Int J Adv Manuf Technol (2005) 25: 793–802
DOI 10.1007/s00170-003-1891-8

ORIGINAL ARTICLE

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Virtual integration with a multi-criteria partner selection model for the multi-echelon manufacturing system

Received: 7 March 2003 / Accepted: 7 July 2003 / Published online: 27 October 2004

Abstract Virtual integration (VI) offers a way to make manufacturing systems more agile and competitive. VI integrates the production resources of many manufacturing systems (partners) efficiently, and that leads to a rapid response to market changes. Based on the VI concept these partners throughout the world will form a virtual enterprise (VE). Thus to select partners is the essential and the most important issue. The main objective of this paper is to develop a partner selection and production-distribution planning with the novel partner selection model, based on the analytic hierarchy process (AHP) methodology, multi-attribute utility theory (MAUT) and integer programming (IP), for the VI with multiple criteria. The AHP and MAUT methods are use to assess and set weights for each partner candidate and the IP model applies these weights to find the optimal partners from the potential ones and provide the suitable production-distribution plan to the elective partners. Finally, a case study has been provided to substantiate a feasible quality solution of the proposed model.

Keywords Partner selection · Production-distribution planning · Virtual enterprise · Virtual integration

1 Introduction

Virtual integration (VI) is a collaborative production-distribution network that unifies many independent business partners to plan, perform, and control operational interchanges effectively and efficiently, from acquisition of raw materials to delivery of the finished product to the end user/customer. Every collaborative partner (enterprise) collectively interacts by sharing their product information, to transport the right quality and quantity of product at the right time. Under this concept these enterprises constitute a larger organization, that is, a virtual enterprise (VE).

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VE is a joint venture, which consists of suppliers, manufacturers, distributors, and customers to develop and produce products for fulfilling consumer requirements in the rapidly changing environment of the global manufacturing area. Davulcu et al. [1] stated that a VE is a temporary consortium of autonomous, diverse, and possibly geographically dispersed organizations that pool their resources to meet short-term objectives, and exploit fast changing market trends. The VE is a dynamic alliance of member companies, which join to take advantage of a market opportunity. Each member company will provide its own core competencies in areas such as marketing, engineering, and manufacturing to the VE [2]. In addition, Walton and Whicker [3] and Song and Nagi [4] separately explain "The VE consists of a series of co-operating 'nodes' of core competencies which form into a supply chain in order to address a specific opportunity in the market place" and "A VE, different from a traditional enterprise, is constructed by partners from different companies, who collaborate with each other to design and manufacture high quality and customized products. It is product-oriented, team-collaboration styled, and featured as being fast and flexible." From these definitions, it is without doubt that the supply chain management (SCM) will be a good quality approach to enhance the competitiveness of the VE.

Christopher [5] stated that an adequate definition of supply chain from a logistical perspective is "a network of organizations that are involved, through upstream and downstream linkages, in different processes and activities that produce value in the form of products and services in the hands of the ultimate consumer." The SCM increases the competitiveness of the industrial environment, and involves planning and managing the flow of information, material, and product through a multi-echelon of design, production/manufacturing, transportation, and distribution until it reaches the customer. While satisfying customer demand, the problem of distributing products/goods involves determining the optimal cost, size, and time of those participants so as to minimize the total cost associated with the supply chain transactions such as order, setup, production, delivery, inventory, quality, and reliability cost. The distribution decision is a long- or short-term strategy. If the distribution volume is very large, and the relationship of the participants is not easily converted, the decision would be treated as a long-term strategy. Conversely, the short-term decision strategy usually involves a small volume of distribution and easily changed relationships among collaborators (suppliers or manufacturers/distributors).

SCM can help to simultaneously achieve the goals of the supplier and customer satisfaction in the manufacturing industry. The essence of the supply chain management is considered to be the integration of business activities to serve end customers, by establishing a strategic partner alliance. Figure 1 illustrates the relationship between the dependent natures of supplier-customer relations. For the supply chain, the relationship between supplier and customer tends to create a problem requiring a decision involving multiple selections. That is to say, the relationship is strategically collaborative, as shown in Fig. 1d. Achieving competitiveness in this industry thus requires efficient collaboration between suppliers and customers. Therefore, to select appropriate partners in the processes of strategic collaboration is the major subject for promoting a smooth integration among independent enterprises in the supply chain.

To integrate enterprises completely, the product structure is the foundation, while computer aided implementation is indispensable for being successful in selecting partners. This paper proposes an interactive approach, based on analytic hierarchy process (AHP) methodology, multi-attribute utility theory (MAUT), and the integer programming (IP) model, to solve the partner selection and production-distribution problem of a multi-echelon manufacturing system assuming a particular optimal satisfaction. This approach is preceded by an analysis to define the best potential production partner members to release a quantity of products for companies upstream, to determine a feasible distribution of downstream collaborators and volume of products, and to gather extensive information on these possible collaborators. The proposed approach aims to help determine which companies among the feasible collaborators will be included in the production-distribution network, and the size of the release quantity obtained from upstream suppliers.

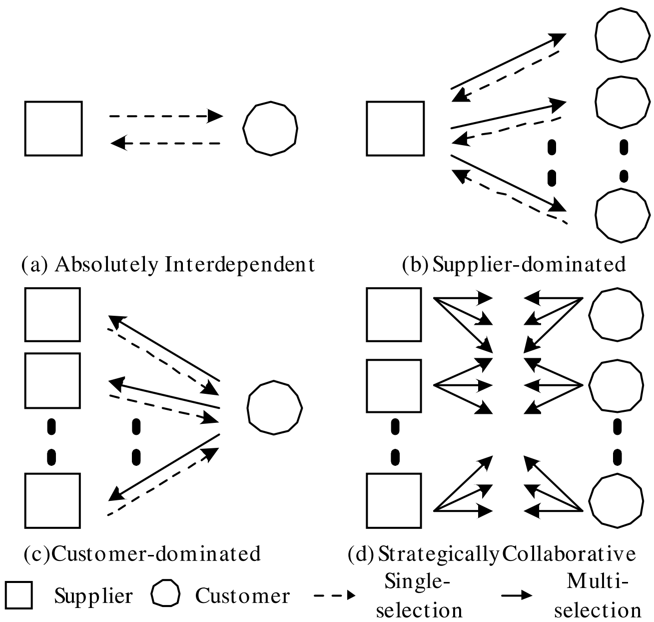
The application of this approach is demonstrated through a case study involving the complex semiconductor manufacturing system. To obtain an optimum solution, this study focused on presenting an efficient and systematic approach for modeling the distribution behavior of the semiconductor supply chain, so as to maximize overall satisfaction with the chain.

This paper is organized as follows: Sect. 2 presents a brief literature survey on related current approaches and models in partner selection. The proposed interactive methodology, combining the AHP, MAUT and IP approaches, can identify a partner selection decision for VI of manufacturing systems, and will be discussed in Sect. 3. Section 4 illustrates the effectiveness and efficiency of the proposed research approach in the actual semiconductor industry environment. Finally, Sect. 5 summarizes the conclusions of this study.

2 Literature review

Capital investments are especially large for keeping the chain operating effectively. Successful partnerships create a synergistic supply chain in which the entire chain is more effective than the sum of the individual parts. Therefore, partner selection is a particularly important activity in establishing strategic alliances to enhance the competitive advantage of the entire supply chain.

This section describes the literature survey related to partner selection of VE and SCM. Korhoren [8] and Davis [9] stated that the partner selection process is an important function for



Comparison of different types of supplier-customer relationships			
State	No. of suppliers	No. of customers	Description
(a)	one	one	The supplier and customer must closely collaborate.
(b)	one	many	The supplier has many choices of customers for collaborating, but it is unique to every customer.
(c)	many	one	The customer has many choices of suppliers for collaborating, but it is unique to every supplier.
(d)	many	many	These suppliers and customers may have their choices among them to collaborate.

Fig. 1. Supplier-customer relationship

the information management systems of extended virtual enterprises. Talluri et al. [10], Papazoglou et al. [6], and Mikhailov [7] claimed that the key issue in forming a VE is to select agile, competent, and compatible partners.

In addition, many literatures presented that using multiple criteria decision for partner selection is necessary. Weber and Desai [12] illustrated multi-criteria evaluation and other effective methods for selecting vendors to secure a competitive advantage. Wang et al. [13] presented multiple factors (cost, due date, and the precedence of sub-project) to select appropriate partners. Muralidharan et al. [11] defined nine criteria to select good suppliers for achieving business efficiency. Cavusgil et al. [14] noted that distributor selection is a very important strategy for an international production-distribution system and showed that 35 criteria are grouped into five major dimensions (financial and company strengths, product factors, marketing skills, commitment, and facilitating factors).

According to the literature mentioned above, efficient virtual integration must be performed through partner selection with multi-criteria for the manufacturing systems. The interactive approach proposed in this study, and combined with the AHP approach, MAUT method, and IP model, is therefore a useful means of achieving these goals as defined above. AHP, a scoring method designed to visually structure complex decision problems involving multiple criteria, is based on the principles of decomposition, comparative judgment, and the synthesis of priorities [15, 16]. Meanwhile, AHP is a measurement theory for dealing with quantifiable and intangible criteria, and has been applied to such diverse areas as decision theory and conflict resolution [17]. The MAUT, is comprised of the preference functions for individual attributes, and the weights that reflect the relative importance of these attributes, provides a logical and tractable means to make tradeoffs among conflicting objectives [18]. Furthermore, the IP is the mathematical technique that is concerned with optimization, which is finding the best possible answer to a problem under relevant restrictions.

Many researches have illustrated the wider fields of application research by associating with AHP, MAUT, or IP approaches. For example, the AHP have been used effectively earlier by Korpela et al. [19–21] for formulating logistics network design. In addition the MAUT has previously been used for the capital allocation process of a petroleum exploration company by Walls and Dyer [22], for the transaction selection problem by Kumar and Sheble [24], and for technological innovation effect in a financial portfolio by Nepomuceno et al. [23].

VI is a team endeavor within manufacturing systems. The AHP is one available method for creating a systematic framework for group interaction and decision making [25]; the MAUT method should be able to display tradeoffs among different attributes in a useful manner; and the IP model is usually used to find an optimal solution for a decision problem. For handling this situation, the AHP should be incorporated into the construction procedure of the MAUT model, so as to construct the framework of educing multi-attribute utility functions and weighting parameters. Then, the utility values, calculated by the MAUT model are included as decision variables in the IP model.

3 Proposed approach for partner selection

The VI requires a systematic and efficient mathematical method for making decisions regarding relationships and component and/or product distribution, among related co-operators. Meanwhile, this method needs to cover all procedures involved in the multi-echelon manufacturing systems, from raw material supply to product distribution. Figure 2 depicts the decision making process for partner selection planning for VI.

A step-by-step explanation of the proposed methodology is presented in the following.

3.1 Attribute priorities assessment

To analyze VI behavior in the multi-echelon manufacturing systems, an interaction oriented model based on the AHP, MAUT and IP approaches and designed to optimize distribution while explicitly satisfying all participants was used.

The AHP, a systematic decision approach first developed by Saaty [15], is a powerful tool for solving complex decision problems that may have interactions and correlations among decision criteria. AHP is based on three principles: decomposition, comparative judgments, and the synthesis of priorities. Figure 5a– b separately show two hierarchies used for customers of corporation A and suppliers of corporation B in the illustrative example. Then, pair-wise comparisons among factors in each level of each hierarchy are made with respect to the factor in the level above, resulting in a set of pair-wise comparison matrices as shown in Table 3. The pair-wise matrix A, in which the element a_{ij} of the matrix is the relative importance of the ith factor with respect to the jth factor, could be created as shown below:

$$A = \left[a_{ij}\right] = \begin{bmatrix} 1 & a_{12} & \dots & a_{1n} \\ \frac{1}{a_{12}} & 1 & \dots & a_{2n} \\ \vdots & \vdots & \dots & \vdots \\ \frac{1}{a_{1n}} & \frac{1}{a_{2n}} & \dots & 1 \end{bmatrix} \quad (1)$$

For all i and j, it is necessary that $a_{ij} = 1/a_{ji}$ and $a_{ij} = 1$. In order to calculate the individual and overall influence of factors in the goal, the eigenvector analysis [15], which is a unique technique to determine the relative ranking of factors with respect to a certain objective, is used. The priority vector can be generated by normalizing the principal eigenvector W of the matrix A

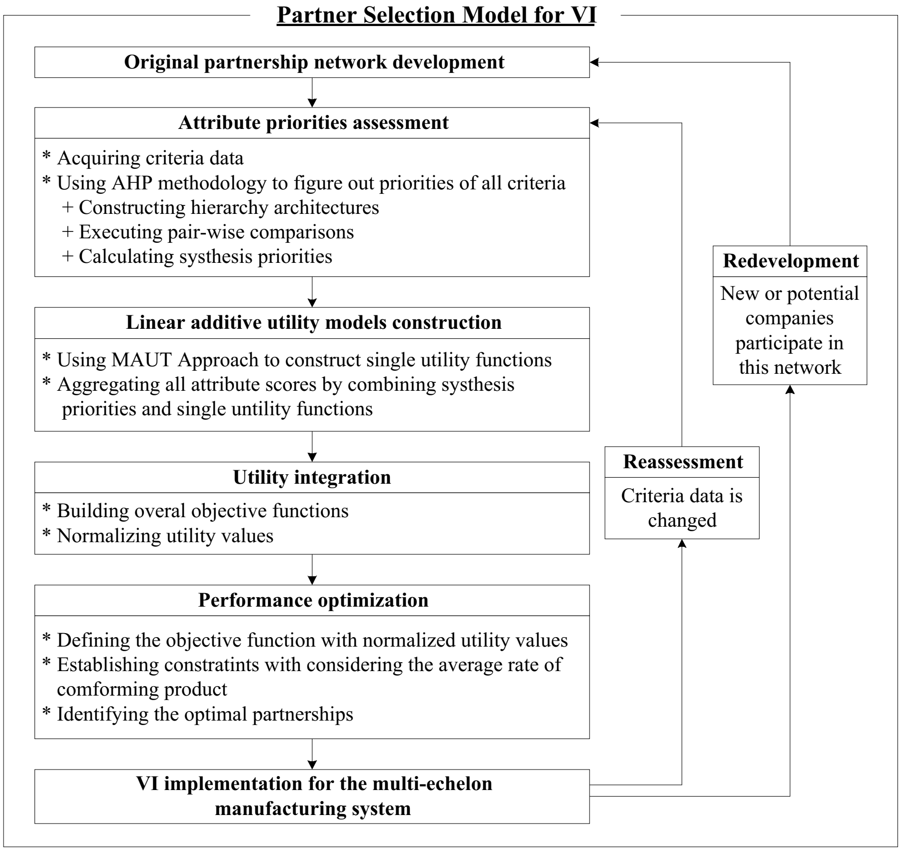
$$A\,W = \lambda_{\max} W \quad (2)$$

where $\lambda_{\max}$ is the principal or the largest eigenvalue of positive real values of judgment matrix.

Each pair-wise comparison contains many decision elements for the consistency index (CI) that measures the entire consistency judgment for each comparison matrix, and the hierarchy architecture. The consistency ratio (CR) is useful for this task, and the accepted upper limit value for CR is 0.1 for a good judgment. CR is calculated using

$$CR = \frac{CI}{RI} \quad (3)$$

Fig. 2. The proposed framework for VI



where

$$CI = \frac{\lambda_{\max} - n}{n - 1} \tag{4}$$

RI (Random Index) is obtained by n from a random index table, as displayed in Table 1 below. If the consistency test is not eligible ($CR > 0.1$), then the AHP may not yield meaningful results and must reconstruct the matrix A.

3.2 Linear additive utility models construction

The MAUT approach is based on the construction of individual utility functions for each attribute, which is comprised of the preference functions for individual attributes and the weights that reflect the relative importance of these attributes. The first step of MAUT is to assign utility values for each attribute. The $U_i(x_i)$, the single utility function or preference function associated with attribute i, represents the utility values the decision maker attaches to each attribute. The utility value is usually defined as a normalized scale that is bound between the lower and upper bounds of the attribute evaluate unit. The specific processes of single utility function setting and utility value calculating can be referred to in Keeney and Raiffa [18]. These utility values must be criticized carefully to ensure that the results of the evaluation are consistent with the preferences of the decision maker.

Table 1. Random index table [26]

n	3	4	5	6	7	8	9
RI	0.58	0.90	1.12	1.24	1.32	1.41	1.45

The next step is to aggregate the scores of each attribute in the MAUT process. The linear additive utility form is the frequently simplified assessment procedure as given by

$$V^{x\to y} = \sum_{i=1}^{n} w_i^{x\to y} U_i^{x\to y}(x_i) \tag{5}$$

where $x \to y$ is the viewpoint from corporation x to its candidate customer y; $V^{x\to y}$ is objective function, which is the overall utility for the perspective of x to its specific candidate y; w_i is the appropriate weight that represents the relative importance (priority) of attribute i, for the n attributes, where $\sum_{i=1}^{n} w_i = 1$. In this paper, the w_i value is obtained by using the AHP process, which is described in the above Sect. 3.1.

3.3 Utility integration

The dependent nature of the supplier-customer relationship in the manufacturing system is strategically collaborative as shown in Fig. 1d. Therefore the integrate utility between corporation x

and y can be formulated by using the multiplication method as follows

$$V^{x\leftrightarrow y} = V^{x\rightarrow y} \times V^{x\leftarrow y} \quad (6)$$

where $x \leftrightarrow y$ denotes to integrate the viewpoints of corporation x and y and $x \leftarrow y$ denotes the viewpoint from corporation y to its supplier y. $V^{x\leftarrow y}$ is the utility for the perspective of y to its specific supplier x, and $V^{x\leftrightarrow y}$ is the overall objective function, which is the overall utility between corporation x and y.

To consider more then one corporation in the multi-echelon manufacturing system, for each corporation, the utility value between it and any customer would be normalized to a total of 1 to represent the utility of each customer. The normalized process for each customer is shown below.

$$Normalized\ V^{x\leftrightarrow y_j} = \frac{V^{x\leftrightarrow y_j}}{\sum_{j=1}^{m} V^{x\leftrightarrow y_j}} \quad (7)$$

where j is the number of downstream co-operators for the specific corporation x. Afterward, the multi-echelon manufacturing system could be established completely and efficaciously by normalized efficacious $V^{x\leftrightarrow y_j}$ as shown in Table 6 of the illustrative example.

3.4 Optimization model

The delivery quantity between one corporation and its customer is a very important issue. Therefore, for the partner selection to achieve VI, to assign the right delivery quantities on all linkages between two corporations of multi-echelon manufacturing system is the final task. The partner selection and distribution model is proposed to make a decision for the delivery quantities by using the IP approach. The objective function formulation effectively integrates all evaluative criteria for designing a partner selection as follows:

$$Max \sum_{k=1}^{K-1} \sum_{i=1}^{I_k} \sum_{j=1}^{J_{k+1}} \left(Normalized\ V_p^{x(k,i)\leftrightarrow y(k+1,j)} \right) Q_{(k,i)(k+1,j),p} \quad (8)$$

where $Q_{(k,i)(k+1,j),p}$ represents the number of units shipped from supplier i of echelon k to customer j of echelon $k+1$ in period p. k is the echelon index, $k = 1, \ldots, K$. K is the number of echelons in the multi-echelon manufacturing system. i, j are corporation indices, $i = 1, \ldots, I_k$, $j = 1, \ldots, J_k$. I_k, J_k are number of corporations in the echelon k. p is the period index, $p = 1, \ldots, P$. P is the number of periods.

Four varieties of relevant restrictions must be involved in our proposed model. (1) Capacity constraints (Eqs. 9 and 10): the quantity of the product should be greater than the minimum quantity of the starting production and less than the processing capacity of each corporation. (2) Conservation-of-flow constraints (Eq. 11): to ensure that the commodity shipped into a corporation must also leave. (3) Demand constraints (Eq. 12): to ensure that the customer demand is satisfied by using this production-distribution process. (4) Non-negative-integer constraints (Eq. 13): the shipping quantity of the product should be a non-negative integer between two corporations:

$$LC_{(k+1,j),p} \leq \sum_{\substack{i=1 \\ k\leq K-1}}^{I_k} Q_{(k,i)(k+1,j),p} \leq UC_{(k+1,j),p}\,, \quad \forall j, k, p \quad (9)$$

$$LC_{(k,i),p} \leq \sum_{j=1}^{J_{k+1}} Q_{(k,i)(k+1,j),p} \leq UC_{(k,i),p}\,, \quad \forall i, p, k = 1 \quad (10)$$

$$\sum_{\substack{i=1 \\ k\leq K-2}}^{I_k} Q_{(k,i)(k+1,j),p} = \sum_{\substack{l=1 \\ k\leq K-2}}^{L_{k+2}} Q_{(k+1,j)(k+2,l),p}\,, \quad \forall j, k, p \quad (11)$$

$$\sum_{i=1}^{I_{k-1}} \sum_{j=1}^{J_k} Q_{(k-1,i)(k,j),p} = D_p\,, \quad \forall p, k = K \quad (12)$$

$$Q_{(k,i)(k+1,j),p} \geq 0 \quad and \in integer\,, \quad \forall i, j, k, p \quad (13)$$

where $LC_{(k,I),p}$ and $UC_{(k,I),p}$ separately represent the minimum quantity of starting production, and the processing capacity of corporation i of echelon k in period p. D_p is the total market demand in period p. l is the corporation index, $l = 1, \ldots, L_k$. L_k is the number of corporations in the echelon k.

4 Illustrative example

This application study will demonstrate the effectiveness and efficiency of our proposed approach in the actual environment of multi-echelon manufacturing systems within the semiconductor industry. Figure 3 demonstrates the multi-echelon semiconductor manufacturing system. Specifically, this application involves several selectable partnerships for each enterprise for achieving efficient VI, to enhance the competitiveness of the entire industry.

In this illustrative example, the multi-echelon semiconductor manufacturing system with the architecture 2-3-3-2 is applied. This architecture 2-3-3-2 expresses that there are 2, 3, 3, and 2 corporations in the first, second, third, and fourth echelon of this multi-echelon manufacturing system as is shown in Fig. 4. Following the above procedure, the foremost task of the proposed approach is to identify the related decision criteria for each corporation. These criteria are used for ranking the proposed partnerships of the corporation A's downstream customers and corporation B's upstream suppliers that may influence collaboration decisions. These factors, which were initially presented by the outsourcing team from corporations A and B, were used to veritably assess the partnerships and were listed in Table 2. Herein, the details of the technique of the corporation A (node 2.1) and B (node 3.1) are described in detail. For the sake of expediency, the program of other corporations is the same with corporation A and B and will not

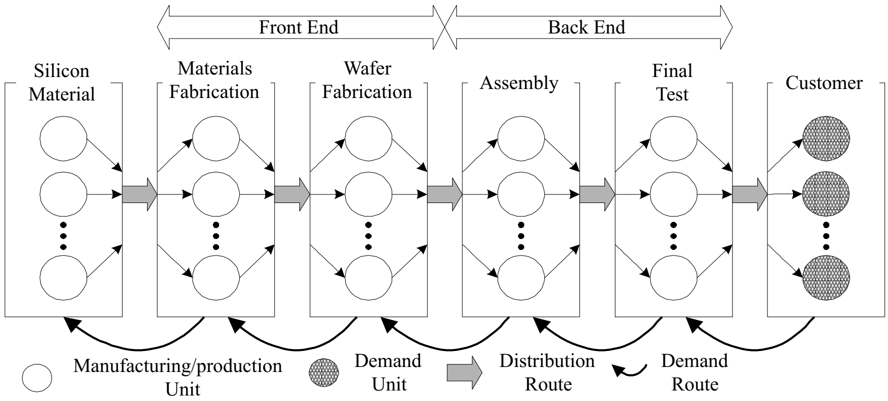


Fig. 3. Multi-echelon semiconductor manufacturing system

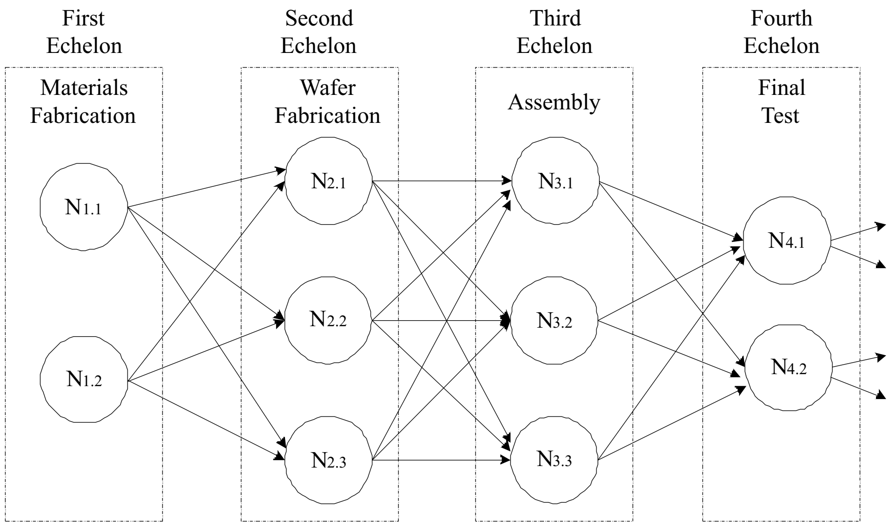


Fig. 4. {2-3-3-2} original partnership network topology

Table 2. The factors for ranking the proposed partnerships of corporation *A* and *B*

For upstream supplier of corporation *B*	
Factor (criterion)	Description
Price	Unit product price
Matching	Conjugation with products
Delivery	On-time delivery capability
Quality	Quality of incoming material
For downstream customer of corporation *A*	
Factor (criterion)	Description
Quality	Production quality
Yield	The yield of O/S or assembly
Delivery	On-time delivery capability
Price	Unit product price
Service	Production capacity for fitting demand

to be explained again. The hierarchical structures used in this work of corporations *A* and *B* are shown in Fig. 5. After constructing the complete hierarchies, the pair-wise comparisons of decision criteria are used rather than the absolute measurement scales, since absolute measurements tend to be very subjective. For the hierarchies of Fig. 5, the pair-wise matrices and priority vectors are calculated by Eqs. 1 and 2 and shown in Table 3. It needs to be mentioned that, for the sake of business privacy considerations, in this paper, these analytic data have been modified. However, these data accord with the reality of production.

Table 3. The pair-wise comparison matrixes of corporation *A* and *B*

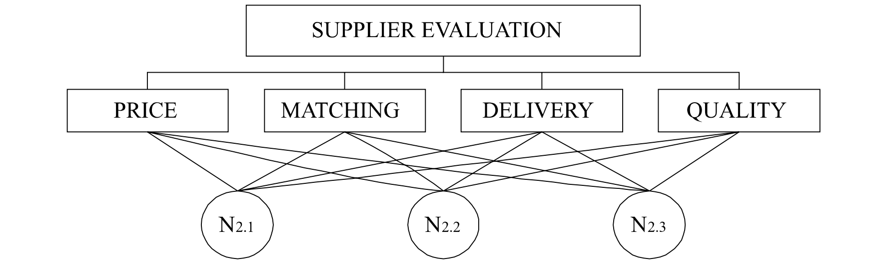
For upstream supplier of corporation *B*

Criterion	Price	Matching	Delivery	Quality	Priority
Price		1/2	1/2	3	0.179
Matching			1	8	0.384
Delivery				8	0.384
Quality					0.052

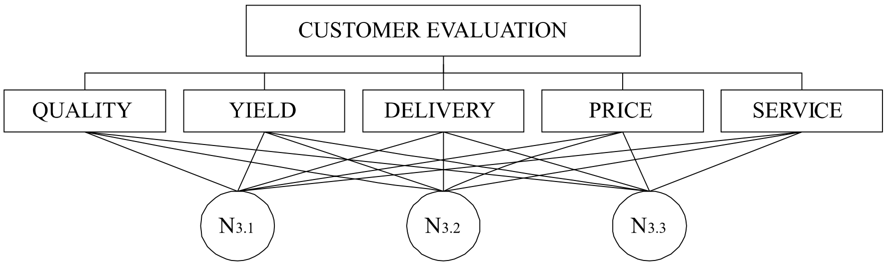
For downstream customer of corporation *A*

Criterion	Quality	Yield	Delivery	Price	Service	Priority
Quality		2	2	1/2	3	0.357
Yield			1	1/2	2	0.255
Delivery				1/2	2	0.153
Price					4	0.153
Service						0.081

Fig. 5. The AHP-hierarchies for analyzing the partnerships of corporation A and B



(a) by corporation B (node $N_{3.1}$)



(b) by corporation A (node $N_{2.1}$)

After obtaining the relative importance for each attribute by the AHP procedure, the preference functions for all attributes are assessed. To consider the single utility function for the attribute of delivery of corporation B for its upstream suppliers as an example, the value of this attribute delivery is in the range between 70 and 100%. The lower and upper bound of delivery represent the worst and best function performances respectively. Therefore, $U_{delivery}(70\%) = 0$ and $U_{delivery}(100\%) = 1$ can be set cleanly and definitely. According to the MAUT methodology, in order to obtain the $U_{delivery}(x_{delivery})$, three equivalent utility values $U_{delivery}(x^{0.25}_{delivery})$, $U_{delivery}(x^{0.5}_{delivery})$, and $U_{delivery}(x^{0.75}_{delivery})$ in this range of delivery measurements must be assessed. With respect to $U_{delivery}(x^{0.5}_{delivery}) = 0.5$, there are four candidates (80, 85, 90, and 95%) for the preference to be selected for $x^{0.5}_{delivery}$. To pair-wise compare these preferences of these four candidates and use the eigenvector analysis for this pair-wise matrix, the judgment matrix and the priority vector is figured out by Eqs. 1 and 2 and given as

$$\left[x^{0.5}_{delivery}\right] = \begin{matrix} 80 \\ 85 \\ 90 \\ 95 \end{matrix} \begin{bmatrix} 1 & 1/1.5 & 1/3.5 & 1/9 \\ 1.5 & 1 & 1/2 & 1/6 \\ 3.5 & 2 & 1 & 1/3.5 \\ 9 & 6 & 3.5 & 1 \end{bmatrix},$$

$$priority\ vector = \begin{bmatrix} 0.06 \\ 0.11 \\ 0.20 \\ 0.63 \end{bmatrix}.$$

With the result that the $x^{0.5}_{delivery}$ would be calculated by its candidates and priority vector as

$$x^{0.5}_{delivery} = [80\ 85\ 90\ 95](\%) \times \begin{bmatrix} 0.06 \\ 0.11 \\ 0.20 \\ 0.63 \end{bmatrix} = 92(\%)\,.$$

$x^{0.25}_{delivery}$ and $x^{0.75}_{delivery}$ also can be computed with the similar method for $U_{delivery}(x^{0.25}_{delivery}) = 0.25$ and $U_{delivery}(x^{0.75}_{delivery}) = 0.75$, and then those values are 83% and 97%. Having developed to this point, in accordance with five points ($x^{k}_{delivery}$, $U_{delivery}(x^{k}_{delivery})$), $k = 0$, 0.25, 0.5, 0.75, and 1, the utility function of this delivery attribute could be formularized by a third-polynomial function. In a similar manner, the preference functions for other attributes of corporation B to assess its upstream suppliers and corporation A to assess its downstream customers can be formularized. Table 4 represents preference functions for all attributes that are used to assess utilities for suppliers (s) of corporation B and customers (c) of corporation A.

Table 4. Preference functions to assess utilities for suppliers (s) of corporation B and customers (c) of corporation A

For suppliers (s) of corporation B	
Preference function	
$U^{s\leftarrow B}_{price}(x_{price})$	$= -0.8168x^3_{price} + 4.2775x^2_{price} - 7.6741x_{price} + 5.2125$
$U^{s\leftarrow B}_{matching}(x_{matching})$	$= 0.0160x^3_{matching} - 0.1038x^2_{matching} + 0.3762x_{matching} - 0.2889$
$U^{s\leftarrow B}_{delivery}(x_{delivery})$	$= 60.2196x^3_{delivery} - 144.2768x^2_{delivery} + 116.7063x_{delivery} - 31.6544$
$U^{s\leftarrow B}_{quality}(x_{quality})$	$= 0.0022x^2_{quality} - 0.0774x_{quality} + 1.0057$
For customers (c) of corporation A	
Preference function	
$U^{A\rightarrow c}_{quality}(x_{quality})$	$= 87.3494x^3_{quality} - 55.8424x^2_{quality} + 2.7840x_{quality} + 1.0009$
$U^{A\rightarrow c}_{yield}(x_{yield})$	$= 22.9973x^3_{yield} + 15.0292x^2_{yield} + 3.7672x_{yield} + 0.0002$
$U^{A\rightarrow c}_{delivery}(x_{delivery})$	$= 27.1192x^3_{delivery} - 63.1545x^2_{delivery} + 51.3218x_{delivery} - 14.2801$
$U^{A\rightarrow c}_{price}(x_{price})$	$= 0.1455x^3_{price} - 1.1677x^2_{price} + 2.3027x_{price} - 0.3344$
$U^{A\rightarrow c}_{service}(x_{service})$	$= 1.3427x^3_{service} - 1.0313x^2_{service} + 0.6846x_{service} - 0.0002$

As mentioned previously, the linear additive utility function can be used for constructing the unidirectional objective functions for the suppliers and customers of the corporation B and A by combining the single preference functions, and priority parameters can assume the following forms:
For suppliers of corporation B:

$$V^{s\leftarrow B} = 0.179U^{s\leftarrow B}_{price}(x_{price}) + 0.384U^{s\leftarrow B}_{matching}(x_{matching}) + 0.384U^{s\leftarrow B}_{delivery}(x_{delivery}) + 0.052U^{s\leftarrow B}_{quality}(x_{quality})$$

For customers of corporation A:

$$V^{A\rightarrow c} = 0.357U^{A\rightarrow c}_{quality}(x_{quality}) + 0.255U^{A\rightarrow c}_{yield}(x_{yield}) + 0.153U^{A\rightarrow c}_{delivery}(x_{delivery}) + 0.153U^{A\rightarrow c}_{price}(x_{price}) + 0.081U^{A\rightarrow c}_{service}(x_{service})$$

Table 5 shows corporation A's candidate customers and B's candidate suppliers, which are assessed by specific combination of criterion values. The criterion values, which were initially presented by the outsourcing team from corporations A and B, are used to elicit the preference of each criterion with respect to all candidate participants. By these criterion values, the overall (integrated) objective utility $V^{x\leftrightarrow y}$ and normalized $V^{x\leftrightarrow y}$ between two adjacent corporations for this illustrated multi-echelon system can be figured out correctly as depicted in Table 6 by Eqs. 6 and 7. The results for upstream suppliers and downstream customers of each corporation are displayed in Table 6.

For effective VI, quality corporations should organize the multi-echelon manufacturing system. As a result of the quality corporation participation, the competition of the manufacturing system will be increasing effectively and rapidly. Consequently, the optimal VI network could be constructed by using the IP-model (Eqs. 8–13), which involves the normalized overall objective utility (*normalized* $V^{x\leftrightarrow y}$). In addition, this IP model can assign the optimal product volume to each appropriate company and it enhances the operational performance of the manufacturing system.

In this illustrative example, based on customer requirements, the total market demand is assumed at 1000 units (one hundred dies). The least and the most process units are associated with each node of the network, and depicted by enclosing their values in brackets attached to the node as shown in Fig. 6. The optimal VI structure, with the total supplier and customer preferences optimized, is a multi-echelon network system that is constructed by some corporations (nodes) with the thicker arcs and appears in Fig. 6. Furthermore, the optimal number of transportation units to be shipped from a node to another is clearly identified and enclosed in a box attached to each arc. For example, in terms of the solution, $N_{3.3}$ must process 450 units from its upstream node $N_{2.3}$ and ship 0 and 450 to its downstream nodes $N_{4.1}$ and $N_{4.2}$ separately.

Table 5. Criterion values of (1) corporation A's candidate customers and (2) corporation B's candidate suppliers

(1)		Price	Matching	Delivery	Quality	
	$N_{3.1}$	0.8	1.8	0.75	0.50	
Candidate	$N_{3.2}$	2.0	4.8	0.73	0.10	
	$N_{3.3}$	2.3	1.5	0.94	0.10	
(2)		Quality	Yield	Delivery	Price	Service
	$N_{2.1}$	0.080	0.40	0.97	2.0	0.95
Candidate	$N_{2.2}$	0.150	0.20	0.88	2.0	0.50
	$N_{2.3}$	0.150	0.45	0.88	2.5	0.85

Table 6. The results of normalized overall (integrated) objective utility

For upstream supplier		For downstream customer		Overall (integrated)	Normalized $V^{x\leftrightarrow y}$
Viewpoint	Prior weight ($V^{x\leftarrow y}$)	Viewpoint	Prior weight ($V^{x\rightarrow y}$)	objective utility ($V^{x\leftrightarrow y}$)	
$N_{1.1} \leftarrow N_{2.1}$	0.442	$N_{1.1} \rightarrow N_{2.1}$	0.367	0.217	0.420
$N_{1.1} \leftarrow N_{2.2}$	0.352	$N_{1.1} \rightarrow N_{2.2}$	0.225	0.072	0.139
$N_{1.1} \leftarrow N_{2.3}$	0.611	$N_{1.1} \rightarrow N_{2.3}$	0.408	0.228	0.441
$N_{1.2} \leftarrow N_{2.1}$	0.558	$N_{1.2} \rightarrow N_{2.1}$	0.435	0.182	0.428
$N_{1.2} \leftarrow N_{2.2}$	0.648	$N_{1.2} \rightarrow N_{2.2}$	0.102	0.088	0.207
$N_{1.2} \leftarrow N_{2.3}$	0.389	$N_{1.2} \rightarrow N_{2.3}$	0.463	0.155	0.365
$N_{2.1} \leftarrow N_{3.1}$	0.239	$N_{2.1} \rightarrow N_{3.1}$	0.376	0.100	0.378
$N_{2.1} \leftarrow N_{3.2}$	0.610	$N_{2.1} \rightarrow N_{3.2}$	0.225	0.158	0.597
$N_{2.1} \leftarrow N_{3.3}$	0.016	$N_{2.1} \rightarrow N_{3.3}$	0.389	0.007	0.025
$N_{2.2} \leftarrow N_{3.1}$	0.392	$N_{2.2} \rightarrow N_{3.1}$	0.621	0.255	0.746
$N_{2.2} \leftarrow N_{3.2}$	0.111	$N_{2.2} \rightarrow N_{3.2}$	0.357	0.080	0.233
$N_{2.2} \leftarrow N_{3.3}$	0.240	$N_{2.2} \rightarrow N_{3.3}$	0.022	0.007	0.021
$N_{2.3} \leftarrow N_{3.1}$	0.369	$N_{2.3} \rightarrow N_{3.1}$	0.136	0.063	0.142
$N_{2.3} \leftarrow N_{3.2}$	0.279	$N_{2.3} \rightarrow N_{3.2}$	0.224	0.064	0.145
$N_{2.3} \leftarrow N_{3.3}$	0.744	$N_{2.3} \rightarrow N_{3.3}$	0.640	0.317	0.713
$N_{3.1} \leftarrow N_{4.1}$	0.440	$N_{3.1} \rightarrow N_{4.1}$	0.534	0.234	0.670
$N_{3.1} \leftarrow N_{4.2}$	0.105	$N_{3.1} \rightarrow N_{4.2}$	0.466	0.116	0.330
$N_{3.2} \leftarrow N_{4.1}$	0.102	$N_{3.2} \rightarrow N_{4.1}$	0.223	0.033	0.163
$N_{3.2} \leftarrow N_{4.2}$	0.221	$N_{3.2} \rightarrow N_{4.2}$	0.777	0.172	0.837
$N_{3.3} \leftarrow N_{4.1}$	0.458	$N_{3.3} \rightarrow N_{4.1}$	0.420	0.105	0.241
$N_{3.3} \leftarrow N_{4.2}$	0.674	$N_{3.3} \rightarrow N_{4.2}$	0.580	0.330	0.759

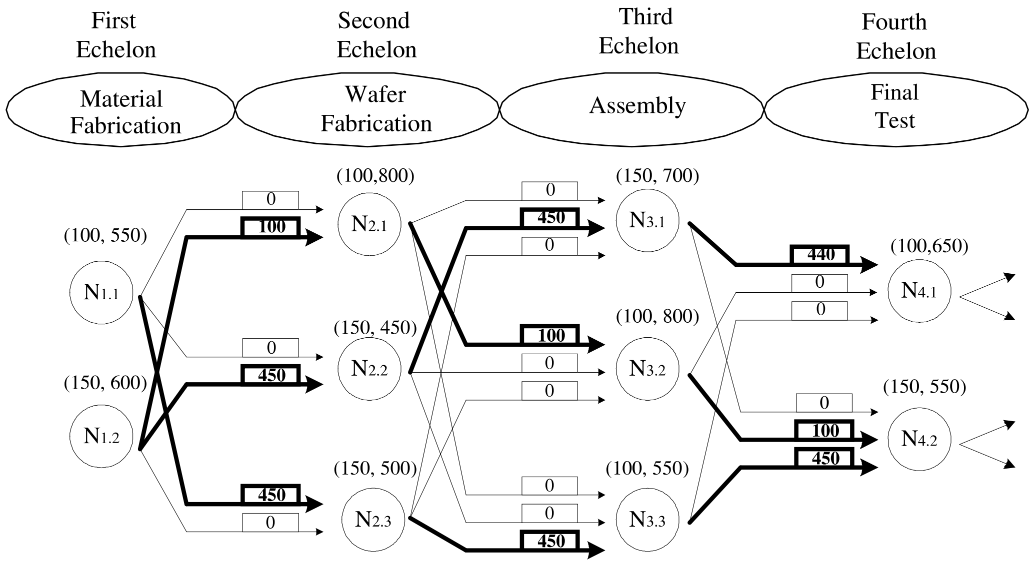


Fig. 6. The optimal solution for VI

Table 7. Illustration of the best VI patterns at different market demands

Transportation	Demand (unit: hundred dies)				
	600	800	1000	1100	1200
$N_{1.1} \to N_{2.1}$				50	150
$N_{1.1} \to N_{2.2}$					
$N_{1.1} \to N_{2.3}$	350	450	450	450	450
$N_{1.2} \to N_{2.1}$	100	100	100	150	150
$N_{1.2} \to N_{2.2}$	150	250	450	450	450
$N_{1.2} \to N_{2.3}$					
$N_{2.1} \to N_{3.1}$				100	200
$N_{2.1} \to N_{3.2}$	100	100	100	100	100
$N_{2.1} \to N_{3.3}$					
$N_{2.2} \to N_{3.1}$	150	250	450	450	450
$N_{2.2} \to N_{3.2}$					
$N_{2.2} \to N_{3.3}$					
$N_{2.3} \to N_{3.1}$					
$N_{2.3} \to N_{3.2}$					
$N_{2.3} \to N_{3.3}$	350	450	450	450	450
$N_{3.1} \to N_{4.1}$	150	250	450	550	650
$N_{3.1} \to N_{4.2}$					
$N_{3.2} \to N_{4.1}$					
$N_{3.2} \to N_{4.2}$	100	100	100	100	100
$N_{3.3} \to N_{4.1}$					
$N_{3.3} \to N_{4.2}$	350	450	450	450	450
Optimal solution	1098.864	1452.350	1776.841	1923.979	2070.724

In the result of our demonstrative example, each corporation finds optimal suppliers and customers for performing VI to satisfy the end customer demand with maximum preferences. For instance, under customer demand 1,000 units $N_{1.2}$, $N_{2.2}$, $N_{3.1}$ and $N_{4.1}$ are virtual integrated corporations. In Table 7, we show the best VI patterns at different market demands given by our proposed method. According to this analytical outcome that reveals that the best VI pattern and the quantities of each node for processing in its own plant and transporting to its downstream customers simultaneously matches the supplier and customers' multi satisfactory preferences.

5 Conclusions

Without a doubt, the VI is at the core of strategic planning for multi-echelon manufacturing systems. All virtually integrated companies possess core business functions, and virtually integrated firms are very tightly organized. As a result, the firms operate as a single organization with shared goals, processes, and, oftentimes, corporate cultures. The integration will be constantly shifting to take advantage of existing conditions and changed as the competitive environment is altered. Therefore, for keeping the competitive edge in an often and fast changing environment, the evaluation and selection of good corporations for integration is an absolute necessity.

This work proposed a systematic and flexible approach to efficiently and effectively solve the complex partner selection and product distribution decision problems by integrating various systems. Relationships are acquired by using AHP-, MAUT- and IP-based methodologies, which enables both quantitative and qualitative factors to be included in the decision process. It models the veritably behavior of a multi-echelon manufacturing process by employing the interactive technique, which simultaneously integrates suppliers and customers' multi-satisfactory preferences.

This novel approach is an interactive method to analytically select corporations and distribute entities from the viewpoints of the upstream and downstream corporations, and provides the expected optimal satisfaction for all the participants of the whole multi-echelon system, while the collaborative information is shared totally and effectively. The present companies can be analyzed periodically, e.g., thrice a year, or non-periodically, to keep relationships between corporations prospective. In the future, new or potential companies could be readily included in the existing multi-echelon manufacturing system. Accordingly, this approach can provide a feasible quality partner selection and production-distribution planning solutions that can easily and expeditiously be applied to real world applications while the co-operative information of all participators is shared perfectly and effectively in the entire chain.

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