

DEVELOPING A ROBUST GREEN SUPPLY CHAIN PLANNING OPTIMIZATION MODEL CONSIDERING POTENTIAL RISKS

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ABSTRACT: Planning of the green supply chain has a great effect on its performance and on the environment. In this paper, a robust green supply chain network planning optimization model has been developed considering potential risks to identify production, inventory and shipping method. Robustness has been considered in the customers' demands of multi-periods. The developed model aims to maximize the supply chain network profit, maximize customer service level, and minimize the transportation Green House Gases emissions to reduce the negative risks (threats) on the environment, enhance sustainability and raise the value for money gaining from the network for all stakeholders. The proposed mathematical model has been formulated using Mixed Integer Linear Programming and solved using three different solvers; Excel solver, evolver solver and @RiskOptimizer. The results have been discussed and analyzed in a manner to study the effect of robustness on the supply chain network behaviour. It can be concluded that the best optimal value has been achieved using Evolver solver plan which is the smoothest and the most practical.

KEYWORDS: *Robust; Green supply chain; Production planning; Risks Management; Multi-objective; MILP; and Multi-periods*

1. INTRODUCTION

It is not possible to expect many things very accurately because of the uncertainty that leads to risk [1]. Risk is an unavoidable phenomenon and affecting the system respective process, operations ...etc. [2]. SCM is one of the most important fields considered for reducing environmental impacts [3, 4]. Green supply chain management (GSCM) has been studied [5-7] in which every activity is consisting of various risks [8, 9]. Supply chains were optimized with the general objective to minimize total costs [10], M. S. Al-Ashhab, N. Afia, and L. A. Shihata [11] studied the effect of the optimization objective on the SCN performance and concluded that optimizing the total cost has a bad effect on the performance of the business establishments. Sustainability issues are becoming more prevalent and environmental concerns are required to be addressed [12, 13].

The occurrence of risks may adversely impact the system if managers do not take them into consideration [14, 15]. The management of GSC risks is still a gap [16]. Risks understanding and managing are very important for managers to reduce their consequences [17, 18]. Risks cause disruption or disturbance in the system [19]. So, it is necessary to include environmental aspects into SCM [20] especially those of negative impacts like resources, energy consumption and pollution. K. Hoen, T. Tan, J. Fransoo, and G. Van Houtum [21], E. Demir, T.

Bektaş, and G. Laporte [22], and C. Lin, K. L. Choy, G. T. Ho, S. H. Chung, and H. Lam [23] studied green transportation, S. Jain, E. Lindskog, J. Andersson, and B. Johansson [24] and Xie [25] focused on consumption of energy.

F. Wang, X. Lai, and N. Shi [26] studied an SCND problem with environmental concerns but they considered a single period model without inventory stored in each facility. In addition, other works that may be referred to are concerning supplier selection [27, 28], integrated modelling approaches [29, 30], and/or empirical case studies [31, 32]. An optimization model to select transportation modes, minimizing total costs, in addition, minimizing CO₂ emissions has been suggested by Le and Lee [33]. A majority of transportation in the construction industry, and other industries, are completed by road (truck) transport [34].

F. Altıparmak, M. Gen, L. Lin, and T. Paksoy [35] formulated a multi-objective MINL model for a single product SCND. A multi-objective model to solve the problem of SC design taking into account demand satisfaction, the NPV, and financial risk was developed by G. Guillén, F. Mele, M. Bagajewicz, A. Espuna, and L. Puigjaner [36]. Liu and Papageorgiou [37] used a multi-objective MILP formulation in studying the production, capacity planning, and distribution of SCs. M. El-Sayed, N. Afia, and A. El-Kharbotly [38] developed a multi-period multi-

echelon forward–reverse logistics network design under risk model maximizing the total expected profit.

The aim of the present study is to investigate a robust green supply, a robust green supply chain network planning optimization model has been developed considering potential risks. Robustness has been considered in the customers' demands of multi-periods. The developed model aims to maximize network profit, maximize customer service level (CSL), and minimize the transportation gas emissions which can reduce the negative risks (threats) on the environment. These can enhance sustainability and raise the value for money gaining from the network for all stakeholders. The results have been discussed and analyzed in a manner to study the effect of robustness on the supply chain network behaviour. The proposed model has been solved using different solvers; Excel solver, evolver and @RiskOptimizer. This work is an extension of the work done by M. S. Al-Ashhab and E. A. Mlybari [39].

The system consists of one facility which is served by three potential suppliers to serve three potential customers as shown in Fig. 1.

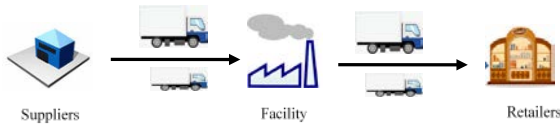


Fig. 1 Supply chain diagram [38].

The following assumptions have been considered:

1. The supply chain is single-product.
2. The supply chain is composed of three echelons; suppliers, factory and customers.
3. Customers' demands are robust and are assumed as normally distributed.
4. There are two types of trucks (Big and small).
5. Each type of trucks has a limited capacity.
6. Each truck should be fully loaded to be used.
7. Each truck should serve only one customer at the same trip.
8. The amount of CO₂ gas emissions of the trucks is assumed to be constant and depends on the type and distance travelled.
9. The model considers three objectives; maximizing both profit and CSL while minimizing the gas emissions.

2. MODEL FORMULATION

In addition to the sets, parameters and variables mentioned in [40], the model involves the following:

Sets:

M: Set of trucks.

Parameters:

CAPTM_m: carrying capacity of truck *m*

GE_{mt}: gas (CO₂) Emissions of truck *m* per km in period *t*

TC_{mt}: transportation cost of the transportation mode *m* per kilometer in period *t*

DEM_{ct}: demand of customer *c* in period *t*,

μ_{ct}: demand mean of customer *c* in period *t*,

σ_{ct}: demand standard deviation of customer *c* in period *t*,

Decision variables:

N_{msft}: The total number of mode *m* shipments from supplier *s* to the facility in period *t*

N_{mftc}: The total number of mode *m* shipments from the facility to customer *c* in period *t*

2.1 Model Objectives

There are three objectives have been considered through this developed model:

- Total Profit
- Customer Service Level (CSL)
- CO₂ Emissions

2.1.1 Total profit objective

The profit is the difference between the total revenue calculated as in Eq. (1) and the total cost Eq. (4). The total cost is the summation of fixed, material, manufacturing, non-utilized capacity, back-ordering, transportation, and inventory holding costs calculated as shown in (4).

$$TR = \sum_{c \in C} \sum_{t \in T} ((Q_{fct} + I_{fct}) * B_f * P_{ct}) \quad (1)$$

2.1.2 Customer Service Level Objective

The CSL may be calculated as in (2).

$$CSL = \frac{\sum_{c \in C} ((Q_{fct} + I_{fct}) * B_f * W)}{\sum_{c \in C} (DEM_{ct} * W)} \quad (2)$$

2.1.3 CO₂ Emissions

The CO₂ Emissions may be calculated as in (3).

$$CO_2 \text{ Emissions} = \sum_{m \in M} \sum_{t \in T} \sum_{s \in S} N_{msft} * GE_{mt} * D_{sf} + \sum_{m \in M} \sum_{t \in T} \sum_{c \in C} N_{mfct} * GE_{mt} * D_{fc} \quad (3)$$

$$\begin{aligned} & T \ C \\ & = \sum_{s \in S} \sum_{t \in T} Q_{sft} * B_s * MatCost + (I_{if} - F_{if}) * W \\ & * MatCost + \sum_{c \in C} \sum_{t \in T} (Q_{fct} + I_{fft}) * B_f * MH * MC_{ft} \\ & + (I_{if} - F_{if}) * MH * MC_{ft} \\ & + \sum_{t \in T} (CAPH_{ft} \\ & - (\sum_{c \in C} (Q_{fct} + I_{fft}) * B_f * MH)) * NUCC_f \\ & + \sum_{c \in C} (DEM_{c1} - (Q_{fc1} + I_{fc1})B_f) * SCPU) \\ & + \sum_{c \in C} (\sum_{g \in 2..T} DEM_{c2} \\ & - \sum_{g \in 2..T} (Q_{fct} + I_{fct}) * B_f) * SCPU) \\ & + \sum_{m \in M} \sum_{t \in T} \sum_{c \in C} N_{mfct} * T_m * D_{fc} + I_{if} * B_f * W * HF \\ & + \sum_{t \in (1-T)} R_{ft} * B_f * W * HF \\ & + FCf \end{aligned} \quad (4)$$

2.2 Constraints

There are two categories of constraints that have been taken into consideration in this model to ensure flow balancing and capacity limits

2.2.1 Balancing constraints

Constraint (5-9) are the flow balancing equations of materials and products.

$$\sum_{s \in S} Q_{sft} * B_s = \sum_{c \in C} Q_{fct} * B_f * W_p + I_{fft} * B_f * W_p, \forall t \in T \quad (5)$$

$$I_{fft} * B_f + I_{if} = R_{ft} * B_f + \sum_{c \in C} I_{fct} * B_f \quad (6)$$

$$I_{fft} * B_f + R_{ft(t-1)} * B_f = R_{ft} * B_f + \sum_{c \in C} I_{fct} * B_f, \forall t \in (2 - T) \quad (7)$$

$$R_{ft} * B_f = FI_f \quad (8)$$

$$\begin{aligned} & (Q_{fct} + I_{fct})B_f \\ & \leq DEM_{ct} \\ & + \sum_{1 \rightarrow t} DEM_{c(t-1)} - \sum_{d \in D} (Q_{fct(t-1)} + I_{fct(t-1)})B_f, \forall t \\ & \in T, \forall c \in C \end{aligned} \quad (9)$$

2.2.2. Capacity constraints

Constraints (10-15) are the capacities equations.

$$Q_{sft} * B_s \leq CAP_{st}, \forall s \in S, \forall t \in T \quad (10)$$

$$\sum_{s \in S} Q_{sft} * B_s \leq CAPM_{ft}, \forall t \in T \quad (11)$$

$$\left(\sum_{c \in C} Q_{fct} * B_f + I_{fft} * B_f \right) MH \leq CAPH_{ft}, \forall t \in T \quad (12)$$

$$Q_{sft} * B_s = \sum_{m \in M} CAPTM_m * N_{msft}, \forall s \in S, \forall t \in T \quad (13)$$

$$(Q_{fct} + I_{fct}) * B_f * W = \sum_{m \in M} (CAPTM_m * N_{mfct}), \forall c \in C, \forall t \in T \quad (14)$$

$$R_{ft} * B_f * w_p \leq CAPFS_{st}, \forall t \in T \quad (15)$$

3. MODEL VERIFICATION

The problem has been solved using different solvers; Excel solver, evolver and @RiskOptimizer to check the ability of the @RiskOptimizer to solve it. Since Excel Evolver solver can solve only the deterministic problems and to make a comparison between the results of them with the results of @RiskOptimizer, the variability of demands will be reduced to Zero. The comparison has been made considering the profit optimization.

3.1 Model Inputs

Demands of each customer over the three periods are assumed as 11000, 10000, and 9000 units per period. Table 1 represents the model parameters while the assumed demands are shown in Table 1.

3.2 Model Outputs and Analysis

The model is solved using different solvers; Evolver, Excel, and @RiskOptimizer solvers on an Intel® Core™ i3-2310M CPU @2.10 GHz (3 GB of RAM).

The results of the three solvers are presented and analyzed in this section.

Table 1 List of input parameters and their respective values

Parameter	Value	Unit
S and C	3	--
Iif	500	Unit
Fif	1000	Unit
Pct	100	\$/Unit
W	1	Kg
MH	1	Hrs
CAPst	50000	Kg
CAPHft	12000	Hrs
CAPMft	10000	Kg
CAPFSft	2,000	Kg
CAPTM _m	300& 200	Kg/truck
MatCost	10	\$/kg
MCft	10	\$/hr
MH	1	hrs
MCft	10	\$/hr
NUCCf	5	\$/hr
SCPU	5	\$/unit.
HC	3	\$/kg.
Bs	100	Unit
Bf	10	Unit
FCmt	0.02& 0.01	gallon/km
GEmt	3, 2	g/km
TCmt	0.3& 0.2	\$
FC	50,000	\$

The optimal values of the three solvers are shown in Table 2 from which it can be concluded that the best optimal value has been achieved using Evolver solver plan which is the smoothest and the most practical as it is obvious from Tables 3-5. But the other optimal values obtained using Excel, and @RiskOptimizer solvers are also accepted where they have a small deviation as shown in Table 2. So, using @RiskOptimizer in optimizing this problem is accepted since its plan also achieves the same CSL as achieved by the other solvers as presented in Table 6. Table 7 shows the transportation plan resulted from Evolver solver from which it is noticed that truck of type 2 has been used in most shipments because of its low cost while truck of type 1 has been used only for one trip to transfer the remaining quantities.

Table 2 Optimal values of the three solvers

Solver	Evolver	Excel	@ Risk
Total Profit	1649705	1646799	1648571
CSL	100 %	99.8 %	99.9 %
Deviation	0 %	0.18 %	0.07%

Table 3 Evolver results

	Cust.	Period		
		1	2	3
Demand	1	11000	10000	9000
	2	11000	10000	9000
	3	11000	10000	9000
QFC	1	0	0	0
	2	10000	10000	9000
	3	0	0	0
IFC	1	0	0	0
	2	500	0	0
	3	0	0	0
Deliv.	1	0	0	0
	2	10500	10000	9000
	3	0	0	0

Table 4 Excel Solver results in thousands

	Customer	Period		
		1	2	3
Demand	1	11000	10000	9000
	2	11000	10000	9000
	3	11000	10000	9000
QFC	1	0	0	0
	2	10000	5800	5281
	3	0	0	0
IFC	1	200	800	0
	2	100	0	3719
	3	0	3600	0
Deliv.	1	200	800	0
	2	10100	5800	9000
	3	0	3600	0

Table 5 @RiskOptimizer results

	Customer	Period		
		1	2	3
Demand	1	11000	10000	9000
	2	11000	10000	9000
	3	11000	10000	9000
QFC	1	9646	0	6348
	2	0	0	193
	3	0	0	0
IFC	1	854	9400	252
	2	0	400	207
	3	0	200	0
Deliv.	1	10500	9400	6600
	2	0	400	2400
	3	0	200	0

Table 6 Customer Service Level of the three solvers

Customer	CSL		
	Evolver	Excel	@Risk
1	0%	0%	88%
2	98%	98%	9%
3	0%	0%	1%

Table 7 Transportation plan resulted from Evolver solver

	Customer	Period		
		1	2	3
Truck 1	1	0	0	0
	2	300	0	0
	3	0	0	0
Truck 2	1	0	0	0
	2	10200	10000	9000
	3	0	0	0

4. RESULTS AND DISCUSSIONS

The problem has been solved using @RiskOptimizer and the results are presented and analyzed in this section. The demands are assumed as in the previous section in addition to assuming that the demands are normally distributed and their parameters are shown in Table 8. All demands are assumed to be normally distributed with a 10% variability. @RiskOptimizer supports around 83 types of distributions.

Table 8 Demands parameters

	MIN	MEAN	MAX
DEMCT11	8,119	11,001	13,978
DEMCT12	7,164	9,997	12,477
DEMCT13	6,379	8,995	11,304
DEMCT21	8,169	11,001	13,962
DEMCT22	7,583	10,000	12,441
DEMCT23	6,545	9,001	11,421
DEMCT31	8,022	11,001	13,915
DEMCT32	7,469	10,000	12,450
DEMCT33	6,783	9,001	11,578

To verify the solving capability of the @RiskOptimizer, the problem has been solved four times to optimize different objectives; Total profit, CLS, CO₂ emissions, and the summation of the three objectives (as a multi-objective with equally weighted objectives). The results of these four cases are tabulated in Table 9 from which it is clearly noticed that the results are logical. But the problem is that the Archimedean procedure used in the fourth case is not accepted because the three objectives do have the same units since the profit is in dollars, CSL is unitless,

and CO₂ emissions are in kg. So, it is suggested to develop the model to optimize multi-objectives using the lexicographic procedure.

Table 9 Expected objectives values for the four cases

Val	Optimized objective			
	Profit	CSL	CO ₂	MO
Profit	1648391	1607273	-1165000	1645504
CSL	33%	33%	0%	33%
CO ₂	224357	173876	0	2549

Initially, profit, CLS, and CO₂ emissions have been optimized individually and the resulted optimal distributions are depicted in Figs. 2, 3 & 4 respectively. Finally, they have been optimized as a multi-objective using the Archimedean procedure and the results of optimization are depicted in Figs 5-8. Since, Fig. 5. shows the distribution of the optimal resulted equally weighted objectives summation while Fig. 6 presents the distribution of the optimal profit, Fig. 7 presents the distribution of the optimal CSL, and Fig. 8 presents the distribution of the optimal CO₂ emissions.

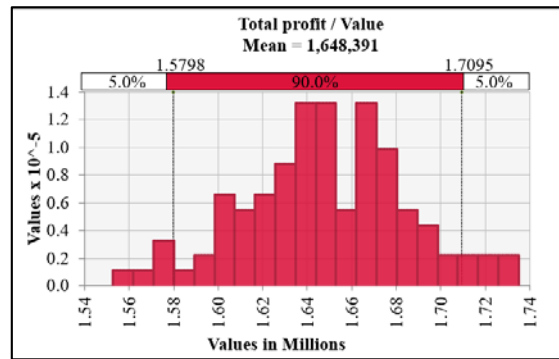


Fig. 2 Optimal resulted Total Profit distribution

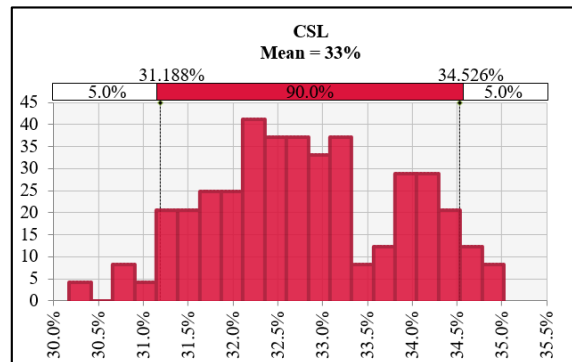


Fig. 3 Optimal resulted CSL distribution

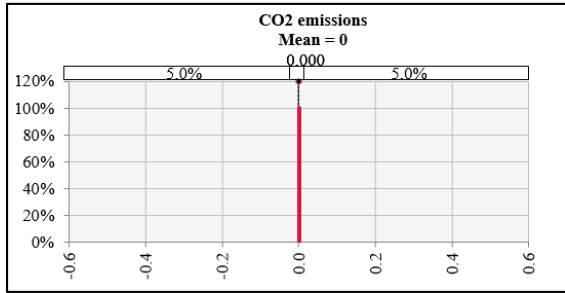


Fig. 4 Optimal resulted CO₂ emissions distribution

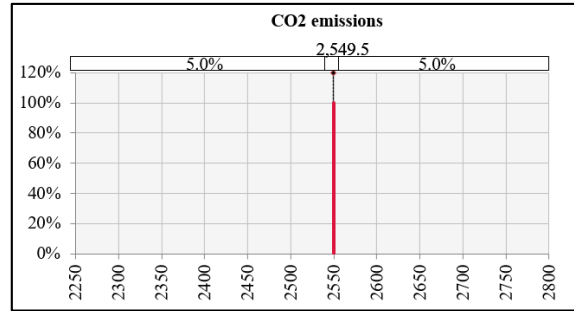


Fig. 8 Optimal resulted CO₂ emissions distribution when optimizing objectives summation

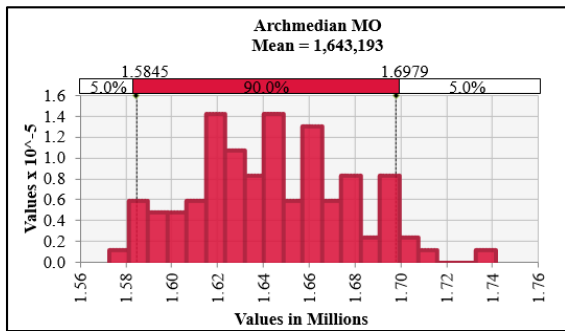


Fig. 5 Optimal objectives summation distribution



Fig. 6 Optimal resulted total profit distribution when optimizing objectives summation

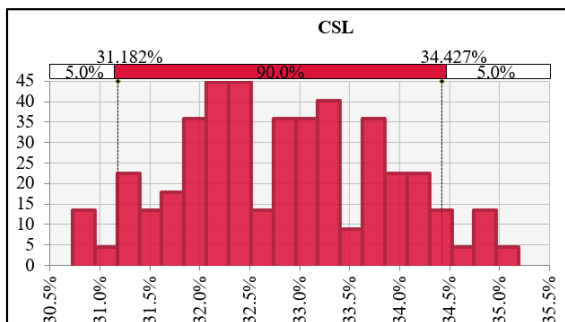


Fig. 7 Optimal resulted CSL distribution when optimizing objectives summation

5. CONCLUSIONS

In this research, a robust green supply chain network planning mathematical optimization model has been developed considering potential risks to identify production, inventory and shipping method. Robustness has been considered in the multi-period's customers' demands. The developed model successfully maximizes network profit, maximizes customer service level, and minimizes the transportation Green House Gases emissions which reduce the negative risks (threats) on the environment. These should enhance sustainability and raise the value for money gaining from the network for all stakeholders. But the problem is that the Archimedean procedure used in optimizing the summation of the three objectives (as a multi-objective with equally weighted objectives) is not accepted because the three objectives do have the same units since the profit is in dollars, CSL is unitless, and CO₂ emissions are in kg. So, it is suggested to develop the model to optimize multi-objectives using the lexicographic procedure.

Future work:

It is recommended to include:

1. the multi-product problem.
2. the uncertainty of other factors in addition to customers' demands.
3. different modes of transportations.
4. Each truck should serve more than one customer at the same trip.
5. Using the lexicographic procedure to optimize multi-objectives.

6. ACKNOWLEDGEMENT

The authors thank Perfect Building Contracting Establishment for its support to do this research.

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