SUPPLY CHAIN NETWORK DESIGN PROBLEM FOR A NEW MARKET OPPORTUNITY IN AN AGILE MANUFACTURING SYSTEM

Reza Babazdeha,1, Jafar Razmia, Reza Ghodsi

a Department of Industrial Engineering, College of Engineering, University of Tehran, Tehran, Iran
r_babazadeh@ut.ac.ir

Abstract
The characteristics of today’s competitive environment, such as the speed with which products are designed, manufactured, and distributed, and the need for higher responsiveness and lower operational cost, are forcing companies to search for innovative ways to do business. The concept of agile manufacturing has been proposed in response to these challenges for companies. This paper copes with the strategic and tactical level decisions in agile supply chain network design. An efficient mixed integer linear programming (MILP) model is developed that is able to consider the key characteristics of agile supply chain such as direct shipments, outsourcing, different transportation modes, discount, alliance (process and information integration) between opened facilities and maximum waiting time of customers for deliveries. In addition, in the proposed model the capacity of facilities is determined as decision variables which are often assumed to be fixed. Computational results illustrate that the proposed model can be applied as a power tool in agile supply chain network design as well as integration of strategic decisions with tactical decisions.

Keywords: Supply chain management, Agile supply chain network design, Outsourcing, Responsiveness.

JEL Classification: C 26, D 12, D 13, M 31

1. Introduction

In recent years, the design and implementation of agile supply chain strategies has increasingly attracted and some companies such as Zara and Gina Tricot have achieved many advantages by employing agile strategy. Agile supply chain includes companies such as suppliers, production centers and distribution centers which are legally separate but terms of operations are linked together by flow forward materials and feedback information. Agile supply chain is focused on improving responsiveness, speed and flexibility.

1 Corresponding author,
Phone number: +98(021) 88021067, Fax number: +98(021) 88013102
E-mail addresses: r.babazadeh@ut.ac.ir (R. Babazadeh), jrazmi@ut.ac.ir (J. Razmi), ghodsi@ut.ac.ir (R.Ghodsi).
that is able to respond and react quickly and effectively to changing markets [1]. In other words, Agility is a term applied to an organization that has created the processes, tools, and training to enable it to respond quickly to customer needs and unforeseen market changes while still controlling costs and quality [2]. Traditional supply chains have long lead-times and are forecast-driven which makes that these supply chains to be inventory-based, while the agile supply chain with quick response has shorter lead-time and is demand-driven and information-based in contrast with traditional supply chains. Additionally, whilst the market winner factor in agile supply chain is responsiveness and improved service level, in traditional supply chain the cost have been market winner factor [3]. Agile supply chain practices can be identified by four factors [4]:

(1) Market sensitive, it is concerned with end customers in order to be able to specify customer needs and responds to them as soon as possible.

(2) Virtual integration, it depends on information sharing along the supply chain. (3) Network-based, it provides flexibility by employing the strengths of specialization in each partner within the supply chain; therefore it is critical to leverage the strengths and competencies of partners to realize quick responsiveness to market needs. (4) Process integration, it is related to high level of integration between partners within the supply chain and enables collaborative working methods such as joint product design. Therefore, the partners within supply chain network will be able to improve variety of products and deal with the uncertainty.

Supply chain network design (SCND) decisions, as the most important strategic level decisions in supply chain management, concerned with complex interrelationships between various tiers, such as suppliers, plants, distribution centers and customer zones as well as determining the number, location and capacity of facilities to meet customer needs effectively. Supply chain management integrates interrelationships between various entities through creating alliance, such as, information-system integration and process integration, between entities to improve response to customers in various aspects such as, higher product variety and quality, lower costs and faster responses. One of the vital challenges for organizations in today’s competitive markets is the need to respond to customer needs which are very volatile and can be occurred in volume and variety of customer needs [5]. Agility with its various contexts is the most popular strategy which enables organizations to confront with unstable and high volatile customer demands. Since the SCND is the most important strategic level decision which affects the overall performance of supply chain, it is necessary to consider agility concepts such as response to customers in maximal allowable time, direct shipment, alliance (information and process integration) between entities in different echelons, discount to achieve competitive supply chain, outsourcing and using different transportation modes to achieve flexibility and safety stock to improve responsiveness. It is evident that considering agility concepts in SCND plays incredible role in agility of the overall supply chain. As yet many researchers have tried to show the most important factors in agile supply chain management theoretically and this context has omitted in mathematical modeling area especially in supply chain network design area.

In this paper to overcome literature gaps in agile supply chain network design, we present a mixed-integer linear programming (MILP) model which is able to consider agility concepts such as response to customers in maximal allowable time, direct shipments besides the traditional shipments, alliance between opened facilities in different tiers, safety stock, different transportation modes, discount and outsourcing besides the traditional features of SCND area.

The reminder of this paper is organized as follows. The related works are reviewed in Section 2. Section 3 includes the description and formulation of the proposed model. The numerical results are reported in Section 4. Finally, Section 5 concludes this paper and offers some directions for further research.

2. Related Works

In this section we concisely review some SCND model developed recently. Melo et al. [6] presented a general review on supply chain network design to identify basic features that such models must capture to support decision-making involved in strategic supply chain planning and support a variety of future research directions. Other interesting reviews in this field can be found in Dullaert et al. [7] and Snyder and Lawrence [8]. The most of the presented models in the literature
focus on minimization of total costs and ignore other objectives such as responsiveness and flexibility which are effective in the success of supply chain management. Zanjirani Farahani et al. [9] give a comprehensive review on multi-criteria facility location problems in the SCND. Their study shows that only approximately 8% of presented models have considered responsiveness as a determinant factor in SCND. You and Grossmann [10] developed a responsive bi-objective MINLP model by considering demand uncertainty and economic criterion. Their model was able to determine the safety stock levels to confront uncertainty. They used $\varepsilon$-constraint method to produce Pareto front. Rajabalipour Cheshmehegaz et al. [11] presented a multi-objective, multi-stage and flexible model to design logistics network with the aim of minimization response time and cost criteria. The efficient multi-objective evolutionary algorithm based on genetic algorithm (GA) was proposed. Ross and Jayaraman [12] developed a MILP model to determine location of the cross-docks in the SCND. Also, they utilized simulated annealing and Tabu search to solve the presented model. Amiri [13] presented a MILP model to coordinate production and distribution activities. Additionally, the presented model was able to determine the optimum number, location and capacity of facilities which should be opened. Altiparmak et al. [14] developed a SCND model in a practical case and then proposed a GA by using priority-based encoding to escape from infeasible solutions. Thanh et al. [15] proposed a dynamic MILP model for the facility location in the SCND. The proposed model includes strategic and tactical decisions.

As yet, among the numerous SCND models, which are presented to design SCN in efficient way and improve supply chain management, agility as a winning factor in today’s turbulent markets has been omitted. However, in recent years some studies have tried to consider the agility concepts in SCND. Bachlaus et al. [16] presented an integrated multi-objective MILP model to integrate of production, distribution and supply chain activities at the strategic decision considering agility as a key design criterion. They defined agility index in three levels including low, medium and high for each facility, which should be satisfied in constraints. Additionally, they used flexibility as available capacity of each facility which should be maximized in objective function. Pan and Nagi [17] developed a robust optimization approach to deal with demand uncertainty in supply chain network in agile manufacturing. The presented model was able to consider alliance costs, which is one of the important factors of agile supply chain, between opened facilities. They proposed an efficient heuristic based on a k-shortest path algorithm to solve the presented model in large scales. However, their model doesn’t cover distribution centers and delivery time to customer as well as one facility should be determined in any echelon of supply chain network and the robust optimization is based on scenarios. Hasani et al. [18] presented a closed-loop supply chain network for perishable goods under uncertainty of demand and purchasing costs. The agility can be seen as handling products in their lifetime period. They used a bounded-box robust optimization approach to confront uncertainty in their model and solved it using LINGO.

3. Description and formulation of the proposed model

The concerned agile supply chain network in this paper is a multi-echelon and direct acyclic network which integrates the production, outsourcing, flexibility, discount, shortage and distribution activities. In each echelon, there are some candidate facilities which should be determined to design the network in question. The discussed echelons are linked together with a forward shipment of products and backward flow of information in a pull system. As it is shown in Figure 1, the finished products manufactured in plants and semi-finished products which have been outsourced, after processing in plants, are shipped to distribution centers or directly shipped to customer zones. We assume that the certain amount of products can be directly shipped. Some of products shipped to distribution centers are stored and the rest are shipped to customer zones according to customer needs. It is should be noted that agile supply chains tries to satisfy all customer demands; however, some of customer needs may be not satisfied in real world. Therefore, the shortage can be occurred based on predefined customer service level.
Fig. 1. Structure of the concerned agile supply chain network

To achieve flexibility and deal with disruption risks, the plants can perform outsourcing and use different transportation modes to deliver new products to customers. As it is mentioned in previous sections, alliance between facilities is a key factor to improve agility of supply chain, so the opened facilities in different echelons pay certain cost to create alliance between facilities. As regards delivering time to customers plays an incredible role in improving responsiveness to customers, we assume that all demands of customers should be met in their expected times.

Another important issue in SCND is determining the capacity of facilities which should be opened. Most of previously presented models consider fixed capacities for facilities, whereas determining the capacity of facilities is often difficult in practice [19]. Therefore, it is assumed that the capacity level of facilities is determined as a decision variable to avoid additional and useless costs.

The following notation is used in the formulation of the proposed model.

**Indices**
- \( I, M \) Index of candidate locations for plants \((i, m = 1, \ldots, I)\)
- \( J, C \) Index of candidate locations for distribution centers \((j, c = 1, \ldots, J)\)
- \( K \) Index of Fixed locations of customers \((k = 1, \ldots, K)\)
- \( N \) Index of transportation’s modes \((n = 1, \ldots, N)\)
- \( R \) Index of capacity levels \((r = 1, \ldots, R)\)

**Parameters**
- \( d_k \) Demand of customer \(k\)
- \( f_{ir} \) Fixed cost of opening plant \(i\) with capacity level \(r\)
- \( g_{jr} \) Fixed cost of opening distribution center \(j\) with capacity level \(r\)
- \( pr_i \) Production cost per unit of products at plant \(i\)
- \( CPA_{1im} \) Process and information (alliance) integration cost between plants \(i\) and \(m\)
- \( CPA_{2jc} \) Process and information integration cost between distribution centers \(j\) and \(c\)
- \( CPA_{ij} \) Process and information integration cost between plants \(i\) and distribution center \(j\)
- \( CD_i \) Discount amount by plant \(i\) to customers
- \( \alpha_k \) Penalty cost per unit of non-satisfied demand of customer \(k\)
- \( mh_j \) Material handling and inventory cost per unit of products at distribution center \(j\)
- \( oc_i \) Outsourcing cost per unit of products at plant \(i\)
- \( a_{ijn} \) Unit transportation cost from plant \(i\) to distribution center \(j\) by mode \(n\) for product \(p\)
Transportation cost per unit of products from distribution center \( j \) to customer \( k \) by mode \( n \)

\( c_{ikn} \)

Delivery time from plant \( i \) to customer \( k \) by mode \( n \)

\( t_{ckn} \)

Delivery time from distribution center \( j \) to customer \( k \)

\( t_e \)

Expected delivery time of customer \( k \)

\( M_{ij} \)

Minimum inventory should be hold in distribution center \( j \)

\( M_{Vi} \)

Maximum amount of products which can be outsourced in plant \( i \)

\( D_{Pi} \)

Minimum amount required that plant \( i \) offers discount to customers

\( caw_i^r \)

Capacity with level \( r \) for plant \( i \)

\( cay_j^r \)

Capacity with level \( r \) for distribution center \( j \)

**Decision variables**

\( x_{ui} \)

Quantity of products produced at plant \( i \)

\( In_j \)

Quantity of products hold at distribution center \( j \)

\( v_i \)

Quantity of products outsourced at plant \( i \)

\( \delta_k \)

Quantity of non-satisfied demand of customer \( k \)

\( x_{ijn} \)

Quantity of products shipped from plant \( i \) to distribution center \( j \) by mode \( n \)

\( Q_{jkn} \)

Quantity of products shipped from distribution center \( j \) to customer \( k \) by mode \( n \)

\( L_{ijn} \)

Quantity of products shipped directly from plant \( i \) to customer \( k \) by mode \( n \)

\( W_i^r \)

1 if plant \( i \) with capacity level \( r \) is opened; Otherwise 0

\( y_j^r \)

1 if distribution center \( j \) with capacity level \( r \) is opened; Otherwise 0

\( PA_{1im} \)

1 if process and information integration is performed between plant \( i \) and plant \( m \); Otherwise 0

\( PA_{2jc} \)

1 if process and information integration is performed between distribution center \( j \) and distribution center \( c \); Otherwise 0

\( PA_{ij} \)

1 if process and information integration is performed between plant \( i \) and distribution center \( j \); Otherwise 0

\( \lambda_i \)

1 if plant \( i \) gives discount to customers; Otherwise 0

\[
\begin{align*}
\min & \sum_i \sum_r f_r^i w_r^i + \sum_j \sum_r g_j^r y_j^r + \sum_i (p_r^i x_{ui} + oc_r v_i) \\
& + \sum_j mh_j In_j + \sum_i \sum_j \sum_n a_{ijn} x_{ijn} \\
& + \sum_j \sum_k \sum_n b_{jkn} Q_{jkn} + \sum_i \sum_k \sum_n e_{jkn} L_{ijn} \\
& + \sum_i \sum_{m\neq i} \frac{1}{2} CPA_{1im} PA_{1im} + \sum_j \sum_{c\neq j} \frac{1}{2} CPA_{2jc} PA_{2jc} \\
& + \sum_i \sum_j CPA_i PA_{ij} + \sum_k \alpha_k \delta_k - \sum_i CD_i \lambda_i
\end{align*}
\]

(1)

\[
\begin{align*}
\sum_i \sum_n L_{ijn} + \sum_j \sum_n Q_{jkn} + \delta_k \geq d_k & \quad \forall k \\
\delta_k \leq (1 - csl) d_k & \quad \forall k \\
\lambda_i \leq \frac{d_k}{DP_i} & \quad \forall i, k
\end{align*}
\]

(2)
Objective function (1) minimizes the total costs includes fixed opening costs, production cost, outsourcing cost, inventory holding cost, transportation and processing costs, alliance costs between opened facilities and shortage costs as well as the amount of discount is maximized to improve competitiveness of the agile supply chain network. Coefficient \((1/2)\) is considered to avoid re-calculation of alliance costs between opened facilities in a specific echelon. Constraint (2) ensures that all demands of customers are not satisfied and shortage is possible. Constraint (3) imposes the maximum allowable shortage based on predefined customer service level. Constraint (4) is inequality for decision making on giving discount to customers. Constraints (5) and (6) are...
the flow balances at the plants and warehouses, respectively. Constraint (7) imposes the minimum inventory should be stored in opened warehouses. Constraint (8) assures that the amount of outsourced products don’t exceed from the certain amount. Constraints (9) to (15) ensure that alliance between opened facilities in a specific echelon as well as between opened facilities in different echelons is created. Constraints (16) and (17) ensure that all the products are delivered to customers in the maximum allowable delivery time. Restriction (18) express that only opened plants are allowed to give discount to customers. Constraints (19) and (20) are capacity constraints in any facility. Constraint (21) ensures that only opened plants can send products to warehouses and customer centers. Constraint (22) expresses the utilization of lower bound percentage of capacity of opened plants. Constraint (23) expresses the limitation on total number of products directly sent to customers. Constraints (24) and (25) ensure that any facility can be opened at most in one of the capacity levels. Finally, Constraints (26) and (27) enforce the binary and non-negativity restrictions on corresponding decision variables.

4. Computational results

In order to evaluate the performance of the presented model for designing agile supply chain network two test problems are randomly generated according to information specified in Table 1 inspired from literature. Interested readers can reach the detailed data set for the two test problems from authors. Customer service level is considered to be 75% (i.e., csl=0.75) in two test problems. It is should be mentioned that opening and closing a facility is a strategic decision, time-consuming and costly process. Therefore, changing facility location is impossible in the short run. On the other hand determining the quantity of flow between network facilities as a tactical decision is more flexible to change in short run [20]. Therefore, strategic decisions (binary variables) should be determined independently from realizations, whereas the tactical decisions can be changed and updated during the realizations.

| parameter | value | parameter | value |
|-----------|--------|-----------|--------|
| $d_k$ | $\sim$ Unif (00,1200) unit | $a_{ijn}$ | $\sim$ Unif (40,60) $|
| $f_r$ | $\sim$ Unif (170000,4000000) $ | $b_{kn}$ | $\sim$ Unif (40,60) $|
| $g_r$ | $\sim$ Unif (1600000,3000000) $ | $e_{kn}$ | $\sim$ Unif (90,130) $|
| $p_r$ | $\sim$ Unif (120,150) $ | $t_{a_{kn}}$ | $\sim$ Unif (10,16) day |
| $m_{h_i}$ | $\sim$ Unif (60,75) $ | $t_{c_{kn}}$ | $\sim$ Unif (6,12) day |
| $c_{s_i}$ | $\sim$ Unif (90,170) $ | $t_{e_k}$ | $\sim$ Unif (10,12) day |
| $M_{l_i}$ | $\sim$ Unif (80,100) $ | $c_{aw_i}$ | $\sim$ Unif (2000,5000) unit |
| $M_{v_i}$ | $\sim$ Unif (90,110) unit | $c_{ay_j}$ | $\sim$ Unif (2000,3500) unit |
| $D_{p_i}$ | $\sim$ Unif (400,550) unit | $C_{P1_{iin}}$ | $\sim$ Unif (50000,60000) $|
| $C_{D_i}$ | $\sim$ Unif (10500,14500) $ | $C_{P2_{jc}}$ | $\sim$ Unif (30000,35000) $|
| $\alpha_k$ | $\sim$ Unif (4000,6000) $ | $C_{P2_{ij}}$ | $\sim$ Unif (60000,70000) $|
The proposed model is solved by ILOG CPLEX 10.1 optimization software on a Pentium dual-core 2.60 GHz computer with 4 GB RAM. To reduce the complexity of deterministic model, we relax the decision binary variables PA_{1im}, PA_{2jc} and PA_{ij} as continuous variables. It is should be noted that minimization of the objective function and binary variables W_i^r and Y_j^r in constraints (8)-(14) assure that the relaxed variables are set equal to 0 or 1.

**Table 2: Computational results and complexity of presented models**

| Problem size | O.F.V  | Constraints | Variables | Run time(s) |
|--------------|--------|-------------|-----------|-------------|
| 10*5*8 *3*2 | 16015980 | 813 | 690 | 0.8 |
| 15*10*10 *3*2 | 22917570 | 1578 | 1861 | 29 |

**Table 3: Share of different components of objective functions**

| Problem size | Fixed costs | Production costs | Outsourcing costs | Inventory costs | Transportation costs | Alliance costs | Shortage costs | Discount amount |
|--------------|-------------|-----------------|------------------|-----------------|---------------------|----------------|----------------|----------------|
| 10*5*8 *3*2 | 1340330 0 | 1220666 | 30400 | 12130 | 801739 | 583819 | 0 | 36076 |
| 15*10 *3*2 | 1914281 0 | 1764269 | 30700 | 18269 | 1145611 | 840050 | 12168 | 36309 |

Acquired results illustrated in Table 2 show that by increasing the size of the problem in question, objective function value (O.F.V) and complexity of discussed problems increase.

Table 3 demonstrates share of different components of objective function for proposed model in details. As it is illustrated in Table 3, the fixed costs for opening facilities have the largest share in the objective function value for both of the models. Therefore, determining the number and location of facilities in each stage of the SCND process is the most important and strategic decision which affects on the overall performance of the SCN. Moreover, the total costs of the production cost, outsourcing cost, inventory cost and transportation cost are significant in the objective function. This is due to that demand of customers must be satisfied based on predefined customer service level behalf upstream the supply chain management. Additionally, the share of outsourcing cost is fewer than production cost in the objective function value. It could be explained because of the limitation on the majority of the products that could be outsourced (see constraint 8 in Section 3).

As be described in previous sections, alliance between facilities in the supply chain network plays important role in integration and successful of the agile supply chain. The model pays alliance cost to improve information and process...
integration. In addition, although discount issue can improve competitiveness of the agile supply chain, its amount should be balanced with other costs.

As depicted in Figure 2, Sensitivity analysis on demand of customers shows that the proposed model is sensitive to demand of customers. This observation can be explained by the demands effect on overall supply chain network. In other words, the configuration of supply chain network is constructed according to customer demands.

The considered agile supply chain network in this paper has a general structure which is able to support the agility concepts besides the traditional features of the SCND area and therefore can be applied in different kind of industries with lead time restriction such as food industries and semiconductor industries. It is can be concluded from acquired results that the proposed model can be utilized as a power tool in practical cases with less shortage and high degree of responsiveness.

5. Conclusions remarks

In this paper we proposed supply chain network design problem for a new market opportunity in an agile manufacturing system. The proposed agile SCND model is able to integrate production, outsourcing, discount, flexibility and distribution activities by considering the most important factors of agile supply chain. The experimental results show the efficiency of the proposed model in agile supply chain network design. Also, it is can be concluded from obtained results that location of facilities in supply chain network design is strategic decision and therefore, integration of facility location decisions with other decisions such as outsourcing, Inventory control, production and etc can improve supply chain performance and responsiveness.

Many possible future research avenues can be defined for future research directions. For example addressing multi-product, multi-period agile supply chain network design under different kind of operational and disruption risks is an attractive research direction with significant practical relevance. Moreover, time complexity is not addressed in this paper, however, this issue might be important in large-sized problems so that the commercial solvers fail to solve them, therefore developing efficient exact or heuristic solution methods can be interesting in this area.

References

[1] Lin CT, Chiu H, Chu PY (2006) Agility index in the supply chain. International Journal of Production Economics, 100(2): 285-299.

[2] Christopher M, Lowson R, Peck H (2004) Creating agile supply chains in the fashion industry. International Journal of Retail & Distribution Management, 32(8): 367-376.
[3] Mason-Jones R, Naylor JB, Towill DR (2000) Engineering the agile supply chain. *International Journal of Agile Manufacturing Systems* 02 (1): 54–61.

[4] Harrison A, Hoek R & Christopher M (1999) Creating the Agile Supply Chain, Institute of Logistic & transport, London.

[5] Amir F (2011) Significance of Lean, Agile and Leagile Decoupling Point in Supply Chain Management. *Journal of Economics and Behavioral Studies*, 3(5): 287-295.

[6] Melo MT, Nickel S & Saldanha-da-Gama F (2009) Facility location and supply chain management: a review. *European Journal of Operational Research* 196: 401–12.

[7] Dullaert W, Braysy O, Goetschalckx M & Raa B (2007) Supply chain (re)design: support for managerial and policy decisions. *European Journal of Transport and Infrastructure Research* 7(2):73–91.

[8] Snyder, Lawrence V (2006) Facility location under uncertainty: a review. *IIE Transactions* 38(7):547–564.

[9] Zanjirani Farahani R, SteadieSeifi M, Asgari N (2010) Multiple criteria facility location problems: A survey. *Applied Mathematical Modelling* 34: 1689–1709.

[10] You F & Grossmann IE (2008) Design of responsive supply chains under demand uncertainty. *Computers and Chemical Engineering*, 32: 3090–3111.

[11] Rajabalipour Cheshmehgaz H, Ishak Desa M & Wibowo A (2011) A flexible three-level logistic network design considering cost and time criteria with a multi-objective evolutionary algorithm. *Journal of Intelligent Manufacturing* DOI 10.1007/s10845-011-0584-7.

[12] Ross A & Jayaraman V (2008) An evaluation of new heuristics for the location of cross-docks distribution centers in supply chain network design. *Computers and Industrial Engineering*, 55: 64–79, doi:10.1016/j.cie.2007.12.001.

[13] Amiri A (2006) Designing a distribution network in a supply chain system: Formulation and efficient solution procedure. *European Journal of Operational Research* 171: 567–76.

[14] Altiparmak F, Gen M, Lin L & Paksoy T (2006) A genetic algorithm approach for multi-objective optimization of supply chain networks. *Computers and Industrial Engineering* 51: 197–216.

[15] Thanh P N, Bostel N & Pe’ton (2008) A dynamic model for facility location in the design of complex supply chains. *International Journal of Production Economics* 113: 678–693.

[16] Bachlaus M, Mayank KP, Chetan M, Ravi S & Tiwari MK (2008) Designing an integrated multi-echelon agile supply chain network: a hybrid taguchi-particle swarm optimization approach. *Journal of Intelligent Manufacturing*, 19:747–761.

[17] Pan F & Nagi R (2010) Robust supply chain design under uncertain demand in agile manufacturing. *Computers & Operations Research*, 37:668–683.

[18] Hasani A, Zegordi SH & Nikbaksh H (2011) Robust closed-loop supply chain network design for perishable goods in agile manufacturing under uncertainty, *International Journal of Production Research*, DOI:10.1080/00207543.2011.625051

[19] Wang S, Watada J & Pedrycz W (2009) Value-at-Risk-Based Multi-stage fuzzy facility location problems. *IEEE transactions on industrial informatics*, 5:465–482.

[20] Fishvae MS, Jolai F & Razmi J (2009) A stochastic optimization model for integrated forward/reverse supply chain network design. *Journal of Manufacturing Systems*, 28:107–114.