Adaptable distribution management for agile supply chains

Pei-Ju Wu¹, Cheng-Min Feng¹* and Yan-Fang Chen²

¹Institute of Traffic and Transportation, National Chiao Tung University, Taipei, Taiwan, ROC.
²Global Logistics Department, Trade-Van Information Services Company, Taipei, Taiwan, ROC.

Accepted 30 March, 2011

Agile supply chains enable companies to compete in turbulent business environments. However, to be workable, supply chains require agility in both manufacturing and distribution. This study investigates the feasibility of applying adaptable distribution management of agile supply chains to provide adaptable distribution guidance on strategies and operations for decision makers to help facilitate their response to environmental variations. This study develops adaptable distribution strategies, including speedy distribution, low cost distribution, and event avoidance distribution, based on in-depth interviews with global logistics companies. Furthermore, the proposed model can help global logistics companies seek appropriate alternative routes and transport modes in response to unexpected events. The implications of the findings are also discussed.

Key words: Distribution management, agile supply chain, turbulence business environment, global logistics.

INTRODUCTION

The main trend in supply chain management is increasing supply chain agility (Ivanov et al., 2010; Lancioni, 2000; Raisinghani and Meade, 2005; Ren et al., 2009; Samaranayake, 2005; Shaw et al., 2005). Agile supply chains are considered an effective survival strategy for companies facing intense global competition and a turbulent environment (Bottani, 2009; Christopher, 2000; Ganguly et al., 2009; Mason-Jones and Towill, 1999; Power, 2005; Swafford et al., 2008; Swafford et al., 2006b; Vinodh et al., 2008; Wadhwa et al., 2007; Xu et al., 2003; Yusuf et al., 2004). Specifically, an agile supply chain should be able to respond appropriately to a changing business environment (2010; Bottani, 2010; Lin et al., 2006; Prater et al., 2001). Companies such as Volvo (Holmqvist and Pessi, 2006), Argos (Baker, 2008), and HP (Tang and Tomlin, 2008) have utilized agile supply chain practices to rapidly respond to turbulent business environments. Qi et al. (2009) investigated the phenomenon of companies focused on supply chain agility outperforming other companies. Braunscheidel and Suresh (2009) further argued that agile companies can promptly adapt to environmental change and disruption, and can also contribute to extended supply chain agility.

A growing body of literature focuses on agile manufacturing (Avittathur and Swamidass, 2007; Brown and Bessant, 2003; Giachetti et al., 2003; Guisinger and Ghorashi, 2004; Hallgren and Olhager, 2009; Maskell, 2001; Sanchez and Nagi, 2001; Sharifi and Zhang, 2001; Vazquez-Bustelo et al., 2007; Zhang and Sharifi, 2000). However, workable agile supply chains require not merely agile manufacturing but also agile distribution. Specifically, distribution flexibility impacts supply chain agility (Reichhart and Holweg, 2007; Swafford et al., 2006a; Vastag et al., 1994). Schonsleben (2000) mentioned that firm agility is contingent on effective logistics networks. Furthermore, the rising importance of the agile strategy forces companies to pay attention to logistic
services (Caris et al., 2008). Agarwal et al. (2007) pointed out that supply chains need to offer an effective means of controlling costs for agile distribution systems. Moreover, based on a survey approach, K et al. (2009) demonstrate empirically that agile distribution can enhance company performance. Liu et al. (2009) further indicated that expanding agility can increase the global competitiveness of container terminals. Meng et al. (2010) concluded that agility is one key client satisfaction factor influencing client satisfaction for logistics providers. Hence, it is essential for global logistics companies to ponder agile distribution approaches in volatile environments.

Nonetheless, few studies have investigated distribution management for agile supply chains to provide adaptable distribution guidance for decision-makers who can then effectively respond to environmental variations. Furthermore, global logistics companies aspire to own adaptable distribution abilities to grapple with turbulent environments in an intensely competitive global market. Consequently, the purpose of this study was to explore agile supply chains with an emphasis on adaptable distribution management. Specifically, this study aims to develop adaptable distribution approaches involving strategies and a model for agile supply chain on the basis of strategic and operational levels, respectively.

ADAPTABILITY DISTRIBUTION STRATEGIES

This study was conducted with in-depth interviews with global logistics companies to identify global distribution hurdles in complex and turbulent business environments. The interview method (Bossard and Peterson, 2005; Lumsdon, 2006) was used because it provides detailed insights into respondent experiences and enables further inquiry into the meanings of their responses. This study uses strict conditions for selecting logistics companies and respondents for interview. First, this investigation focuses on successful logistics companies with global distribution capacity. Second, interview respondents from sampled logistics companies were selected based on their expertise in planning global distribution. Moreover, conducting in-depth interviews requires the consent of a limited number of selected managers. Four face-to-face interviews lasting 40 to 60 min were conducted with respondents over a one-month period. Respondents respected confidentiality rules. The face-to-face interviews involved open-ended questions. Following each interview, transcripts were inspected to identify important findings. Finally, key adaptable distribution strategies for dealing with volatile environments were generated (Figure 1), including: speedy distribution, low cost distribution, and event avoidance distribution. Moreover, the related literature was used to support the proposed strategies.

Speedy distribution

Operating speed is crucial to supply chain agility (Agarwal et al., 2006, 2007; Agarwal and Selen, 2009; Baker, 2008; Bernardes and Hanna, 2009; Bottani, 2010; Braunscheidel and Suresh, 2009; Bruce et al., 2004; Jin, 2004; Kumar and Motwani, 1995; Lee, 2004; Li et al., 2006; Prater et al., 2001; Schonsleben, 2000; Swafford et al., 2006a; Zhang and Sharifi, 2007). Hence, speedy distribution enables products to be promptly shipped between locations. Specifically, agility requires products to be delivered as swiftly as possible, using the fastest mode available between the origin and destination. For
example, both domestic and overseas distribution may use airline transport where customers require urgency.

**Low cost distribution**

Effective cost management is also crucial to achieving supply chain agility. (Agarwal et al., 2007; Barve et al., 2009; Feng and Nagi, 2010; Herer et al., 2002; Hooper et al., 2001; Jin, 2004; Lee, 2004; Li et al., 2006; Swafford et al., 2006a). Therefore, low cost distribution enables products to be shipped using the cheapest approach. Considering a cost saving idea, Kiesmüller et al. (2005) developed a model for quantifying the value of using an additional slow mode rather than only using the existing fast mode. For example, regarding Canada-Mexico shipments, shipping by water is 20% cheaper than shipping by truck, but the latter is two days faster (Bookbinder and Fox, 1998).

**Event avoidance distribution**

Response ability is the core of agile supply chains (Baker, 2008; Bernardes and Hanna, 2009; Bottani, 2010; Braunscheidel and Suresh, 2009; Bruce et al., 2004; Christopher, 2000; K et al., 2009; Lee, 2004; Liu et al., 2009; Oloruntoba and Gray, 2006; Perry et al., 1999; Reichhart and Holweg, 2007; Sarks et al., 2007; Sherehiy et al., 2007; Yusuf et al., 2004; Zhang and Sharifi, 2007).

Accordingly, event avoidance distribution enables the transfer of products via other routes (besides rational routes), thus avoiding unexpected events such as interruption of flights by volcanic ash, industrial strikes, pirate assaults, traffic accidents, etc. For example, when unexpected events influence the best choice of airport or seaport, products need to be delivered via the second best choice, typically some area adjacent to the best (main) port.

**MODELING**

A key question is how global logistics companies effectively and efficiently respond to sudden events. A further question is whether appropriate alternative routes and modes exist via which global logistics companies can redistribute their products by utilizing adaptable distribution when facing unexpected events. Given the problem statement, an adaptable distribution model is formulated to derive the optimal solution that minimizes distribution time (based on speedy distribution strategy) and distribution cost (based on low cost distribution) to identify the best alternative route and mode (based on event avoidance distribution strategy) as well as to achieve agile supply chains under a turbulent environment. Clarifying the study scope and facilitating model formulation involves the following three assumptions: (1) The time-varying quantity of product demand is randomly given; (2) The proposed model considers only one product type; (3) Supply chain members include DCs, ports (both sea and air), and demand points (wholesalers, retailers, or end customers). Moreover, the number and location of all supply chain facilities are given.

Before formulating the proposed model, the notations, and definitions for sets, decision variables, and parameters are summarized, as follows.

**Sets**

- $K$: Set of demand points
- $M$: Set of transportation modes
- $P$: Set of ports
- $T$: Set of time periods
- $W$: Set of DCs

**Parameters**

- $CAPL_{ijmt}$: Capacity of a mode $m$ for delivering products from a node $i$ to another node $j$ in period $t$
- $CAPN_{jt}$: Capacity of a node $j$ in period $t$
- $CSF$: Cycle stock factor
- $D_i$: Demand of products at node $i$ in period $t$
- $E_i$: Exchange rate of a node $i$ in period $t$
- $NODE$: Number of DC and port nodes.
- $SIT_{ijmt}$: Frequency of goods shipments from node $i$ to node $j$, using a transportation mode $m$ in period $t$
- $SSF_{it}$: Safety stock factor at a node $i$ in period $t$
- $TC_{ijmt}$: The transportation cost of products shipped from a node $i$ to another node $j$, using a transportation mode $m$ in period $t$
- $\overline{TC}_{ijmt}$: Unexpected events triggered abnormal transportation costs for a movement between node $i$ and node $j$, using transportation mode $m$ in period $t$ when $Z_{ijmt}$ equals 1
- $TR_{ijmt}$: Average transportation time from node $i$ to node $j$, using a transportation mode $m$ in period $t$
- $TT_{ijmt}$: Total transportation time from node $i$ to node $j$
using a transportation mode $m$ in period $t$.

$TT_{ijmt}$ Unexpected events triggered abnormal total transportation time for a movement between node $i$ and node $j$, using a transportation mode $m$ in period $t$ when $Z_{ijmt} = 1$.

$TTV_t$ Time value of products in period $t$.

$Z_{ijmt}$ The binary variable indicates whether unexpected events occur during a movement between node $i$ and node $j$, using a transportation mode $m$ in period $t$.

**Decision variables**

$ord_i$ Number of nodes visited on the transfer path from the origin up to node $i$ (namely, the visit number of the $i$th node).

$q_{inv_{it}}$ The time-varying inventory amount at a node $i$ in period $t$.

$x_{ijmt}$ Quantity of products shipped from node $i$ to node $j$ using transportation mode $m$ in period $t$.

$y_{ijmt}$ Binary decision variable representing whether products are shipped from node $i$ to node $j$ using a transportation mode $m$ in period $t$.

The objective function simultaneously minimizes the distribution cost and distribution time, as Equation (1) demonstrates. Herein, total transportation time $TT_{ijmt}$ equals $TR_{ijmt} + (SIT_{ijmt}) + SSF_{it} \sqrt{TR_{ijmt}}$ (Vidal and Goetschalckx, 2000). The safety stock used the gamma distribution to model stochastic lead times and inventory problems (Vidal and Goetschalckx, 2000).

$$
\begin{align*}
\text{Min} & \quad \sum_{i \in W \cup P} \sum_{j(i \neq j) \in W \cup P \cup K} \sum_{m \in M} \sum_{t \in T} \left( \frac{1}{E_{jt}} \right) TC_{ijmt} x_{ijmt} y_{ijmt} (1 - Z_{ijmt}) \\
& + \sum_{i \in W \cup P} \sum_{j(i \neq j) \in W \cup P \cup K} \sum_{m \in M} \sum_{t \in T} \left( \frac{1}{E_{jt}} \right) TT_{ijmt} TTV_t x_{ijmt} y_{ijmt} (1 - Z_{ijmt}) \\
& + \sum_{i \in W \cup P} \sum_{j(i \neq j) \in W \cup P \cup K} \sum_{m \in M} \sum_{t \in T} \left( \frac{1}{E_{jt}} \right) TC_{ijmt} x_{ijmt} y_{ijmt} Z_{ijmt} \\
& + \sum_{i \in W \cup P} \sum_{j(i \neq j) \in W \cup P \cup K} \sum_{m \in M} \sum_{t \in T} \left( \frac{1}{E_{jt}} \right) TT_{ijmt} TTV_t x_{ijmt} y_{ijmt} Z_{ijmt}
\end{align*}
\tag{1}$$

The inventory amount at a node $i$ remaining in the current time $q_{inv_{it}}$ equals the sum of the remaining inventory at node $i$ during the previous time $q_{inv_{i(t-1)}}$ and the inbound flows transported from a node $l$ to another node $i$, minus the outbound flows transported from node $i$ to another node $j$. Equation (2) expresses the corresponding flow conservations.

$$
q_{inv_{i(t-1)}} + \sum_{l(i \neq l) \in W \cup P} \sum_{m \in M} x_{limt} y_{limt} - \sum_{j(i \neq j) \in W \cup P \cup K} \sum_{m \in M} x_{ijmt} y_{ijmt} = q_{inv_{it}}, \quad \forall i \in W \cup P, t \in T
\tag{2}
$$

To meet demand requirements, the corresponding constraint is given by Equation (3).
The current inventory at node $i$ cannot exceed the capacity of that node. Moreover, the quantities of product shipped from node $i$ to node $j$ through transportation mode $m$ cannot exceed the capacity of mode $m$ on each link. Accordingly, the corresponding constraints on the capacities of nodes and transportation modes are expressed as Equation (4) and (5), respectively.

$$\sum_{i\in W\cup P} x_{ijmt} \leq CAPN_{it}, \forall i \in W \cup P, t \in T \quad (4)$$

$$\sum_{i\in W\cup P} y_{ijmt} \leq CAPM_{mt}, \forall j \in W \cup P \cup K, m \in M, t \in T \quad (5)$$

The constraint denoted by Equation (6) indicates that products cannot be simultaneously shipped by plural transportation modes.

$$\sum_{m \in M} y_{ijmt} \leq 1, \forall i \in W \cup P, j \neq j', \forall j, m \in M, t \in T \quad (6)$$

One demand point only can receive one batch of products during the assignment process. Accordingly, the corresponding constraint is given by Equation (7).

$$\sum_{i \in W \cup P} \sum_{m \in M} y_{ijmt} \leq 1, \forall j \in K, t \in T \quad (7)$$

Since goods can transfer among DCs and ports, Equation (8) prohibits the formation of subtours among them.

$$ord_i - ord_j + NODE \sum_{m \in M} y_{ijmt} \leq NODE - 1, \forall i \neq j \in W \cup P \quad (8)$$

The constraint denoted by Equation (9) indicates that those variables are binary.

$$y_{ijmt} \in [0, 1], \forall i \in W \cup P, j \neq j', \forall j, m \in M; t \in T \quad (9)$$

The constraints denoted by Equations (10) and (11) indicate that those variables are non-negative.
3. The third scenario is analogous to the second scenario except that a global logistics company encounters a link failure, such as disruption of flights by volcanic ash that renders the passage between two ports (nodes 5 and 6) impassable. Logistics behavior indicates that to solve the problem of the link becoming non-functional, products shipped from nodes 5 to 6 are indirectly transferred through another port (node 7) in country C, replacing the route by which products are shipped directly from a port (node 5) to a port (node 6). Figure 4 shows that products are delivered from a DC (node 2) to a port (node 5) by truck, from node 5 to node 6 by airplane, from node 7 to node 6 by airplane, and from node 6 to node 10 by truck. Scenario four resembles scenario two, but involves a global logistics company encountering a node failure, such as industrial strike action, that renders a port (node 5) inoperable. The model results indicate that to solve the problem of the node being rendered non-functional, products are shipped from a DC (node 1) to a port (node 6) indirectly via another port (node 4) in country A rather than using the pre-scheduled route by which products are shipped from a DC (node 2) to a port (node 6) directly via a port (node 5). As shown in Figure 5, products are delivered from a DC (node 1) to a port (node 4) by truck, from a port (node 4) to another port (node 6) by airplane, and from a port (node 6) to a demand point (node 10) by truck.

4. The scenario analyses demonstrate the robustness of the proposed adaptable distribution model for an agile supply chain. Specifically, the scenario results indicating the adaptable distribution reveal that the proposed model with minimum distribution time (speedy distribution strategy) and distribution cost (low cost distribution) can effectively respond to sudden events (event avoidance distribution strategy) in an unstable environment (Baker, 2008; Bernardes and Hanna, 2009; Bottani, 2010;
The distribution routes in the fourth scenario.

Global logistics companies should arrange backup distribution centers

The proposed model can identify appropriate backup DCs in the event of sudden demand turbulence. For example, the scenario results for logistics behavior in the second scenario indicate that a DC (node 2) supports the inventory shortage of a DC (node 3). This finding implies that global logistics companies had better ensure that their DCs possess sufficient responsive capacity (Sting and Huchzermeier, 2010), such as arranging backup distribution centers to cope with volatile demand.

Global logistics companies should settle for alternative routes

If the distribution of pre-scheduled nodes or links fails because of industrial strikes, volcanic ash, and so on, products are rerouted according to the recommendations of the proposed adaptable distribution model, as indicated by the model results for scenarios three and four. This finding implies that global logistics companies need to devise second best choice alternative routes in the event of node or link failures (Beroggi and Wallace, 1995; Verma and Tiwari, 2009).

Conclusions

This study stresses distribution management from both strategic and operational perspectives that global logistics companies can use to manage unexpected events. Specifically, this investigation presents adaptable distribution strategies and develops an adaptable distribution model for agile supply chains.

This study differs from previous investigations addressing agile supply chain problems in several ways. First, this study proposes adaptable distribution strategies to deal with environmental turbulence through reference to both literature review and in-depth interviews with global logistics companies. Those distribution strategies include: speedy distribution, low cost distribution, and event avoidance distribution. The proposed adaptable distribution strategies provide practical and theoretical ideas through systematically utilizing the valuable perceptions of senior managers in the areas of global distribution. Second, the adaptable distribution model for agile supply chains helps global logistics companies identify solutions that simultaneously minimize distribution time and distribution cost. The proposed model can determine the optimal adaptable route and transport mode for each order on the basis of adaptable distribution strategies. Global logistics companies can utilize the proposed adaptable distribution model to achieve agility in volatile environments.

The proposed approaches may stimulate further
research on agile supply chains and help address issues related to adaptable distribution.

Future investigations may incorporate manufacturing operations into the proposed agile supply chain model. Moreover, large-scale examples of agile supply chain problems in a scenario study should be carefully generated to closely approximate reality. The proposed model is expected to remain relevant in the future.

ACKNOWLEDGEMENTS

This research was supported by grant NSC 97-2420-H-009-002-DR from the National Science Council of Taiwan. The authors are deeply indebted to numerous personnel of the examined global logistics companies for cooperating with interviews and scenario design. Any errors or omissions remain the sole responsibility of the authors.

REFERENCES

Prater E, Biehl M, Smith MA (2001). International Supply Chain Agility -