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A ROBUST BI-OBJECTIVE UNCERTAIN GREEN SUPPLY CHAIN NETWORK MANAGEMENT

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Abstract

Conflicting objectives becomes a common issue in many supply chain network optimization problems. In this paper, a new model is formulated to design a green supply chain network through a new mixed integer linear programming problem. Uncertain demand and stochastic environmental respect levels are the main parameters of the formulation. The first objective function minimizes the cost of the supply chain while the second objective function minimizes CO_2 emission. Conditional Value at Risk (CVaR) approach is adapted to deal with demand uncertainty and the stochastic CO_2 emission level. Finally, the model outputs and its results discussion are illustrated through a numerical example.

Keywords: Green supply chain, conditional value at risk, uncertainty, stochastic programming, robust optimization

1. INTRODUCTION

Nowadays, environmental concern becomes a crucial global issue. Green Supply Chain (GrSC) is an effective approach to deal with this significant global attitude (Golpîra et al., In Press). Thus, Green Supply Chain Network Design (GrSCND) becomes very important area for both practitioners and researchers (Coskun et al., 2016). That is, it not only reduces negative environmental impacts, but also enhances the competitiveness of companies (Wu et al., 2015). In this paper, a new model is formulated to design a Green Supply Chain Network (GrSCN) through a robust bi-objective programming.

Jamshidi et al. (2012), proposed a multi-

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objective GrSC optimization, however, the approaches and the contributions were quite different. The proposed study formulates the problem under uncertain environment, which makes the proposed method more realistic. Rather than the impact of CO_2 emission in the network upstream, the demand uncertainty and the retailers' risk averseness are addressed in the proposed model. To do these, a bi-objective mathematical programming is formulated in order to design a multi-tiered single product GrSCN. Environmental protection investment and fixed production, alliance, and transportation costs are considered in the first objective function while, second objective function is used to handle the environmental aspects. To the best our knowledge, there is no similar research to address this collaboration incorporated with the risk averseness of retailers and stochastic CO_2 emission level only in the network upstream. Reformulation of the second objective function makes the model analytically solvable. The main contributions of this paper are as follows:

a) Formulating a new robust GrSCND problem in compliance with retailers' risk averseness and stochastic CO_2 emission level is the main contribution of the paper.

b) Integrating stochastic environmental parameters with risk management results in a new method in the area of Green Supply Chain Network Design Problem (GrSCNDP).

The rest of the paper is as follows: The mathematical formulation will be described in section 2 with details. Model formulation and solution approach will be pointed out in section 3. Computational results will be presented in section 4 and finally, conclusions will be presented in section 5.

2. LITERATURE REVIEW

According to the extensive review, reported by Seuring (2013); Brandenburg et al. (2014); El bounjimi et al. (2014); Gunasekaran et al. (2015); Eskandarpour et al. (2015), some more recent close researches are studied as follows. Feng et al. (2014) investigated a Closed-Loop Supply Chain Network Design Problem (CLSCNDP), regarding the demand uncertainty. Talaei et al. (2016) examined a facility location/allocation model for the same problem with collection/inspection, manufacturing/remanufacturing, and disposal centers through a robust fuzzy programming approach. Garg et al. (2015) formulated a CLSCNDP through a bi-objective nonlinear integer programming approach and leveraged interactive multi-objective programming to solve the model. Soleimani and Kannan (2015) formulated a new CLSCNDP given both the design and the planning decision variables. They solved their model by a new hybrid meta-heuristic algorithm. Mallidis et al. (2014) analized the impact of GrSCND and inventory optimization problem in a Supply Chain Network (SCN). Gui-tao et al. (2014) introduced a SCNDP considering the customers' price rigidities in compliance with the manufacturers' risk awareness. Sharifzadeh et al. (2015) designed a biofule SCN subject to seasonal and geographical uncertainties, throughout a Mixed Integer Programming (MIP) problem. Coskun et al. (2016) considered customers' green expectations in a new GrSCNDP. Kawasaki et al. (2015) proposed a GrSCNDP via multi-criteria decision making methods for the lead times, costs and CO_2 emissions. Rezaee et al. (2015) proposed the same GrSCNDP in a carbon trading environment through a two-stage stochastic programming approach. Demand uncertainty and SCN responsiveness under different carbon policies are successfully addressed in the model proposed by Martś et al. (2015). Kagawa et al. (2015) analyzed the importance of the CO_2 emissions in Global Supply Chain Network (GSCN). Dotoli et al. (2015) rated the candidates companies in each tier of SCN, using the cross-efficiency Data Envelopment Analysis (DEA) in fuzzy environment. Kannegiesser et al. (2015) tried to minimize the time to sustainability parameter in a SCND problem. Urata et al. (2015) balanced the costs and the CO_2 emmision volumes via a MIP approach. Golpîra et al. (2015) investigated the same problem using multi-objective mathematical programming and the CO_2 emmission in all of the tiers of the network. Concidering the greenness in the last tier of the network, in their research, may reduce the importance of the parameter risk averseness. Miret et al. (2016) formulated a biomass SCNDP via multi-objective optimization approah, considering all sustainable development dimensions. Chibeles-Martins et al. (2016) formulated a mixed integer linear multi-objective programming model for GrSCNDP and solved it throughout a meta-heuristic algorithm based on Simulated Annealing (SA) approach. Nakamichi et al. (2016) estimated the cost and CO_2 emission with a sustainable SCN in a Thailand automobile industry. Nouira et al. (2016) investigated the impacts of a carbon emission-sensitive demand on SCNDP and examined their model in a textile industry.

This paper formulates a new robust GrSCNDP in compliance with stochastic CO_2 emission level and retailers' risk averseness in the network last tier. The proposed method and Gui-tao et al. (2014) have the same methodology to deal with the risk averseness parameter. But, Gui-tao et al. (2014) considered the risk averseness of the manufacturer, whereas the proposed model is based on the risk averseness of the network demand side. Li et al. (2014) investigated a SCN designation with risk averse retailer and risk natural manufacturer. They considered single objective dual-channel SCND with no attention to greenness attitude. Also, Rezaee et al. (2015) considered the same idea regarding uncertain demand and environmental investment, but they reached different results. This paper not only considers the uncertain demand and stochastic level of CO_2 emission, but also reflects the risk averseness of the network, simultaneously.

3. PROBLEM DESCRIPTION, FORMULATION AND SOLUTION

The problem consists of several companies to produce a single product in a multi-tiered GrSCN. Uncertain demand and retailers' risk awareness are considered in the model. The first objective function contains of fixed alliances set-up costs, environmental protection investment, and transportation and manufacturing costs. Holding and shortage costs are not assumed in the model in order to achieve simpler model. Consumer relationship is allowed in the last echelon for the SCN. Thus, the demand uncertainty affects the SCN directly from this tier. The following notation for the model formulation is described:

$l \in L$	set of scenarios for the environmental respects level
$a \in A$	set of operations
$i \in I$	set of potential companies available for tier a
$j \in J$	set of potential companies available for tier $a+1$
$(i,j) \in \Gamma$	set of available alliances
$v \in V$	set of environmental protection level
I_a	number candidates in tier a
$\eta_{i,a,j,a+1}$	fixed cost of linking candidate i in tier a to candidate j in tier $a+1$
$\vartheta_{i,a,v}$	fixed environmental protection investment at candidate i in tier a according to environmental protection level v
$\tau_{i,a,j,a+1}$	transportation unit cost from candidate i in tier a to candidate j in tier $a+1$
$\xi_{i,a}$	unit processing cost at candidate i in tier a
$q_{i,a}$	the environmental protection level of candidate i in tier a
s_l^-	under-achievement of the goal regarding the environmental respects level l
s_l^+	supper-achievement of the goal regarding the environmental respects level l
ψ	a very large number
ϕ	unit penalty cost, assigned to control the level of CO_2 emission
α	risk averseness of the DM
ε	adequately small number as a penalty for the s^-
$\tilde{\Delta}$	uncertain amount of total CO_2 emission level in all the SC
$\chi_{i,a,v}$	per-unit environmental influence in facility i in tier a at level v
$\pi_{i,a,j,a+1}$	amount of CO_2 emission for the arc $i,a,j,a+1$
$\tilde{d}$	uncertain demand
$x_{i,a,j,a+1}$	amount of product shipped from candidate i in tier a to candidate j in tier $a+1$
$z_{i,a}$	amount of product manufactured at candidate i in tier a

$$y_{i,a,j,a+1} = \begin{cases} 1 & \text{if relation between member } i \text{ in tier } a \text{ and member } j \text{ in tier } a+1 \text{ is included} \\ 0 & \text{otherwise} \end{cases}$$

$$\omega_{i,a} = \begin{cases} 1 & \text{if candidate } i \text{ in tier } a \text{ is included in the chain} \\ 0 & \text{otherwise} \end{cases}$$

$$q_{i,a,v} = \begin{cases} 1 & \text{if the environmental protection } v \text{ is selected} \\ 0 & \text{otherwise} \end{cases}$$

The bi-objective mixed integer linear programming formulation of the model is described as follows:

$$\Theta = \min \sum_{a=1}^{\varphi}\sum_{j=1}^{I_{a+1}}\sum_{i=1}^{I_a}\eta_{i,a,j,a+1}y_{i,a,j,a+1} + \sum_{a=1}^{\varphi}\sum_{i=1}^{I_a}\xi_{i,a}z_{i,a} + \sum_{a=1}^{\varphi}\sum_{j=1}^{I_{a+1}}\sum_{i=1}^{I_a}\tau_{i,a,j,a+1}x_{i,a,j,a+1} + \sum_{a=1}^{\varphi-1}\sum_{i=1}^{I_a}\sum_{v=0}^{V}\vartheta_{i,a,v}q_{i,a,v} \quad (1)$$

$$\Theta' = \min \sum_{a=1}^{\varphi-1}\sum_{i=1}^{I_a} z_{i,a}\sum_{v=0}^{V}\chi_{i,a,v} + \sum_{a=1}^{\varphi-1}\sum_{i=1}^{I_a}\sum_{j=1}^{I_{a+1}}\pi_{i,a,j,a+1}x_{i,a,j,a+1} \quad (2)$$

Subject to:

$$\sum_{v=0}^{V} q_{i(a)v} - 1 \le 0, \qquad i \in I, a \in A, \quad (3)$$

$$\sum_{i=1}^{I_a} \omega_{i(a)} - 1 = 0, \qquad a \in A, \quad (4)$$

$$\omega_{i,a} \ge y_{i,a,j,a+1}, \qquad \forall (i,j) \in \Gamma, \ a \in A, \quad (5)$$

$$\omega_{j,a+1} \ge y_{i,a,j,a+1}, \qquad \forall (i,j) \in \Gamma, \ a \in A, \quad (6)$$

$$\omega_{i,a} + \omega_{j,a+1} \le y_{i,a,j,a+1} + 1, \qquad \forall (i,j) \in \Gamma, \ a \in A, \quad (7)$$

$$\omega_{i,a} - \sum_{v=1}^{V} q_{i,a,v} = 0 \quad , i \in I, \ a \in A, \quad (8)$$

$$\omega_{i,a} \times \psi \ge \sum_{j=1}^{I_{a+1}} x_{i,a,j,a+1}, \qquad i \in I, \ a \in A, \quad (9)$$

$$\omega_{j,a+1} \times \psi \ge \sum_{i=1}^{I_a} x_{i,a,j,a+1}, \qquad j \in J \quad a \in A, \quad (10)$$

$$\sum_{j=1}^{I_{a+1}} x_{i,a,j,a+1} = z_{i,a}, \qquad i \in I, \ a \in A, \quad (11)$$

$$\omega_{i,a} \times \tilde{d} \le z_{i,a}, \qquad i \in I, \ a \in A, \quad (12)$$

$$x_{i,a,j,a+1} \ge 0, \qquad \forall (i,j) \in \Gamma, \ a \in A, \quad (13)$$

$$q_{i,a,v} \in \{0,1\}, \qquad i \in I, \ a \in A, \ v \in V \quad (14)$$

$$y_{i,a,j,a+1} \in \{0,1\}, \qquad \forall (i,j) \in \Gamma, \ a \in A, \quad (15)$$

$$\omega_{i,a} \in \{0,1\}, \qquad i \in I, \ a \in A. \quad (16)$$

Equation (1) defines total cost of the network while, facility-depending and linkage-depending CO2 emission are integrated into related variables in Equation (2). By constraint (3) the final SCN selects only one environmental level for each selected company. Constraints (4)-(7), ensure that the final network holds only one company a tier, and Constraint (8) selects the environmental level only from the opening alternatives. By Constraints (9) and (10), the production is performed only through the designed network, balanced by Constraints (11). Constraint (12) is to build the link between $z_{i,a}$ and $w_{i,a}$ while, the type of the variables are defined by Constraints (13) to (16).

To solve the problem, the goal programming approach is adopted to the model with uncertain right hand side value, illustrated in Equation (17).

$$\sum_{a=1}^{\varphi-1}\sum_{i=1}^{I_a} z_{i,a}\sum_{v=0}^{V}\chi_{i,a,v} + \sum_{a=1}^{\varphi-1}\sum_{i=1}^{I_a}\sum_{j=1}^{I_{a+1}}\pi_{i,a,j,a+1}x_{i,a,j,a+1} - \tilde{\Delta} = 0 \qquad (17)$$

Considering scenario based approach to deal with the model, transforms Equation (1) and Equation (17) to Equation (18) and Equation (19) respectively:

$$\Theta = \min\sum_{a=1}^{\varphi}\sum_{j=1}^{I_{a+1}}\sum_{i=1}^{I_a}\eta_{i,a,j,a+1}y_{i,a,j,a+1} + \sum_{a=1}^{\varphi}\sum_{i=1}^{I_a}\xi_{i,a}z_{i,a} + \sum_{a=1}^{\varphi}\sum_{j=1}^{I_{a+1}}\sum_{i=1}^{I_a}\tau_{i,a,j,a+1}x_{i,a,j,a+1} + \sum_{a=1}^{\varphi-1}\sum_{i=1}^{I_a}\sum_{v=0}^{V}\vartheta_{i,a,v}q_{i,a,v} + \sum_{l=1}^{L}\varsigma_l\left(\frac{s_l^+ + s_l^-}{r}\right) \qquad (18)$$

Subject to:

$$\sum_{a=1}^{\varphi-1}\sum_{i=1}^{I_a} z_{i,a}\sum_{v=0}^{V}\chi^l_{i,a,v} + \sum_{a=1}^{\varphi-1}\sum_{i=1}^{I_a}\sum_{j=1}^{I_{a+1}}\pi^l_{i,a,j,a+1}x_{i,a,j,a+1} - \Delta_l + s_l^- - s_l^+ = 0, \quad l = 1,\dots,L \qquad (19)$$

where r is the range of the objective function, assigned only to avoid any scaling problem. The idea that is employed in this paper to deal with demand uncertainty is to remove the best realizations of the data and optimize the problem over the remaining data as a robust optimization against downside risk, introduced by Bertsimas and Brown (2009). To do this, the conditional expectation $E[X | X \le q_\alpha(X)]$ is used in Equation (20), where $q_\alpha(X)$ is the α - *quantile* of the random variable X.

$$q_\alpha(X) = \inf\{x \mid P(X \le x) \ge \alpha\},\ \alpha \in (0,1) \qquad (20)$$

The presented problem in this paper is the minimization, so the cases with the lowest costs are removed and the tail expectation $E[X | X \ge q_\alpha(X)]$ is considered. A nonparametric estimator of the $E[X | X \ge q_\alpha(X)]$ is presented in Equation (21):

$$\mathrm{I}_\alpha = \frac{1}{N_\alpha}\sum_{k=1}^{I_\alpha} X_{(k)}, \qquad (21)$$

where N is the number of in-hand realizations, N_α is the number of remaining cases after trimming to the retailers' risk averseness level $\alpha\left(N_\alpha = \lfloor N\cdot(1-\alpha)+\alpha\rfloor \approx N\cdot(1-\alpha)\right)$

and $X_{(k)}$ is the k-th smallest component of $(X_1, ... X_N)$. In the presented problem, $X_{(k)}$ will be defined as the k-th greatest component.

The $E\,[\,X \mid X \geq q_\alpha\,(X)]$ is finally referred as the Conditional Value-at-Risk (CVaR) which is, in this paper, employed to deal with the demand uncertainty. So, the reformulation of Equation (12) is as follows:

$$z_{i(\varphi)} \geq \beta\left(\frac{1}{s_{1-\alpha}}\sum_{s=1}^{\lfloor s_{1-\alpha}\rfloor} d_{(s)} - \left(\frac{s_{1-\alpha}-\lfloor s_{1-\alpha}\rfloor}{\lfloor s_{1-\alpha}\rfloor}\right)d_{(\lceil s_{1-\alpha}\rceil)}\right).w_{i(\varphi)}, \qquad i=1,2,...,I_{\varphi}, \tag{22}$$

4. COMPUTATIONAL RESULTS AND SENSITIVITY ANALYSIS

Figure 1 illustrates the problem of a 4-tier network, with 3 potential candidates in each tier and 4 levels of environmental protection for each candidate. Each node of echelon $i(i=1,2,3)$ is concerned with a node in echelon j ($j = i + 1$), which yields to $12^3 \times 3 = 5184$ feasible routes altogether. A numerical example is established based on the randomly generated data, revealed in Table 1. Table 2, includes additional data for numerical example, built to study the effectiveness of the model. "Unif" in Table 2 stands for uniform distribution. The resulted problem can be solved by CPLEX 11.0 on a PC that has a 2.20GHz Intel(R) Core(TM)2 Duo CPU and 3.0G RAM. The results are shown in Table 3.

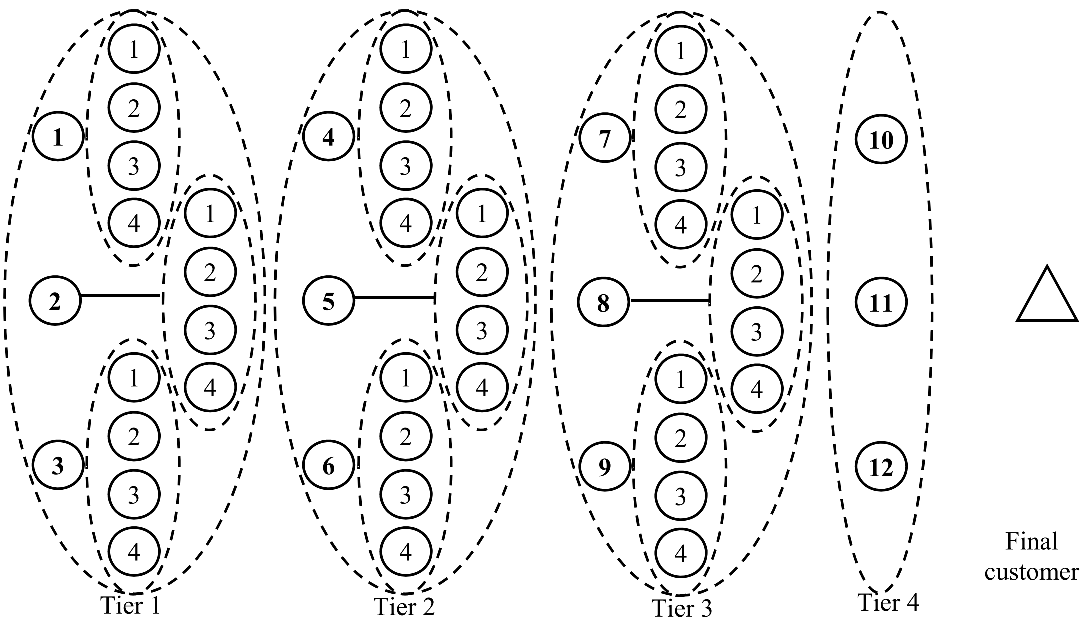

Figure 1. SCN for the example

Table 1. Scenarios

Scenario probability	Value of the environmental respects
0.35	145000
0.45	150000
0.20	160000

Table 2. Data used in the problem

Data type	Range
Uncertain demand	Unif (50, 500)
Transportation unit cost	Unif (10, 15)
Fixed alliance cost	Unif (1000, 5000)
Production unit cost	Unif (20, 60)
Fixed environmental protection investment	Unif (100, 300)

Table 3. Results of computational study

α	1-α	Expected cost	Located facilities (environmental level)	Chain performance	Cost variability	Percent cost variability
0.99	0.01	15206.61	2(4)-4(1)-7(1)-12	100%	-	-
0.98	0.02	15160.37	2(4)-4(1)-7(1)-12	100%	44.30	0.29%
0.97	0.03	15158.15	2(4)-4(1)-7(1)-12	100%	2.12	0.01%
0.96	0.04	15001.93	2(4)-4(1)-7(1)-12	100%	149.65	1.00%
0.95	0.05	14937.33	2(4)-4(1)-7(1)-12	100%	61.87	0.41%
0.94	0.06	14900.38	2(4)-4(1)-7(1)-12	095%	35.40	0.24%
			2(4)-4(1)-7(1)-10	005%		
0.93	0.07	14781.05	2(4)-4(1)-7(1)-12	094%	114.30	0.77%
		14628.05	2(4)-4(1)-7(1)-10	006%		
0.92	0.08	14536.82	2(4)-4(1)-7(1)-12	093%	146.56	1.00%
		14628.05	2(4)-4(1)-7(1)-10	007%		
0.91	0.09	12897.18	2(4)-4(1)-7(1)-12	091%	87.39	0.60%
		14781.05	2(4)-4(1)-7(1)-10	009%		
0.90	0.10	14628.05	2(4)-4(1)-7(1)-12	091%	92.10	0.63%
		14536.82	2(4)-4(1)-7(1)-10	009%		
			2(4)-4(1)-8(1)-11	030%		
0.70	0.30	14628.05	2(4)-4(1)-7(1)-12	055%		
			2(4)-4(1)-8(1)-12	015%		
			2(4)-4(1)-9(1)-12	005%		
0.50	0.50	11994.1	2(4)-4(1)-8(1)-11	040%	⋮	⋮
			2(4)-4(1)-7(1)-11	055%		
			2(4)-4(1)-8(1)-12	015%		
0.40	0.60	11399.66	2(4)-4(1)-8(1)-11	040%		
			2(4)-4(1)-7(1)-11	045%		
0.10	0.90	8725.123	2(4)-4(1)-9(1)-12	092%	-	-
			2(4)-4(1)-8(1)-11	008%		
0.09	0.91	8619.607	2(4)-4(1)-9(1)-12	099%	32.30	0.37%
			2(4)-4(1)-8(1)-11	001%		
0.08	0.92	8554.123	2(4)-4(1)-9(1)-12	100%	62.73	0.73%
0.07	0.93	8541.802	2(4)-4(1)-9(1)-12	100%	11.80	0.14%
0.06	0.94	8510.072	2(4)-4(1)-9(1)-12	100%	30.40	0.36%
0.05	0.95	8505.474	2(4)-4(1)-9(1)-12	100%	4.40	0.05%
0.04	0.96	8452.749	2(4)-4(1)-9(1)-12	100%	50.50	0.60%
0.03	0.97	8375.115	2(4)-4(1)-9(1)-12	100%	74.36	0.89%
0.02	0.98	8317.421	2(4)-4(1)-9(1)-12	100%	55.26	0.66%
0.01	0.99	8313.099	2(4)-4(1)-9(1)-12	100%	4.14	0.05%
			Results average		**58.85**	**0.49%**

The results show that the retailer's level of risk averseness has a significant impact on the final network designation. According to Table 3, it is inferred that by increasing the level of risk averseness, the expected cost is increased. It is obvious that there are only four deigned chains from all of 5184 possible ones. This may validate the model regarding the model robustness. That is, Mulvey et al. (1995) defined the model robustness as the situation in which the model remains "almost" feasible for all the scenarios. Table 3 reveals that chain 2(4)-4(1)-7(1)-12 is optimal for the large value of alpha and it has been substituted by the chain 2(4)-4(1)-9(1)-12 as the value of the parameter alpha decreases. Furthermore, the low cost variability with respect to the level of alpha makes the solution to be robust. Because Mulvey et al. (1995) defined the solution robustness as the remaining of the problem solution "close" to optimal for all of the scenarios. Finally, although Natarajan et al. (2009) set the alpha level to 0.99 or 0.95, Table 3 demonstrates the solution and the model robustness in the extended alpha range.

5. CONCLUSION

This paper investigates the single product GrSCNDP. The CVaR approach is successfully addressed in the formulated bi-objective mathematical programming to report the retailers' risk averseness in the last tier of the network. The model also reflects the effect of CO_2 emission level in the SCN upstream as well as the demand uncertainty in its' downstream. The capability of the model to consider demand uncertainty, stochastic CO_2 emission level, and the risk attitude of the retailer is the superiority of the model. The research found that the level of retailers' risk averseness has a significant impact on the GrSCND. Moreover, using the CVaR approach to deal with uncertainty of the demand in GrSCNDP, leads to robustness. Our numerical experiment simplifies the sensitivity analysis of the model to the parameter.

For practicing managers, there are some helpful information, may be found in the paper dealing with day-to-day motivational problems. Lack of information may clearly be inferred from practice especially in SCNs which contain several companies and marketplaces. The criticality of this uncertain situation is intensified regarding new products introduction from the SCN. According to the novelty of the product, the risk averseness of the retailer becomes a critical parameter in marketing. The model may be useful in such a situation because it makes robust decision which is valid for all the scenarios in such an uncertain environment. Greenness as the other important concept, addressed in the paper, is the crucial issue especially in the area of the car production, energy supply and the food supply networks. In addition, there are many practical real world examples which are using the retailers risk attitude in GrSCND problems. Fashion retailers, such as Zara, H&M, Mango and Top Shot try to be risk averse and green in order to achieve business success. The importance of green agricultural supply chain management in risky environment and policy-makers' risk aversion is also reported by some researchers such as Dwyer (2013).

РОБУСТНО БИ-ОБЈЕКТНО УПРАВЉАЊЕ ЕКОЛОШКИМ ЛАНЦИМА СНАБДЕВАЊА

Hêriş Golpîra

Извод

Конфликти међу циљевима постају чест фактор код оптимизације многих ланаца снабдевања. У овом раду, формулисан је нови модел дизајна мреже еколошких ланаца снабдевања, кроз нови проблем линеарног планирања заснован на миксу целих бројева. Основни параметри формулације су неизвесност потражње и стохастичко понашање окружења. Прва функција циља минимизира трошкове ланца снабдевања, док друга функција циља минимизира емисију CO_2. Приступ условне вредности ризика (CVaR) је прилагођен да би се анализирала неизвесност потражње и стохастички ниво емисије CO_2. На крају рада, излаз модела и дискусија резултата су илустровани преко нумеричког примера.

Кључне речи: Еколошки ланци снабдевања, условна вредност ризика, неизвесност, стохастичко програмирање, робустна оптимизација

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