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A Multi-stage Stochastic model for a multi-product closed-loop supply chain network design

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Abstract: *In this research, amulti-stage stochastic model for multi-product closed-loop supply chain network design is developed. The proposed network structure consists of a forward directionwhich provides the first customer zones with virgin products, and a reverse direction which provides the second customer with refurbished products,the suppliers with the recyclable materials and the factories with the remanufacturable products. A multi-stage stochastic mixed integer linear programming (smilp) is used inthe model formulation. The objective of the model is to optimally configure the closed-loop supply chain network to maximize the total expected profit.*

Keywords: *stochastic programming; risk; closed-loop supply chain; smilp.*

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I. Introduction

Stochastic programming are mathematical programming where some of the objective or constraints data are uncertain; characterized by a probability distribution. When the data or some of it is random, the solutions to the optimization problem are itself random.

There are two types of Stochastic Programmingproblems; two-stage and multi-stage problems. This proposed model is a multi-stage as shown in Figure 1 since the system design decisions are taken first. Next, the operational decisions, which are based on theprobabilistic events such as demand, capacity, and price are taken for all periods.

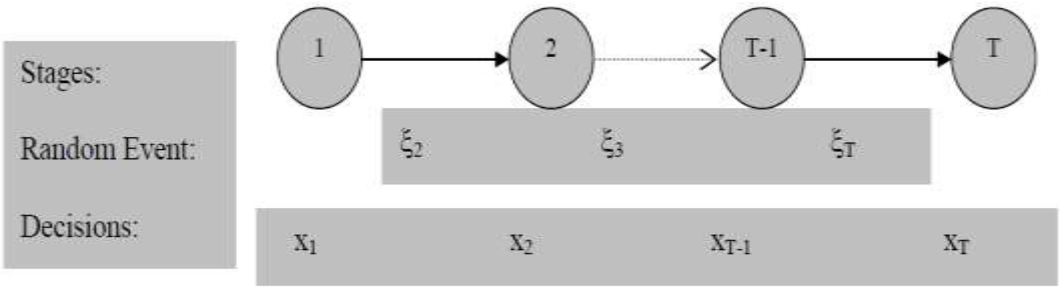

Figure 1: Multi-stage SP problem

In the recent literatures, two new criteria have been brought to the attention of researchers for their consideration: robustness andstability[1].Robustness means that schedule performanceis still acceptable when something unforeseen happens.

The existing uncertainties may be in the demand, the quantity and quality of returned products. SP is a tool used for manipulating the uncertain data[2].The scenario-based SP and the multi-stage SP are developed to design integrated CLSC networks;Pishvaee, M. S.et al. [3] developed anSP model for a single-period single-product integrated forward/reverse logistics network design under uncertainty and El-Sayed, M. et al. (2010) [4] developed anSMILP modelfor a multi-period single-productfor designing a forward–reverse logistics under demand risk.

If there is no enough historical data to guess the probability distribution of the uncertain parameters,robust optimization (RO) can be considered as an alternative approach for dealing with this type of risk. Ben-Tal and Nemirovski[5-7], Mulvey et al. [8], and Bertsimas and Sim[9, 10]introduced the most Three recent RO approaches. Pishvaee et al. [11] and Hasani et al. [12] considered the RO approach developed by Ben-Tal and Nemirovski[5-7]to design a single-product robust CLSCN.Mir SamanPishvaee et al. [11]mentioned that SCND considering robustness is still in its infancy and advised for addressing the problem in a multi-product.

Forward and reverse logistics (RL)activities are subject to remarkable uncertainties. Some researchers dealt with uncertainties;Listes and Dekker [13] proposed a SMIPdesign model with several scenarios to solve reverse network design problem. Listes[14] developed a stochastic model for a network design problem. Salema et al. [15] proposed a SMIPfor multi-product networks to deal with demand uncertainty. Ding et al. [16] develop a stochastic simulation based optimization approach to design a production–distribution network.

Lee and Dong [17]introduced a two stage SP to consider uncertainty in a dynamic RL. A two-stage stochastic programming model is proposed for a paper recycling reverse logistics network design under uncertainty[18]. The authors use the commercial software to solve the proposed mixed-integer linear programming problem.

Initial decisions or system design decisions called as location decisions where it decides which location that optimally to be opened and which are to be closed. And the resource decision or operational decisions called allocation decision where the optimal quantities of material, products, and inventory are assigned to each location for each period. So, the proposed may be called as a location-allocation model.ShafieiKisomiMeysam[19] proposed an integrated MP model based on robust optimization theory to tackle the uncertain environment in Supply chain configuration and supplier selectionproblem.

M. S. Al-Ashhab[20] developed adeterministicmulti-product forward-reverse logistics network design model. Ramezani, M.et al.[21] presented a single period stochastic multi-objective model to design the forward/reverse logistic network under an uncertain environment.

Mutha, A., & Pokharel, S.[22] proposed a mathematical RLN design model considering a third party collectors. Hatefi, S. M., & Jolai, F.[23] formulated a single product, single period, robust and reliable model for CLSCN design based on a robust optimization approach under uncertainty.Serdar E. T. & Al-Ashhab M. S. [24]developed a location and allocation model for a multi-product, multi-periodSCN using MILP to maximize the total expected profit.M. S. Al-Ashhab[25] developeda SMILP model considering uncertain demand, to tackle the multi-product SCND problems.

The objectives of this model are to determine the CLSCN design together with planning decisions that maximize the TEP and at the same time minimizes the risk, considering the uncertainty of the virgin products demand and rate of return (RR) of the reversed products. Uncertainty is captured in terms of a number of possible scenarios during the planning horizon having different associated probabilities. The focus here is on decidingthe number of facilities, their locations, and allocation of correspondingflow.

II. Model Description

The model isdevelopedto solve themulti-product CLSCN design problem. The network is a multi-echelon as shown in Figure 2.

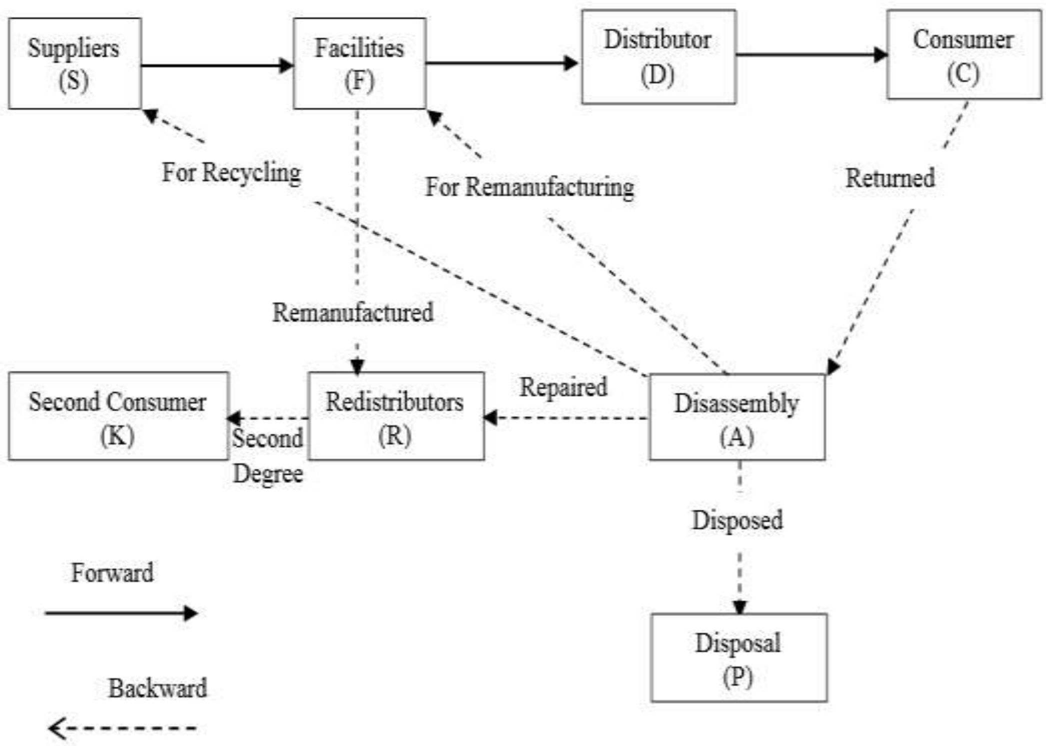

Figure 2: The proposed forward-reverse logistics network[4]

The role of each echelon in the network is:

- Supplier: recycling and providingthe raw material to the factories
- Factories: transforming raw material into product
- Distributors: storing and sending products to the first customers
- Customers: consuming product and return the unwanted to the disassembly ceneters
- Disassembly locations: collecting, disassembling and sorting the received and sending the recyclable to the suppliers, the remanufacturable products to the factories, the disposable to the disposal locations, and to repair the repairable products and supplying them directly to the redistribution locations.in
- Disposal locations: disposing the non-useful things.
- Redistribution locations:storing and sending products to the second customers.

The assumptions considered in the present model are those assumed in [4] in addition to considering multi-products instead of single product.

III. Model Formulation

The model involves the following sets, parameters, and decision variables:

Sets:

- S, F, D, and C: Sets of suppliers, factories, distributors, and first customers,
- A, R, L, and K: Setsof disassembly, redistributors, disposal, and second customers.
- P: Set of products,
- T: Set of periods.

Parameters:

- μ_{cpt}: demand mean of customer c from product pin period t,
- σ_{cpt}: demand standard deviation of customer c from product pin period t,
- D_{kpt}: demand of the second customer k from product p in period t,
- P_{pct}: unit price of product p at customer c in period t,
- P_{pkt}: unit price of product p at second customer k in period t,
- W_p: weight of product p (kg)
- F_i: fixed cost of opening location i,
- DS_{ij}: distance between any two locations i and j,
- $CAPS_{st}$: capacity of supplier s in period t (kg),
- $CAPM_{ft}$: capacity of raw material store of facility f in period t (kg),
- CAPHft: capacity in manufacturing hours of facility f in period t,
- $CAPFS_{ft}$: capacity of final product store of facility f in period t (kg),
- $CAPD_{dt}$: capacity of distributor d in period t (kg),
- $CAPA_{at}$: capacity of disassembly a in period t,
- $CAPRC_{st}$: recycling capacity of supplier s in period t (kg),
- $CAPRM_{ft}$: remanufacturing capacity in hours of factory f in period t,
- $CAPR_{rt}$: capacity of redistributor r in period t,
- $CAPL_{lt}$: capacity of disposal p in period t,
- $MatC_{st}$: material cost per unit supplied by supplier s in period t,
- REC_{st}: recycling cost per unit recycled by supplier s in period t,
- MC_{ft}: manufacturing cost per hour for factory f in period t,
- RMC_{ft}: remanufacturing cost per hour for factory f in period t,
- DAC_{at}: disassembly cost per unit weight disassembled by disassembly location a in period t,
- $REPC_{at}$: repairing cost per unit repaired by disassembly location a in period t,
- $DISPC_{lt}$: disposal cost per unit disposed of by disposal location l in period t,
- $NUCC_f$: non-utilized manufacturing capacity cost per hour of facility f,
- $NURCC_f$: non-utilized remanufacturing capacity cost per hour of factory f,
- $SCPU_p$: shortage cost per unit per period for product p,
- MH_p: manufacturing hours for product p,
- RMH_p: remanufacturing hours for product p,
- FH_f: holding cost per unit weight per period at the store of factory f,
- DH_d: holding cost per unit weight per period at distributor store d,
- B_s, B_f, B_d, B_a& B_r: batch size from supplier s, factory f, distributor d, disassembly a, and, redistributor r respectively,
- T_c: transportation cost per unit per kilometer,

- RR: return ratio at the first customers,
- RQ: Returned products quality
- RC: recycling ratio,
- RM: remanufacturing ratio,
- RP: repairing ratio,
- RD: disposal ratio,

Decision variables:
- L_i: binary variable equals 1 if location i is open and 0 otherwise,
- Q_{ijpt}: batches of product ptransported from location i to location j in period t,
- I_{fpt}: batches of product ptransported from factory f to its store in period t,
- I_{fdpt}: batches of product ptransported from store of factory f to distributor d in period t,
- R_{ipt}: the residual inventory of product p in the period t atat location i.

3.1 Objective Function

Maximize the totalexpected profit of the CLSCNis the objective of this developed model. I may be calculated by subtracting the Total Expected Cost (TEC)from Total Expected Revenue (TER). The TER is the summation of the first and second sales revenues in addition to cost saved in recycling these three parts of the TER are defined in Equations 1, 2, and 3 respectively.

3.1.1 Total Revenue

TER = First Sales + Second Sales + Recycling Cost Saving.

$$\text{First Sales} = \sum_{d\in D}\sum_{c\in C}\sum_{p\in P}\sum_{t\in T} Q_{dcpt}\, B_{dp}\, P_{pct} \tag{1}$$

$$\text{Second Sales} = \sum_{r\in R}\sum_{k\in C}\sum_{p\in P}\sum_{t\in T} Q_{rkpt}\, B_{rp}\, P_{pkt} \tag{2}$$

$$\text{Recycling cost saving} = \sum_{a\in A}\sum_{s\in S}\sum_{p\in P}\sum_{t\in T} Q_{ast}\, B_a\, W_p\, (MatC_{st} - REC_{st}) \tag{3}$$

3.1.2 Total Expected Cost

TECis determined as the summation of the fixed costs, material, manufacturing, non-utilized capacity,shortage, purchasing, disassembly,remanufacturing, repairing, disposal, transportation and inventory holding costs. These different costs have been calculated using Equations 4-16.

1) Fixed Costs

$$\sum_{s\in S} F_s L_s + \sum_{f\in F} F_f L_f + \sum_{d\in D} F_d L_d + \sum_{a\in A} F_a L_a + \sum_{r\in R} F_r L_r + \sum_{l\in L} F_l L_l \tag{4}$$

2) Material Cost

$$\sum_{s\in S}\sum_{f\in F}\sum_{t\in T} Q_{sft}\, B_s\, MatC_{st} \tag{5}$$

3) Manufacturing Costs

$$\sum_{f\in F}\sum_{d\in D}\sum_{p\in P}\sum_{t\in T} Q_{fdpt}\, B_{fp}\, MH_p\, MC_{ft} + \sum_{f\in F}\sum_{d\in D}\sum_{p\in P}\sum_{t\in T} I_{fpt}\, B_{fp}\, MH_p\, MC_{ft} \tag{6}$$

4) Non-Utilized Manufacturing Capacity Cost (for factories)

$$\sum_{f\in F}(\sum_{t\in T}((CAPH_{ft})\,L_f-\sum_{d\in D}\sum_{p\in P}(Q_{fdpt}\,B_{fp}MH_p)-\sum_{d\in D}\sum_{p\in P}(I_{ffpt}\,B_{fp}MH_p))NUCC_f) \qquad (7)$$

5) Shortage Cost (for distributor)

$$\sum_{p\in P}(\sum_{c\in C}(\sum_{t\in T}(\sum_{1}^{t}DEMAND_{cpt}-\sum_{1}^{t}\sum_{d\in D}Q_{dcpt}\,B_{dp})))\,SCPU_p \qquad (8)$$

6) Purchasing Costs

$$\sum_{c\in C}\sum_{a\in A}\sum_{p\in P}\sum_{t\in T}Q_{capt}\,P_{pct}\,B_c\,QL_c \qquad (9)$$

7) Disassembly Costs

$$\sum_{c\in C}\sum_{a\in A}\sum_{p\in P}\sum_{t\in T}Q_{capt}\,B_c\,DAC_{at} \qquad (10)$$

8) Non-Utilized Remanufacturing Capacity Cost (for factories)

$$\sum_{f\in F}(\sum_{t\in T}((CAPRM_{ft})\,L_f-\sum_{r\in R}\sum_{p\in P}(Q_{frpt}\,B_{fp}\,RMH_p))NURCC_f) \qquad (11)$$

9) Remanufacturing Costs

$$\sum_{f\in F}\sum_{r\in R}\sum_{p\in P}\sum_{t\in T}Q_{frpt}\,B_{fp}\,RMH_p\,RMC_{ft} \qquad (12)$$

10) Repairing Costs

$$\sum_{a\in A}\sum_{r\in R}\sum_{p\in P}\sum_{t\in T}Q_{arpt}\,B_a\,W_p\,REPC_{at} \qquad (13)$$

11) Disposal Costs

$$\sum_{a\in A}\sum_{l\in L}\sum_{p\in P}\sum_{t\in T} \mathrm{Q_{alpt}\ B_a\ W_p\ DISPC_{lt}} \tag{14}$$

12) Transportation Costs

$$\begin{aligned}&\sum_{t\in T}\sum_{s\in S}\sum_{f\in F} \mathrm{Q_{sft}\ B_s\ T_s\ DS_{sf}} + \sum_{t\in T}\sum_{f\in F}\sum_{d\in D}\sum_{p\in P} \mathrm{Q_{fdpt}\ B_f W_p\ Tc\, DS_{fd}} + \sum_{t\in T}\sum_{f\in F}\sum_{d\in D}\sum_{p\in P} \mathrm{I_{fdpt}\ B_{fp} W_p T_f\ D_{fd}}(1+SN)\\
&\sum_{d\in D}\sum_{c\in C}\sum_{p\in P}\sum_{t\in T} \mathrm{Q_{dcpt}\ B_{dp}\ W_p T_d\ D_{dc}} + \sum_{t\in T}\sum_{d\in D}\sum_{a\in A}\sum_{s\in S} \mathrm{Q_{aspt}\ B_a W_p\ Tc\, DS_{as}} + \sum_{t\in T}\sum_{d\in D}\sum_{a\in A}\sum_{f\in F} \mathrm{Q_{afpt}\ B_a W_p\ Tc\, DS_a}\\
&\sum_{t\in T}\sum_{d\in D}\sum_{f\in F}\sum_{r\in R} \mathrm{Q_{frpt}\ B_f W_p\ Tc\, DS_{fr}} + \sum_{t\in T}\sum_{d\in D}\sum_{a\in A}\sum_{r\in R} \mathrm{Q_{arpt}\ B_a W_p\ Tc\, DS_{ar}} + \sum_{t\in T}\sum_{d\in D}\sum_{a\in A}\sum_{l\in L} \mathrm{Q_{alpt}\ B_a W_p\ Tc\, DS_{al}}\\
&\sum_{t\in T}\sum_{d\in D}\sum_{r\in R}\sum_{k\in K} \mathrm{Q_{rkpt}\ B_r W_p\ Tc\, DS_{rk}}\end{aligned} \tag{15}$$

13) Inventory Holding Costs

$$\sum_{p\in P}\left(\sum_{f\in F}\sum_{t\in T} \mathrm{R_{fpt}\ W_p\ HF_f} + \sum_{d\in D}\sum_{t\in T} \mathrm{R_{dpt}\ W_p\ HD_d}\right) \tag{16}$$

3.2 Constraints

The balancing and capacity constraints of the model arerepresented in this section:

3.2.1 Balance Constraints

Balancing constraints at factories, stores, distributors, disassembly, and redistributors locations are given in Equations (17-29).

1) Factory balancing

$$\sum_{s\in S} Q_{sft} B_s = \sum_{d\in D}\sum_{p\in P} Q_{fdpt} B_{fp} W_p + I_{fpt} B_{fp} W_p, \forall t\in T, \forall f\in F \tag{17}$$

2) Factory store balancing

$$I_{fpt} B_{fp} + R_{fp(t-1)} B_{fp} = R_{fpt} B_{fp} + \sum_{d\in D} I_{fdpt} B_{fp}, \forall t\in T, \forall f\in F, \forall p\in P \tag{18}$$

3) Distributor store balancing

$$\sum_{f\in F}(Q_{fdpt} + I_{fdpt}) B_{fp} + R_{dp(t-1)} B_{dp} = R_{dpt} B_{dp} + \sum_{c\in C} Q_{dcpt} B_{dp}, \forall t\in 2\to T, \forall d\in D, \forall p\in P \tag{19}$$

4) Customer balancing

$$\sum_{d\in D} Q_{dcpt}B_{dp} \le \mathrm{DEMAND}_{cpt} + \sum_{1\to t} \mathrm{DEMAND}_{cp(t-1)} - \sum_{d\in D} Q_{dcp(t-1)}B_{dp}, \forall t\in T, \forall c\in C, \forall p\in P \tag{20}$$

5) Customer out balancing

$$\sum_{a\in A} \mathrm{Q_{capt}}\,\mathrm{B_c} \le (\sum_{d\in D} \mathrm{Q_{dcpt}}\mathrm{B_d})\,\mathrm{RR}, \forall \mathrm{t}\in \mathrm{T}, \forall \mathrm{c}\in \mathrm{C}, \forall \mathrm{p}\in \mathrm{C}, \forall p\in P \tag{21}$$

6) Disassembly balancing

$$\begin{aligned}&\sum_{c\in C} \mathrm{Q_{capt}}\,\mathrm{B_c} = \sum_{s\in S}(\mathrm{Q_{aspt}}\,\mathrm{B_a}) + \sum_{f\in F}(\mathrm{Q_{afpt}}\,\mathrm{B_a}) + \sum_{r\in R}(\mathrm{Q_{arpt}}\,\mathrm{B_a}) + \\ &\sum_{l\in L}(\mathrm{Q_{alpt}}\,\mathrm{B_a}), \forall \mathrm{t}\in \mathrm{T}, \forall \mathrm{a}\in \mathrm{A}, \forall \mathrm{p}\in \mathrm{P}\end{aligned} \tag{22}$$

7) Recycling balancing

$$\sum_{c\in C}(\mathrm{Q_{capt}}\,\mathrm{B_c}\ \mathrm{RC}) = \sum_{s\in S}(\mathrm{Q_{aspt}}\,\mathrm{B_a}), \forall \mathrm{t}\in \mathrm{T}, \forall \mathrm{a}\in \mathrm{A}, \forall \mathrm{p}\in \mathrm{P} \tag{23}$$

8) Remanufacturing balancing

$$\sum_{c\in C}(\mathrm{Q_{capt}}\,\mathrm{B_c}\ \mathrm{RM}) = \sum_{f\in F}(\mathrm{Q_{afpt}}\,\mathrm{B_a}), \forall \mathrm{t}\in \mathrm{T}, \forall \mathrm{a}\in \mathrm{A}, \forall \mathrm{p}\in \mathrm{P} \tag{24}$$

9) Return balancing

$$\sum_{c\in C}(\mathrm{Q_{capt}}\,\mathrm{B_c}\ \mathrm{RP}) = \sum_{r\in R}(\mathrm{Q_{arpt}}\,\mathrm{B_a}), \forall \mathrm{t}\in \mathrm{T}, \forall \mathrm{a}\in \mathrm{A}, \forall \mathrm{p}\in \mathrm{P} \tag{25}$$

10) Disposing balancing

$$\sum_{c\in C}(\mathrm{Q_{capt}}\,\mathrm{B_c}\ \mathrm{RD}) = \sum_{l\in L}(\mathrm{Q_{alpt}}\,\mathrm{B_a}), \forall \mathrm{t}\in \mathrm{T}, \forall \mathrm{a}\in \mathrm{A}, \forall \mathrm{p}\in \mathrm{P} \tag{26}$$

11) Remanufacturing balancing

$$\sum_{a\in A}(\mathrm{Q_{afpt}}\,\mathrm{B_a}) = \sum_{r\in R}(\mathrm{Q_{frpt}}\,\mathrm{B_f}), \forall \mathrm{t}\in \mathrm{T}, \forall \mathrm{f}\in \mathrm{F}, \forall \mathrm{p}\in \mathrm{P} \tag{27}$$

12) Redistribution balancing

$$\sum_{a\in A}(\mathrm{Q_{arpt}}\,\mathrm{B_a}) + \sum_{f\in F}(\mathrm{Q_{frpt}}\,\mathrm{B_f}) = \sum_{k\in K}(\mathrm{Q_{rkpt}}\,\mathrm{B_r}), \forall \mathrm{t}\in \mathrm{T}, \forall \mathrm{r}\in \mathrm{R}, \forall \mathrm{p}\in \mathrm{P} \tag{28}$$

13) Second customer balancing

$$\sum_{r\in R}(\mathrm{Q_{rkpt}}\,\mathrm{B_r}) \le \mathrm{D_{kpt}}, \forall \mathrm{t}\in \mathrm{T}, \forall \mathrm{k}\in \mathrm{K}, \forall \mathrm{p}\in \mathrm{P} \tag{29}$$

3.2.2 Capacity Constraints

Capacity constraints for suppliers, factories, stores, distributors, disassembly, disposal and redistributors locations are mentioned in Equations (30-38)

1) Supplier capacity constraint

$$\sum_{f \in F} Q_{sft}\, B_s \leq CAPS_{st}\, L_s, \forall t \in T, \forall s \in S \tag{30}$$

2) Factory material capacity constraint

$$\sum_{s \in S} Q_{sft}\, B_s \leq CAPM_{ft}\, L_f, \forall t \in T, \forall f \in F \tag{31}$$

3) Manufacturing hours capacity constraint

$$(\sum_{d \in D} Q_{fdpt}\, B_{fp} + \sum_{d \in D} I_{fpt}\, B_{fp})\, MH_p \leq CAPH_{ft}\, L_f, \forall t \in T, \forall f \in F, \forall p \in P \tag{32}$$

4) Facility store capacity constraint

$$\sum_{p \in P} R_{fpt} B_{fp} W_p \leq CAPFS_{ft}\, L_f, \forall t \in T, \forall f \in F \tag{33}$$

5) Distributor store capacity constraint

$$\sum_{f \in F} \sum_{p \in P} (Q_{fdpt} + I_{fdpt})\, B_{fp} W_p + \sum_{p \in P} R_{dpt\text{-}1}\, B_{dp} W_p \leq CAPD_{dt}\, L_d, \forall t \in T, \forall d \in D \tag{34}$$

6) Disassembly capacity constraint

$$\begin{aligned} &\sum_{s \in S} \sum_{p \in P} Q_{aspt}\, B_a\, W_p + \sum_{f \in F} \sum_{p \in P} Q_{afpt}\, B_a\, W_p + \sum_{r \in R} \sum_{p \in P} Q_{arpt}\, B_a W_p + \\ &\sum_{l \in L} \sum_{p \in P} Q_{alpt}\, B_a W_p \leq CAPA_{lt}, \forall t \in T, \forall a \in A \end{aligned} \tag{35}$$

7) Redistributors capacity constraint

$$\sum_{k \in K} \sum_{p \in P} Q_{rkpt}\, B_r\, W_p \leq CAPR_{rt}, \forall t \in T, \forall r \in R \tag{36}$$

8) Recycling capacity constraint

$$\sum_{a \in A} \sum_{p \in P} Q_{aspt}\, B_a\, W_p \leq CAPRC_{st}, \forall t \in T, \forall s \in S \tag{37}$$

9) Disposal capacity constraint

$$\sum_{a \in A} \sum_{p \in P} Q_{alpt}\, B_a\, W_p \leq PC_{pt}, \forall t \in T, \forall l \in L \tag{38}$$

IV. Computational Results And Analysis

To assess the performance of the model, the following problem is solved and the related resultsare reported in this section.The parameters of the problem are assumed as shown in Table 1.

Table 1: Model parameters

Parameter	Value	Units	Parameter	Value	Units
Ppct	100, 150 and 200	$/unit	Fs	10,000	$
Ppkt	0.8*Ppct	$/unit	Ff	50,000	$
Wp	1, 2 and 3	Kg/unit	Fd	5,000	$
MHp	1, 2 and 3	Hrs/unit	Fa	2,000	$
RMHp	2, 3 and 4	hr/unit	Fr	2,000	$
Dkpt	500	Unit/period	Fl	1,000	$
RQ	20	%	CAPRCst	2,000	kg
MatCst	10	$/kg	CAPSst	4,000	kg
MCft	10	$/hr	CAPFSft	2,000	kg
SCPUp	5, 10 and 15	$/unit.period	CAPMft	4,000	kg
NUCCf	10	$/hr.period	CAPHft	6,000	hrs
NURCCf	10	$/hr.period	CAPRMft	2,000	hrs
FHf	3	$/unit.period	CAPDdt	4,000	Kg
DHd	2	$/unit.period	CAPAat	2,000	Kg
DACat	3	$/unit	CAPRMft	2,000	Kg
RECst	5	$/unit	CAPLlt	1,000	kg
MCft	10	$/unit	RR	50	%
REPCat	5	$/unit	RP	50%	%
DISPClt	1	$	RC	10%	%
S, F, D, A, R	3	--	RM	30%	%
C	4	--	RD	10%	%
K	2	--	Batch sizes	1	unit

The demands of the first customers are assumed to be the same with mean value of 50, 60, and 70 for the first product in the three periods consequently and 80, 90, and 100 for the second product in the three periods consequently, while 80, 90, and 100 for the third product in the three periods consequently. And the standard deviation of each demand is assumed to be 10 units. The demands of the second customers are assumed to be constant of 500 unit per period for all products, periods and customers.

The stochastic dashboard shown in Figure 3 shows that the number of stages of four exceeds the number of planning periods by one; in which the system design decisions (location decision) are taken where it decides which location that optimally to be opened and which are to be closed. The number of generated scenarios of 27 because of dividing the demand distribution into three division powered by three periods. Generation of scenarios and calculating the stochastic random values is discussed in details in [25].

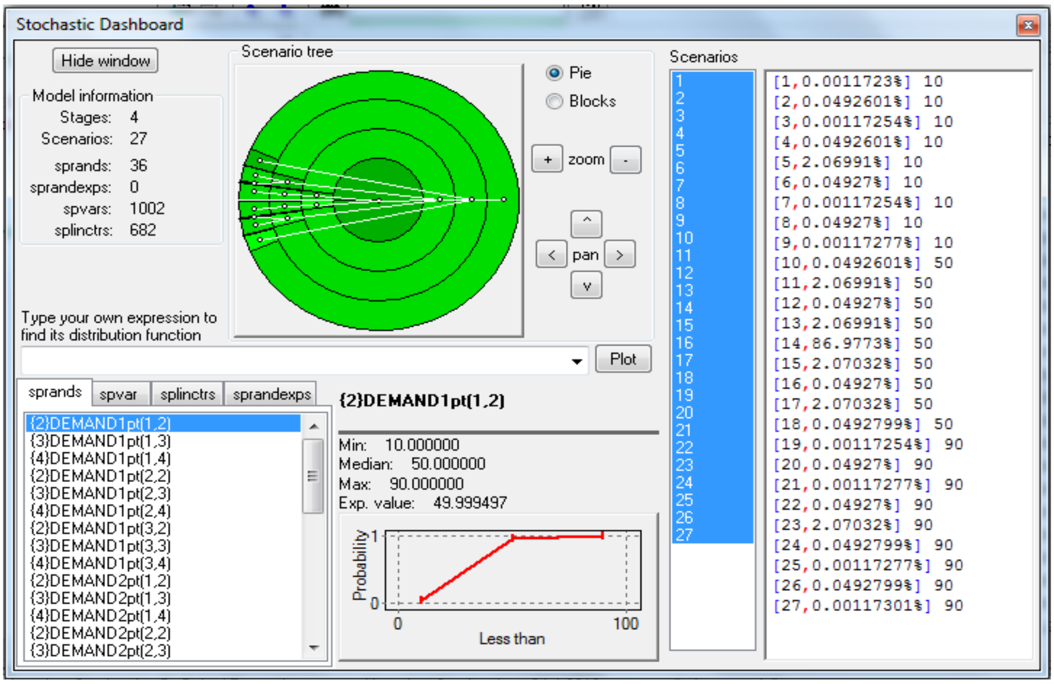

Figure 3: The stochastic dashboard (sprands)

The stochastic dashboard shown in Figure 4 shows the minimum, median, maximum and expected values of each variable (the screenshot depicts only the values of Qsft (2,2,2)) in addition to the values of each variable in all scenarios.

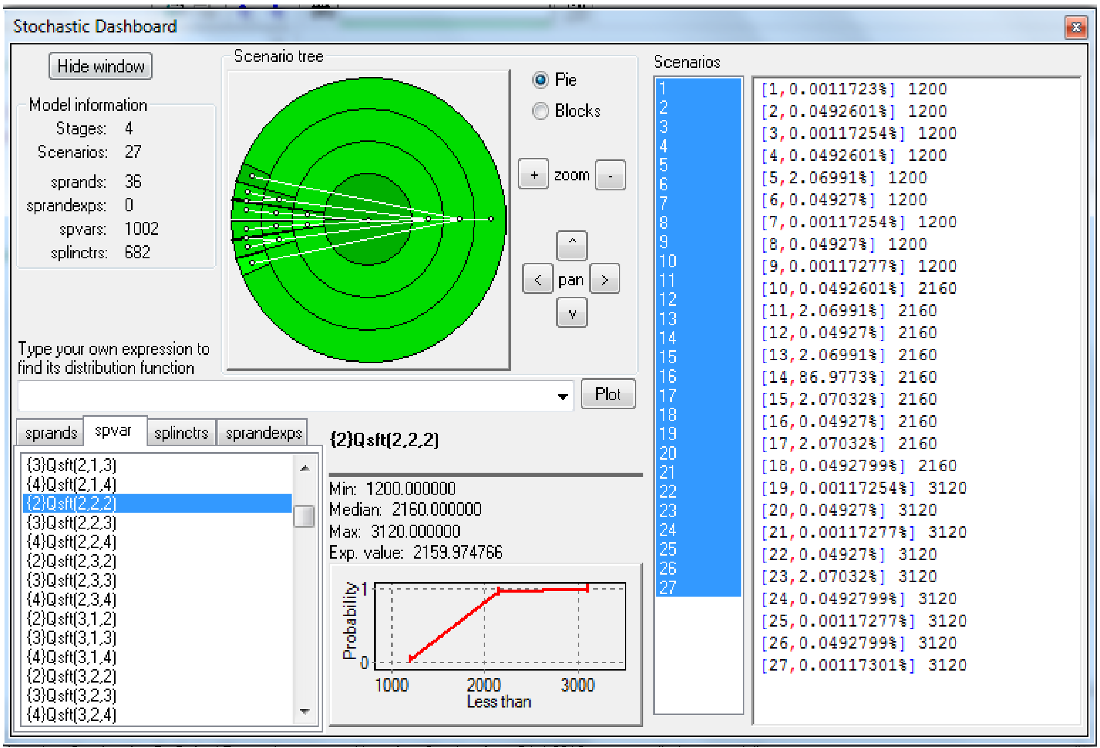

Figure 4: The stochastic dashboard (spvar)

Figure 5 shows the lower and upper bound and the solution for all variables in all scenarios.

	Column	Name	Rows	LB	UB	Solution	Reduced cost	Type
	485	Qcapt(2,2,3,2){2}	24	-0	1e+020	55	N/A yet	Integer
	486	Qcapt(2,3,1,2){2}	24	-0	1e+020	-0	N/A yet	Integer
	487	Qcapt(2,3,2,2){2}	24	-0	1e+020	-0	N/A yet	Integer
	488	Qcapt(2,3,3,2){2}	24	-0	1e+020	-0	N/A yet	Integer
	489	Qcapt(3,1,1,2){2}	24	-0	1e+020	-0	N/A yet	Integer
	490	Qcapt(3,1,2,2){2}	24	-0	1e+020	-0	N/A yet	Integer
	491	Qcapt(3,1,3,2){2}	24	-0	1e+020	-0	N/A yet	Integer
	492	Qcapt(3,2,1,2){2}	24	-0	1e+020	25	N/A yet	Integer
	493	Qcapt(3,2,2,2){2}	24	-0	1e+020	40	N/A yet	Integer
	494	Qcapt(3,2,3,2){2}	24	-0	1e+020	55	N/A yet	Integer
	495	Qcapt(3,3,1,2){2}	24	-0	1e+020	-0	N/A yet	Integer
	496	Qcapt(3,3,2,2){2}	24	-0	1e+020	-0	N/A yet	Integer
	497	Qcapt(3,3,3,2){2}	24	-0	1e+020	-0	N/A yet	Integer
	498	Qcapt(4,1,1,2){2}	24	-0	1e+020	-0	N/A yet	Integer
	499	Qcapt(4,1,2,2){2}	24	-0	1e+020	-0	N/A yet	Integer
	500	Qcapt(4,1,3,2){2}	24	-0	1e+020	-0	N/A yet	Integer
	501	Qcapt(4,2,1,2){2}	24	-0	1e+020	25	N/A yet	Integer
	502	Qcapt(4,2,2,2){2}	24	-0	1e+020	40	N/A yet	Integer
	503	Qcapt(4,2,3,2){2}	24	-0	1e+020	55	N/A yet	Integer
	504	Qcapt(4,3,1,2){2}	24	-0	1e+020	-0	N/A yet	Integer

Figure 5: Table of results

The optimal network is shown in Figure 6 which consists of the second supplier, factory and distributor to serve the first potential customers while opening one disassembly, one disposal and one redistributor location to sell the refurbished products to the second customer.

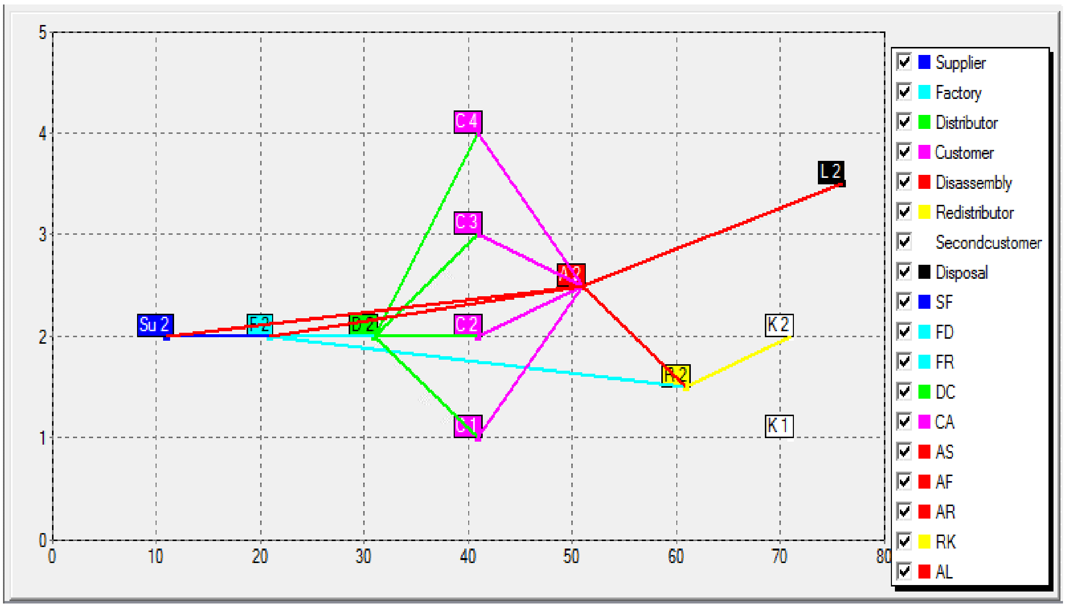

Figure 6: The optimal network design of the problem

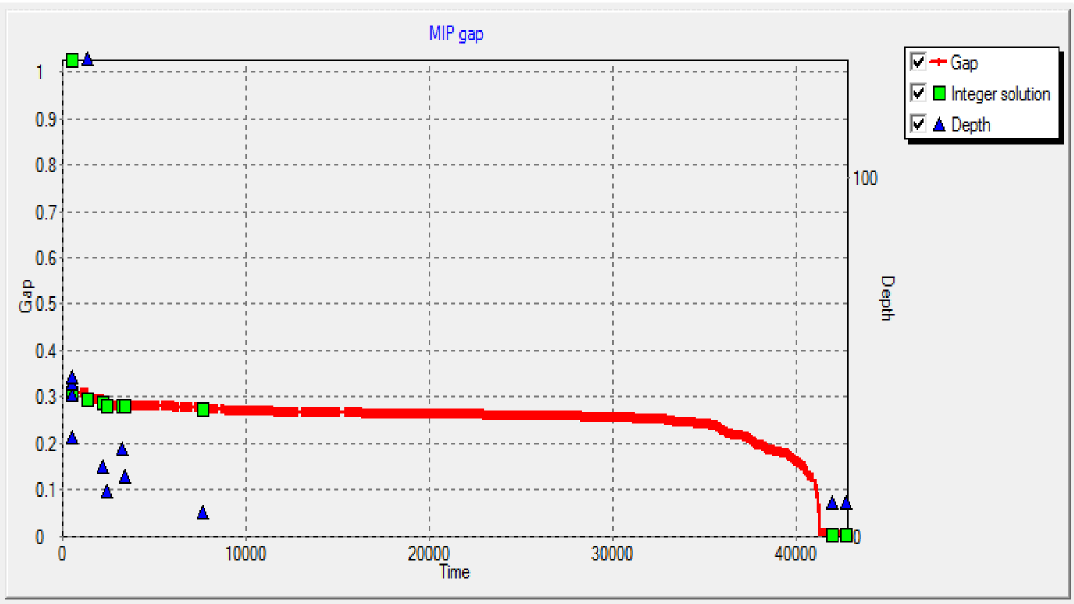

Figure 7: finding the best solution

The optimal solution is achieved when the gap between lower and upper bounds of the objective value is acceptably small as shown in Figure 7Lower bound to the optimal solution can be found by relaxation of constraints; upper bound to the optimal solution can be found by inserting feasible solutions [26].

The global search has been terminated when

$$|\mathrm{MIPOBJVAL} - \mathrm{BESTBOUND}| \leq \mathrm{MIPRELSTOP} * \ \mathrm{BESTBOUND}$$

WhereMIPOBJVAL is the value of the best solution's objective function and BESTBOUND is the current best solution bound. The solution search process has been terminatedas shown in Figure 8 by finding the best integer solution of 297,837 $ in 41,932 second (699 min) after reaching a relative MIP gap less than the MIPRELSTOPat a best bound of 297,837.0625$ after performing11,721 iterations.

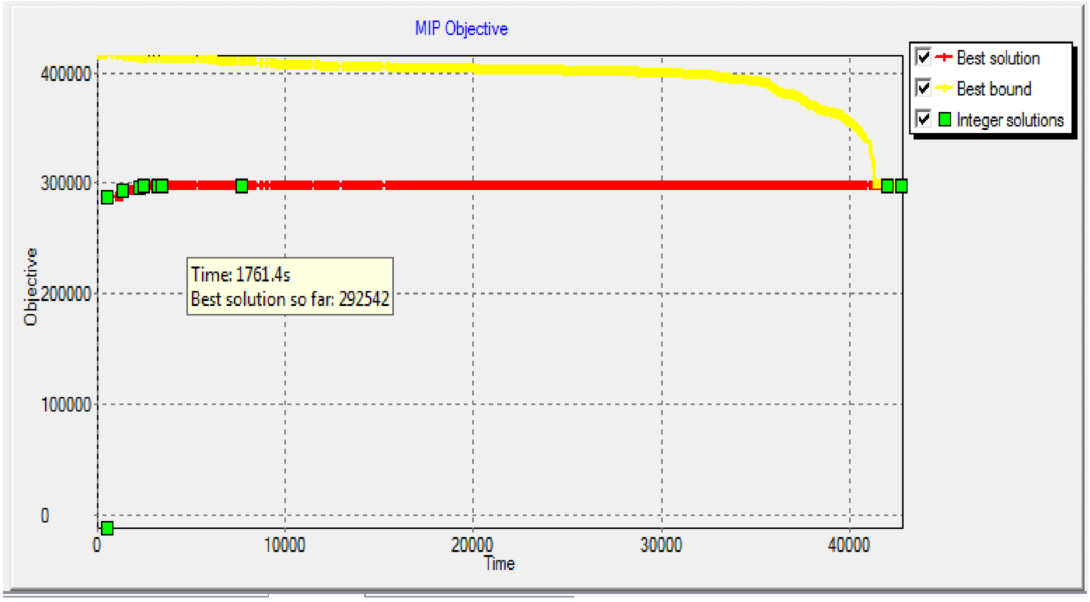

Figure 8: development of the best solution, best bound and integer

Regarding the output data, it is not useful to put it in the context of this paper. So, this huge amount of output data could be found in https://www.dropbox.com/s/8gvf2xqwvjz1ws5/Results.xlsx?dl=0

V. Conclusion

In this work, a multi-stage stochastic model for multi-product closed-loop supply chain network design is developed. The network contains both forward and reverse logistics facilities. The forward directionprovides the first customer zones with virgin products, while the reverse provides the second customer with refurbished products, providesthe suppliers with the recyclable materials and providesthe factories with the remanufacturable products. The formulation of the model has been done using multi-stage SMILP. The objective of the model is to optimally configure the closed-loop supply chain network to maximize the total expected profit.

It is recommened to develop the model to tackle the multi-objective closed loop supply chain network design under risk.

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