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Robust Decision Model for Facility Location in a Global Supply Chain Network

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Abstract

Firm location and relocation in a modern business environment are stressed with many additional constraints under probable and possible uncertainties. Handling both the possibilities and probabilities in plant relocation problems are large scale optimization problems and they were seldom dealt by researchers considering either one of the cases. It's been a big challenge to account these two uncertainties together while decision making process. This research explores a way to combine the possibilities and probabilistic scenarios together by proposing a Hybrid Robust Optimization and Mixed Integer Linear Programming (ROMILP). By proposing a novel hybrid model this research critically investigates the possibility of establishing a facility plant or moving an existing Plant/Distribution Center (DC)/Regional Distribution Center (RDC) in the global supply chain. Solving the proposed model would be helpful for practitioners whom are willing to locate and or relocate an existing plant/DC/RDC in the global supply chain network

Keywords: Robust Optimization; Mixed Integer Linear Programming; Facility Relocation; Global Supply Chain; Network Design

1. Introduction

Globalization is changing the economic geography, scale and size of the manufacturers present in the supply chain. There has been a wave of new assembly and supplier plant construction in places such as China, India, Thailand, Vietnam, Brazil, Mexico and east European countries because of low cost, easy labour and high source of raw materials and very importantly the existing huge market potential. Whereas there appears a saturated market in some of the countries like Japan, Singapore, United States, Switzerland, United Kingdom and negative market growth in Vietnam. If low cost of manufacturing and high emerging market were the only reasons for global manufacturers' migration, then the supply chain structure would have been different in its shape. In addition to low cost, emerging market; well established logistical strength and sophisticated supply chain network, lesser supply chain risk, greater environmental concern etc., are also found out to be viable reasons for the global industry migration.

Borderless trade environments, raising infrastructure, growing demand, raising environmental and regulatory pressures stresses almost all manufacturers to redesign their supply chain network. Therefore modern global supply chain landscapes are kept on changing stressed with such emerging constraints and pressures. Industries often changing their scope from cost minimization to service level improvements, customer satisfaction and inevitably concern about corporate social responsibility. On the other way practitioners argue that a well established logistical structure also reduces the supply chain costs and improves its performance to a greater extent. This can compensate in total supply chain cost reduction challenges with some of its strength but not to great extent. Hence this research motivates the researcher to look around the feasibility of plant or transhipment hub or Distribution Center (DC) location or relocation from its current place in a global supply chain network by facilitating improvement in supply chain performance.

2. Literature Review

Many researchers have attempted to handle different firm relocation problems since its inception by Moses and Willianson (1967). They discussed the firm relocation problem from all origin to alternate locations in the metropolitan area. After this, Brown and Gibson (1972) plant location model got researcher attention because of its simplicity and viable outcome. The Brown-Gibson model is a quantitative model which was developed for evaluating alternative plant locations using certain objective and subjective factors. The model considers that the location factor is critical and its nature may preclude the location of a plant at a particular site. The objective factors are evaluated in monetary terms and the subjective factors are characterized by qualitative type measurement. Schmenner (1978) modeled aggregate employment change due to the birth and deaths of manufacturing establishments. He invented that employment change in suburban jurisdictions results only from the relocation of city plants. Erickson and Wasylenko (1980) developed a model for firm relocation and site selection decision in suburban municipalities.

Because of globalization and liberalization the present supply chain network has been stressed by new emerging constraints and additional cost components. Modern supply chain network problems are faced with additional objective function like price on carbon emission, cost of risk, price on trade friction, price on service level improvements in addition to conventional objectives like cost minimization, reducing the order shipment, inventory minimization etc. It's a big challenging task to take effective decision making in a global supply chain network environment which is adhered to risky, uncertain, emerging exogenous constraints. Fuzzy set theory and stochastic programming have been used to deal with these noisy, erroneous or incomplete data associated with a problem however uncertainty associated with data and model are hard to solve Leung et al. (2007). Therefore we need to address these issues proactively, "close" to optimal for all input scenarios and "almost" feasible to all data scenarios, called "Robust Optimization (RO)" Although there are widely presented definitions for Robust Optimization, definition by Bai et al. (1997) addressed highly in the literature. Bai et al. (1997) defines RO as a special type of stochastic non-linear programming model, in which a concave risk aversion function can be incorporated in the specification of the objectives.

Sengupta (1991) discussed the notion of robustness for stochastic programming models. Escudero et al. (1993) presented an RO formulation for the problem of outsourcing in manufacturing and Gutierrez and Kouvelis (1995) developed RO models for multinational production scheduling. Mulvey et al. (1995) and Castillo (2009) developed RO model for large scale system applications which explicitly incorporates the conflicting objectives of solution and model robustness. Researchers have proposed fuzzy based decision making and modeling on multi objective problems but these approaches in firms' relocation problems faced with risk and uncertainty is missing in the existing literature. Hence we propose a Hybrid approach by combining the Robust Optimization and Mixed Integer Linear Programming model to handle these modern constraints for the facility location and relocation decisions in supply chain management.

3. Research Scope

The research work is aimed to:

- Develop a facility location/relocation model that are coupled with robust decision variables and to
- Identify viable solution procedures to solve such large scale robust optimization problems.

4. Research Methodology: Robust Optimization and Mixed Integer Linear Programming (ROMILP)

In the proposed approach we use a hybrid Robust Optimization method to understand the noise parameter and Mixed Integer Linear Program to sense the uncertainty and possibilities of cost decision variables.

4.1 Assumptions used in the model

The following assumptions are considered pertain to the automotive industry operating on a world-wide environment.

- It is assumed that the brand manufacturers operate globally, having their suppliers, distributors and customers located in a global network
- A homogeneous product economy is considered meaning that all manufacturers produce the same product which is then shipped to the distributors, who, in turn, distribute the product to the end customers
- The material and information transaction takes place in a risky supply chain network with delay and the order of delay is related to the degree of development of the country
- Demands are strictly available with some arrival distribution and demand pattern follows i.i.d without seasonality

- Assembly line is not interrupted by any ecological, operational and political interruptions
- All players associated with the network follow a common currency

Figure 1 represents a four stage global supply chain network with main components coming from primary/tier-1 suppliers to plants, who produce the finished goods and distribute them to RDCs/DCs who inturn distribute them to customers.

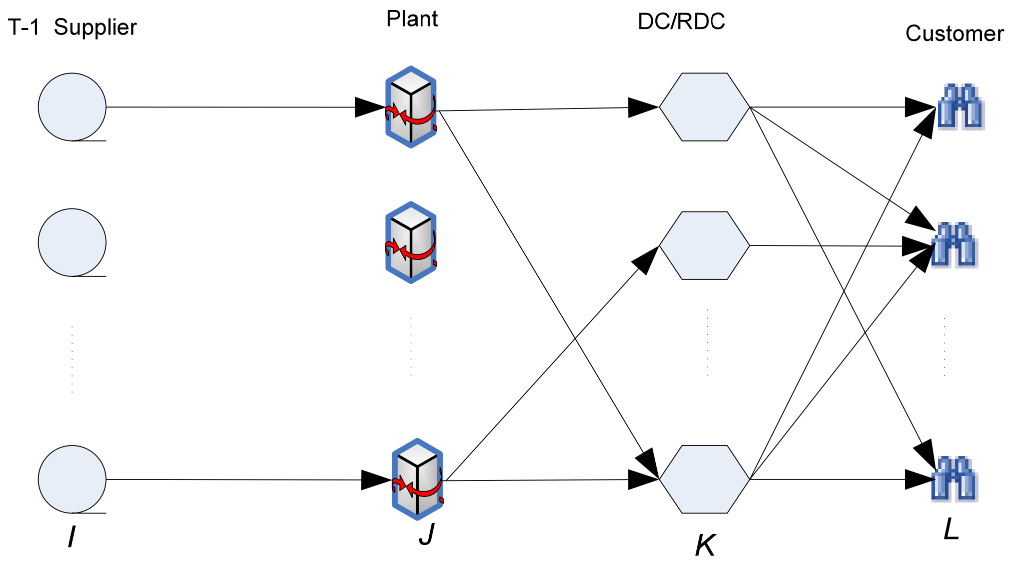

Figure 1. Simple 4-echelon global supply chain network

4.2 The model

Let us consider the network as shown in Figure 1, which consist of four players i, j, k, l located in N different countries. It is assumed that there are i suppliers operating in each country with a common currency *H*.

Notations Used in the model

i index of raw material suppliers ($i=1....I$)

j index of assembly plant ($j=1....J$)

k index of distribution center ($k=1....K$)

l index of customer demand center ($l=1....L$)

s set of scenarios

θ_S^+ deviations for violation of mean

θ_S^- deviations for violation of mean

p_s probability of occurrence of scenario s

$p_{s'}$ probability of occurrence of noisy scenario *s'*

λ weighting scale to decide the trade-off between cost and feasibility

ω weight penalty for surplus or stock-out case

δ optimal case

g_{sj} favored safety stock at different market stock-out risk stage

D_{sj} expected market demand at j

X_{ijkl} Product flow through all nodes from *i* to *l*

Ω_{ijkl} transportation cost by various modes

PC incoming part costs

TAC total assembly costs

IHC Inventory holding costs

MMTC multi-model transportation costs

f fixed cost

Γ_{jkl} total space available for all finished goods at assembly plant *j* and DC *k*

$\wp$ cost penalty for emission

A cost of assembly

r cost penalty for risk and uncertainty

Θ the delay penalty

4.3 Existing Models

Literature shows that there are existing models that can be fitted to match some of its criteria's however lags in taking into account of parameters like uncertainties and risk, tax and levy issues, carbon emissions etc., For instance, Mulvey et al (1995) proposed:

$$\text{Minimize} \sum_{s=1}^{4} p_s (TC + PC + IC) + \lambda \sum_{s=1}^{4} p_s (\theta_S^+ + \theta_S^-) + \sum_{s=1}^{4} \sum_{J=1}^{3} (\omega_{sj}^+ \delta_{sj}^+ + \omega_{sj}^- \delta_{sj}^-) \tag{1}$$

subject to all linear constraints

Yu and Li (2000) proposed:

$$\text{Minimize} \sum_{s=1}^{4} p_s (TC + PC + IC) + \lambda \sum_{s=1}^{4} p_s (\theta_S^+ + \theta_S^-) - \sum_{s=1}^{4} p_s \left[(TC + PC + IC) - 2\theta_S \right] +$$
$$\sum_{s=1}^{4} \sum_{J=1}^{3} \left(\omega_{sj}^+ (z_{1j} + z_{2j} - D_{sj} - g_{sj} + \delta_{sj}^+) + \omega_{sj}^- \delta_{sj}^- \right) \tag{2}$$

subject to all linear constraints

Leung et al. (2007) proposed a multi site production planning problem with noisy data as:

$$\text{Minimize} \sum_{s \in S} p_s (PC_s + LC_s + IC_s + WC_s) + \lambda \sum_{s \in S} p_s (PC_s + LC_s + IC_s + WC_s) -$$
$$\sum_{s' \in S}^{4} p_{s'} \left[(PC_{s'} + LC_{s'} + IC_{s'} + WC_{s'}) + 2\theta_S \right] + \omega \sum_{s=1}^{4} \sum_{i \in I} \sum_{t \in T} p_s \delta_{it}^s \tag{3}$$

subject to all linear constraints

Geoffrion and Graves (1974) discussed a multi-commodity distribution model considering transportation cost, fixed and variable cost as:

$$\text{Minimize}_{x,y,z} \sum_{i} \sum_{j} \sum_{k} \sum_{l} C_{ijkl} X_{ijkl} + \sum_{k} (f_k z_k) + \gamma \sum_{k} \sum_{i} \sum_{l} D_{il} y_{kl} \tag{4}$$

subject to all linear constraints

Many existing research papers in robust programming and fuzzy based approach either discuss the uncertainty indigenously or together with some other noisy input. Whereas the case of uncertainty dealt combined with possibility and probability is a missing element in the research literature and particularly in facility location or relocation problems, they are not reported. This research work is aimed to investigate these issues together with a novel mathematical model and to indentify the solution methodologies to solve this approach in terms of location decisions.

4.4 The Proposed Approach: RObust Mixed Integer Linear Programming problem (ROMILP) for Logistical Network

By combining the Equation (3) and Equation (4), a Robust Mixed Integer Programming model is developed for the proposed methodology. To start with a simple case, a Mixed Integer Programming model of firm relocation decision has been derived targeting to minimize the total supply chain network cost from assembly to customer stage subject to some real constraints. Hence the model aims to:

Minimize [(Incoming Part Cost at assembly center 's') + (Total Assembly Cost including labor cost, quality cost, manufacturing cost and cost penalty for carbon emission at plant 's') + (Inventory Holding Cost including cost penalty for uncertainty and carbon emission at plant 's') + (total multimodal transaction cost from assembly including cost penalty for delay, uncertainty, risk during logistics from supplier until customer '*ijkl*') + (Fixed Cost at 'j & k') + (Variable Cost including variability costs, lead-time cost, anti dumping fees at 'j & k)]

Minimize

$$\sum_{s=1}^{S} p_s\left[\left(PC_s + TAC_s + IHC_s + MMTC_s\right)+\right] + \sum_{j=1}^{J}\sum_{k=1}^{K}\left[\left(f_{jk} z_{jk}\right) + \gamma_{jk}\sum_{l=1}^{L} D_l Y_{jk}\right] +$$
$$\lambda\sum_{s\in S} p_s\left(PC_s + TAC_s + IHC_s + MMTC_s\right) - \sum_{s'\in 1}^{S} p_{s'}\left[\left(PC_s + TAC_s + IHC_s + MMTC_s\right) - 2\theta_S\right] +$$
$$\omega\sum_{s=1}^{S}\sum_{i=1}^{I}\sum_{t=1}^{T} p_s \delta_{it}^{s} \tag{5}$$

Where:

Total Multi Modal Transportation Cost is represented by;

$$MMTC_s = \sum_{i}\sum_{j}\sum_{k}\sum_{l}\Omega_{ijkl}X_{ijkl}\forall, i, j, k, l$$

Incorporating the cost of inbound and outbound logistics journey delay (Levinson, 2005) in the calculation, the revised total Multi Modal Transportation Cost becomes:

$$MMTC_s = \sum_{i}\sum_{j}\sum_{k}\sum_{l}\left\{\left(\Omega_{ijkl}X_{ijkl}\right)+\left(\Phi\left(d^{ijkl}\right)X_{ijkl}\right)\right\} \quad \forall, i, j, k, l \tag{6}$$

In equation (6) the expected journey delay multiplied by the delay penalty is:

$$\Phi\left(d^{ijkl}\right) = \left(q_t + 0.5\left(A_t - 1\right)\right) * \Theta$$

Where: Θ is the delay penalty; q_t the standing queue at time t and A_t is the arrivals at time 't'. Overall, each logistics player will try to reduce the cost penalty for inbound and outbound logistics delay. Hence the total assembly cost consists of;

$$TAC = \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{l=1}^{L}\left\{\left(A_{ijkl}X_{ijkl}\right)+\left(\wp_{ijkl}X_{ijkl}\right)+\left(r_{ijkl}X_{ijkl}\right)\right\} \forall, i, j, k, l \tag{7}$$

4.5 The Constraints

The developed objective function may fall into the optimal and or feasible region subject to supply, demand, capacity, inventory, multimodal transport, trade-friction, risk, recycling, and technology constraints as discussed below:

Total amount of finished goods shipped from assembly plant j $\leq$ Total supply of component from all tier-1 suppliers (J)

$$\sum_{i=1}^{I}\sum_{j=1}^{J}X_{ij} \leq S_i, \text{ for all } j \tag{8}$$

Total amount of finished goods shipped through assembly plant *j* to demand centers = Total Demand by customers *l*. Therefore;

$$\sum_{k=1}^{K}\sum_{l=1}^{L} X_{kl} = D, \text{for all } l \tag{9}$$

The total available storage space for DCs is expressed as:

$$\sum_{k=1}^{K} X_{jkl} \le \Gamma_{jk} y_k, \text{for all } j,k,l \tag{10}$$

Flow constraints between the supplier and the assembler:

$$\sum_{j=1}^{J} X_{jk} \le \sum_{i=1}^{I} X_{ij}, \text{for all } k \tag{11}$$

Flow constraints between the assembler and the DC/RDC:

$$\sum_{k=1}^{K} X_{kl} \le \sum_{j=1}^{J} X_{jk}, \text{for all } l \tag{12}$$

The total available capacity of the assembly plant is expressed as:

$$\sum_{k=1}^{K} X_{jk} \le \mathrm{M}_j y_j, \text{for all } j,k \tag{13}$$

Logistics delay should be allowed within the maximum allowable delay;

$$\sum_{i,j,k,l}^{IJKL} \Phi\left(d^{ijkl}\right)\mathrm{X}_{\mathrm{ijkl}} \le \mathrm{Max}\left(\Phi\ \mathrm{X}_{\mathrm{ijkl}}\right) \tag{14}$$

Total waste disposal from every nodal points should be within the acceptable range. Similarly the total carbon emissions across the supply chain should not exceed the maximum limit. Let c_i^H be the upper bound emission (unacceptable emission), c_i^L be the lower bound emission (acceptable emission) then the borderline emission could be derived as: $c_i^{BL} = \gamma_i c_i^U + (1-\gamma_i)c_i^L$

Following the conditional limitation to the emission criteria the constraints becomes:

$$\sum_{i,j,k,l}^{IJKL} \min\left(c_{i,j,k,l}^{L}, c_{i,j,k,l}^{U}\right) < c_{i,j,k,l}^{BL} < \sum_{i,j,k,l}^{IJKL} \max\left(c_{i,j,k,l}^{L}, c_{i,j,k,l}^{U}\right) \qquad \mathit{for} \quad \mathit{all} \quad i, j, k, l \tag{15}$$

And finally each facility should either be opened or closed,

$$y_j, y_k, \gamma_i \in \{0,1\}, \quad X_{ij}, X_{jk}, X_{kl} \geq 0 \tag{16}$$

5. Solution Approach

When we explore the literature to solve the proposed ROMILP problem, there are enormous algorithms available like branch & bound and benders decomposition supporting its own pros and cons. Benders (1962) decomposition method has been extensively used in solving most of the difficult large scale optimization problems such as stochastic programming problems Infanger (1994) Nielsen and Zenios(1997), mixed-integer nonlinear programming problems Floudas et al. (1989) & Geoffrion (1972) and robust optimization problems Mulvey and Ruszczynski (1995), Bertsimas and Sim (2003). Among the existing methods soft computing based methods give improved results and ease to handle with uncertainty. Non-traditional optimization techniques like Genetic Algorithm + Bacterial Swarm Optimization (Genetically Bacterial Swarm Optimization, in short GBSO**)** Baker, (1987), Muhlenbein and Schlierkamp-Voosen (1993), Kennedy and Eberhart (1995), Kim et al. (2007), can be implemented to solve ROMILP problem subjected with probabilistic and possibility state.

6. Conclusions

Given the list of modern constraints and additional forces with the traditional supply chain network problems this paper proposed a Hybrid Robust Optimization and Mixed Integer Linear Programming (ROMILP) method to solve the modern supply chain network optimization problems. Linking emerging constraints with the conventional supply chain constraints under possibility and probability states the problem lead to an interesting real world network which can only be solved either decomposition method or by extended heuristics algorithms. This work also could be extended by solving them by branch and bound and adapted benders decomposition method. Computational experiments with real world data would be helpful for supply chain practitioners to make facility location decisions.

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