshowthatcases3and4arethebestforthe most performance matrices.

Furtherresearchisneededtoinvestigatethebestheuristicandmeta-heuristicalgorithm forsolvingtheproposedmodel.Additionally,themodelcanbeimprovedtohandlemulti-echelonselectionratherthanthecurrentsingle-echelonselection.Thelastsuggestionisto investigate multiple lot-sizing policies.

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