Ecological Supply Chains Design Mechanism Based on Virtual Enterprises

Guojun Ji
Department of Management Science
Xiamen University
Xiamen Fujian, China
jiking@xmu.edu.cn

***Abstract*—In this paper, the concept of ecological supply chain (ESC) and primary design principles of ESC are discussed. And the paper shows that companies can gain economical, social and environmental efficiencies simultaneously from implementing ESC. The organization framework, the operational process, the dynamic durative of virtual enterprise, those are expounded in detail. Evaluation of virtual enterprises for ESC operation is based on the firms' multi-criteria which are qualitative or quantitative. By using fuzzy AHP technique, the hierarchical and the multi-criteria decision making problems for virtual enterprise are considered and the optimized selection is presented.**

Keywords-ecological supply chain; virtual enterprise; fuzzy AHP

I. INTRODUCTION

Environmental management is more and more important for manufacturers as they face intense scrutiny from diverse stakeholder groups, including end-consumers, industrial customers, suppliers, and financial institutions (Henriques and Sadorsky, 1999). Therefore, they have to struggle for conflicting objectives: pursuing profit, complying with current regulations, and attending to various legal constraints associated with environmental protection strategies. So, how companies can balance these? The authors of Natural Capitalism (Hawken et al., 1999) point out that if companies could practice "a new type of industrialism'' that can create profits and jobs while saving the environment, energy and materials consumption will reduce by 90%. Though researchers have created some new solutions to reconcile prosperity with environmental protection, such as reverse supply chain, they have not put enough attentions to by-products utilization generated during the production processing, such as industrial solid waste, waste gas and waste liquid. Because dealing with by-products from a firm-level means much investment and low benefit, many manufacturers just released them after primary treatment, which causes environmental deterioration and resource waste. Especially in China which industrialization process is at the stage of high-speed development and the peak period of resource consumption, traditional technologies and management used in dealing with by-products currently result to the high production-consumption index, the low resource utilization efficiency, and the big pollutant discharge amount. The resource and environment problem has become an important factor restricting economic development and influencing social harmony. Hence, ecological supply chain (ESC) is proposed as an approach to balance efforts to reduce cost and innovate while maintaining good ecological performance. In ESC, all the wastes discharged in the whole process of the supply chain are recycled, in order to maximize economical, social and environmental efficiencies. It includes tasks referring to the product utilization phase (e.g. service, maintenance, and others), to by-product reusing phase (e.g. byproduct collection, process, exchange and others) and to the end-of-life phase (e.g. product recovery, refurbishing, recycling or reusing), which are accomplished by an environmentally friendly alliance. Ecological supply chain management which optimizes forward and reverse supply chain from the view of the whole society, can solidify the impacts of economical activities on the environment in design phase. The core part of ESC is ecological design, which is looked as a promising approach to sustainable production and consumption (UNEP, 1997). Ecological design considers environmental aspects at all stages of the product development process, striving for products which cause the lowest possible environmental impact throughout the product life cycle. The ecological design would transfer the one-way economy represented by the traditional supply chain into closed-loop economy represented ecological supply chain. Therefore, primary ecological design principles are presented in the paper. Ecological supply chain management mainly involves the contents of eco-procurement, e.g., relationship between eco-procurement and suppliers (Jie Chen et al., 2003); eco-manufacture, such as applied 3R (Reduce, Reuse, Recycle) ecological design in manufacture (Yang, Q.Z. et al., 2006); eco-marketing, for instance ecocertification is propitious to green market (Stephen F. et al., 2006); eco-logistics, e.g., ESC and eco-logistics are all based on the globalization (S.C. Lenny Koh, 2007); eco-consumed, for example, eco-consumed must pay attention on customer's behavior (Yongli Yao, 2007); eco-return, such as eco-return must think much of the complaint management (Guojun Ji, 2008). The interrelated research works are based on those ways. ESC operation management is restricted by the cost, the practice, the human resource and uncertainties in market etc. Considering the environmental consciousness and the policy impact, the outsourcing is the better selection for the enterprises driven by

978-1-4244-2013-1/08/$25.00 ©2008 IEEE

economic profit. In order to make full use of the third provider services' advantage, virtual enterprise (VE) will be most appropriate. The concept of VE was proposed by Kenneth Preiss et al. (1991). The way of only depending on a single enterprise to respond rapidly to changing market opportunities and intensely global competition have been inapplicable. The key technique determined by utilizing agile manufacturing practices is based on VE. With the urgent demand of implementing, it is significant to find an effective operation management mode for ESC. Therefore, we represent an operation management mode based on VE. Some companies have adopted ecological supply chain management with a purpose to a more sustainable development. Their assertive approach toward the environment has helped them to reap the benefits of cost reduction, extended market share, stronger competitive advantage, an environment-friendly image, e.g. to comply with the sometimes cumbersome and burry current legislation, and to anticipate necessary changes to cope with future legal environmental standards, to gain or retain a fine relationship with community. A case study of Guangxi Guitang Group proves the above argument. External Diseconomy in resource utilization leads to the conflict between the thought of optimizing ecological efficiency and the behavior of maximizing economical benefit for traditionally economic man. Thus, economic man should become "ecological-economic man" whose behavior criterion is ecological efficiency maximization (liu & wang, 2007). According to the above premise, the author analyzes the decision-making process of by-product exchange and pricing strategies.

This paper organization is as follows: In section 2 we analyze ESC evolution mechanisms and its design principles. Next, using by the extension technique, the return threshold is evaluated first, then based on the entropy theory, the evaluation modes are introduced in section 4, a case study illustrates our conclusions.

II. ESC Evolution mechanisms and design principles

By optimizing along the entire sequence of steps that are involved in the production of a product whether it is a good or service, the greatest value can be produced at the lowest possible cost (Handfield and Nichols, 1999). In many cases, this approach requires organizations to operate sub-optimally from a cost perspective to create the greatest possible value along the entire supply chain (Leenders and Blenkhorn, 1988). As environmental problems are concerned by governments, consumers, communities, firms have to consider the convergence of supply chains and environment management. Hence, the focus on environmental management is moved from local optimization of environmental factors to consideration of the entire supply chain during the production, consumption, customer service and post-disposal disposition of products. At the same time, in order to meeting the environmental challenges, traditional supply chain has to be re-designed to close material cycles and prevent the leakage of materials in the whole chain, especially in the production process. Note that the outputs of the production process not only conclude main products which are the desired products of the process and represent the great part of value added or something with a substantial value but not the intended results of the process, but also consist of something produced "unintentionally ,with a modest positive value or a negative value". Since companies have to balance with economical benefits and environmental impacts, they would integrate issues and flows that extend beyond the core of supply chain management: manufacturing by-products, by-products produced during product use, product life extension, product end-of-life, and recovery processes at end-of-life. The essence of ESC is to take full advantage of products with a high or modest positive value, while reducing materials with a negative value. That is to say that ESC is a change and improvement to traditional supply chain, in order to maximize economical, social and environmental benefits by integrating environment management into supply chain management. It takes the entire life cycle of a product into account, from the extraction of raw materials and energy, to the consumption of products and the eventual dumping of waste. When ESC management is realized, materials are used more efficiently and resources are conserved. Thus, theoretically, the ideal picture of ESC is very similar to the principles of life cycle management. The whole supply chain is looked as a sustainable ecosystem, in which products are designed and used with the capacity of the environment in mind and wastes are viewed as feedstocks for other users or are recycled as nutrients (Ayres RU, 1996). All the energy, material and information in the chain could be recycled like the natural ecosystem which can achieve the objects of "zero-pollution" and "zero emission". Therefore, ESC can be defined as that the process of efficiently and effectively planning, implementing and controlling the flow of material and information flow in whole supply chain, to maximize ecological efficiency by use of industry ecological thoughts.

According to the above mentioned, the material flow of ESC could be described as Figure 1. ESC includes forward and reverse flows. The forward supply chain processes are source, make, deliver, and use of the products by the end customers. After the initial delivery of the product to the end customer, additional deliveries of parts may be required to repair or upgrade the products installed in the market. Customer returns consist of such as products at the end of their life or parts that have been replaced during repair. During the manufacturing process, returns are generated that consist of such as raw materials surplus, quality test returns and by-products. Returns can also be initiated by an actor in the distribution channel and include product recalls due to safety or health problems with the product, commercial returns induced by agreed take back options, collection of perished goods or redistribution of goods. Returns are collected via the forward distribution channels or via special reverse channels. Recovery processing includes such as recycling recover value on the material level and reprocessing restore products to as good as new state or upgraded state. The recovered materials, parts and products as well as secondary resource are fed into the forward supply chain. As shown in Figure 1, we can say that the ESC is a closed-loop system that not only product of the upstream firm could be used by the down stream firm but also waste of the upstream firm can be reused as useful material by the down stream firm or itself. The business relationships of all actors in the supply chain represent in product and by-product dealing. When the output of one firm can be the input of another firm, there is no difference between material and waster since both can be used fully in an ideal state or reused by other firms and then discharged harmlessly in a non-ideal state. In a word, ESC investigates the total materials cycle from cradle to grave.

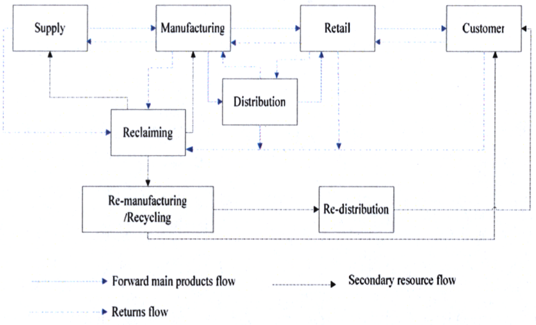

Figure 1. Ecological supply chain

Ecological design could be used to form a new supply chain or improve the existing supply chain. Individuality and generality both exist in ecological design. Strictly speaking, ESC not only combines the comprehensive principles of the conventional supply chain, which are presented by Gattorna, J.L (1997), but also be extended to include other important rules, such as Impose sustainability standards on suppliers; Make use of accounting systems that account for the full lifecycle costing of a product or service, and the environmental impacts it creates; Make use of modern management tools, such as ISO 9000-14000, life cycle analysis, environmental accounting methods, that may help business to identify and select opportunities for improvement; Create new markets; Manage additional uncertainty; Match network design with recovery option; Improve design for recycling; Enhance quality and rate of return. Those principles are similar to discussed by Guojun Ji (2007). In addition, different enterprises have distinct characteristics, such as technology and production condition, lawful restriction. Though design should be customized, there are two primary design principles: (1) Economical benefit would be ensured first and foremost. When designing the supply chain, the economical benefit of the whole supply chain is put first. Business profit is the base of existence and development of firms, as well as the original drive for developing new product and improving technology and management level. If the design shows good in social and environmental efficiency but economical efficiency, no firm would adopt this project willingly under the profit-driven market mechanism. (2) Economical benefit can not be got on the sacrifice of social and environmental efficiency which are the base for firms to gain long-term economical efficiency. Sometimes, we have to scarify temporary economical efficiency for a sustainable development. Ecological design is also a concurrent engineering which tasks are done in parallel. There is an early consideration for every aspect of a product's development process. The design team would consist of persons from purchasing department, manufacture department, marketing department and environment management department so on. Ecological design is composed of two parts. One is the design of ecological supply chain which optimization methods such as Operational Research (OR), and environment assess instruments such as LCA, could be used to select a project of optimizing economic and environmental performance simultaneously. The other is of the elements of ecological supply chain, which includes product design, raw material purchasing, production process, marketing process, distribution process and used-product collection and recovery.

The principles for designing the elements of an ESC are as follows: 1) Product design. Designers not only consider product performance to satisfy demand and preference of customer, but also take into account the effect of design details on energy/material requirements for manufacturing and use, secondary use (repairability, remanufacturability and recyclability) and by-product reuse. While ensuring quality, functions and lifetime of product, environmental impacts should be minimized. Company should use accounting systems that account for the full life-cycle costing of a product or service, and the environmental impacts it creates. Based on this, develop and design recoverable products, which should be technically durable, repeatedly usable, harmlessly recoverable after use and environmentally compatible in disposal. Modularity and standardization also improves opportunities for repair and (cross-supply chain) reuse of components and materials. Also, suppliers may co-design the product to enable modularization and design for recycling, so that the efforts to protect environment are concentrated in the design stage. 2) Procurement. Purchase includes two parts: one is selection of raw material which has the least impact on the environment both in use and origin, the other is selection of environmentally friendly suppliers. Nontoxic, degradable, reused materials with a high recycling rate should be preferred. Endangered animals and plant should be avoided. Primary raw materials should be used only in cases where there would be no stock of secondary ones. Where possible environ-mentally safer substitutes should be used and the abuse of products should be actively prevented. Whether supplier is environmentally friendly is also important to manufacturer, excepting high quality material providing. Therefore, Manufacturer should include suppliers into its environment management system, inspecting the material timely, offering them technical support and detailed material description. 3) Production. Manufacturing is mainstay of national economy which deplete most resource, simultaneously generate much pollution. In ESC, such manufacturing mode would be transformed into a new manufacturing mode, ecological manufacture, which can minimize energy and materials, harmless to environment or least. The whole production process should be controlled tightly to save resource and improve utilization efficiency. The identification of where great amounts energy is used could subsequently lead to redesign of the product or its use in order to make significant energy reductions. Major improvements in energy efficiency can often be achieved at little or no cost, even with net savings, through the use of targeted programs. Installed water-saving techniques and the use of closed re-circulating systems can lead to reduction of water consumption. With a technical reorganization, materials that would formerly have ended as wastes are turned into useful by-products. The wasting of materials and energy either due to inappropriate design, or due to excessive number of defects should be avoided. To replace non-renewable and polluting technologies, it is crucial to use eco-friendly energy, such as solar, wind, water and geothermal energy (among others), as well as reduction in energy consumption, and keep control of pollution sources In addition, the elimination of the stochastic factors, which affect pollution, may lead to greener production. Safe and healthy production method generating least waste, such as clean production, should be preferred. 4) Marketing. Ecological marketing could not only satisfy customer demand, but also balance profit and environmental effects of product with a purpose to realize simultaneously firm benefit and consumer welfare, environmental performance. A green marketing approach in the product area is the integration of environmental issues into all aspects of the corporation's activities, from strategy formulation, planning, construction through production and into dealings with consumers. Developing of ecological marketing effectively request firms to green 4P's: designing green product, setting green price, developing green channel policies and green marketing policies. Enhancing product function, establishing product update policies and extending service at usage phase could improve ecological efficiency. Firms also would mark products with recycling symbols and reprocessing codes that indicate the return, reuse and recovery possibilities, and motivate customers to maximize return volume. Ecological marketing is also related to the selection of goods package. Packaging design which affects environment in many aspects, is important for a company to attain environmental objectives. Choosing package according to the rule of"3R1D" (Reduce, Reuse, Recycle, Degradable) and limiting packaging to the necessary size could prevent resource waste. The opposite case not only is contrary to environment protection, but it also affects transportation negatively. Furthermore, environmentally safe packaging can be used as a marketing argument. And refilling or recycling, standardized packaging should be used when applicable. 5) Distribution and forward logistics. Facilities should be located close to possible end-users. Such a policy would ease the direct delivery of used products from end-users. During logistics process, effective and efficient transportation and storage mode should be adopted according to product type, with a view to energy consumption and environment pollution. Ecological impacts are also considered in distribution processing and loading-unloading. Environmental-friendly measurement is one of important logistics performance evaluation indexes. The location and layout of warehouses should be rational to reduce transportation cost, which would increase if they are too concentrated. But transportation efficiency would decrease if they are too decentralized. In addition, negatively environmental effects of warehouse system would be reduced, such as equipment noise, soot pollution, soil pollution. 6) Collection and reverse logistics. Firstly, companies would formulate a policy for the recovery of used products, offer waste disposal services and optimize collection network according to returns quality and collection rate. Companies could establish cooperation via local or more extended networks for the collection and recycling of similar products, or consider using existing forward supply chain facilities and transportation system as much as possible for the reverse supply chain. Transportation and the consequent environmental effects can be significantly limited. Secondly, collector should classify used products as early in the recovery chain as possible, which eases the planning of storage of used products and avoid redundant processes. In the recovery of used products, nonpollution technologies should be adopted. Note that second pollution should be avoided as by-products are difficult to store and transport. Third, the supply loop should be closed by recycling effectively and efficiently and the volume and amount of materials going to landfill should be reduce considering alternative uses of used products or wastes. Waste disposed in every activity in supply chain which could be recycled, could be collected and returned material cycle again by reverse logistics network.

III. ESC OPERATION MANAGEMENT BASED ON VE

The difficulties of ESC management are enlarged by lots of partners and their flexibility. Hence a "leader enterprise or organization" is necessary to administer the VE, namely the core enterprise. The sponsor manufacturer always plays the role of core enterprise; the fourth-party service provider is also an appropriate option (Guojun Ji, 2008). Comparing with the traditional organization structure, the VE organized by two layers (core enterprises and non-core enterprises) is flat, availing interaction of partners. The flat structure is easy to respond the changing market, as well as to eliminate the information distortion effectively. There are three main reverse logistic functions: collection, inspection/sort, and reprocessing. Collection refers to bringing the products from the customer to a point of recovery, including return, transportation, and storage. At this point the products are inspected, i.e. their quality is assessed and a decision is made on the options of disposal, according to that the products are sorted. The disposal of reprocessing includes the following options: direct reuse, repair, recycling, remanufacturing and harmless disposal. The type of recovery can be separated between product recovery, component recovery, material recovery and energy recovery. The abovementioned functions are necessary for ESC. Based on VE operation, subdividing the functions to several independent enterprises by integrating their core competencies is just the advantage we seek for, e.g., lowering cost, evading risk, etc. Table I depicts the process of ESC operation management based on VE, which follows four phases: Identifying opportunity: In order to utilizing the rapid response attribution of VE with respect to the uncertainties of ESC, enterprises have to track the trends of market development timely. A mass of collected data using for forecasting should be from enterprises, customers, industries, markets, legislation and so on. The useful information will be evaluated relative to reliability, worthiness, feasibility. Constructing organization: Based on abovementioned, VE means the integration of the core competencies for participating in enterprises. Therefore identifying the core competency, evaluating the alternative enterprises and estimating the entire performance are crucial, that directly influence the operation efficiency of ESC. The core competencies concerning ESC reflect return channels, logistics capabilities, design or research & development technology, manufacture arts and crafts, assets proprietary etc., determined by the relevant decision support system (DSS). Information system and the logistics network are necessary absolutely to support the VE. Organization operation: The organization form of VE is at the expense of coordination among partners. It implies that the excellent organization management is the precondition of VE operation. The operation management is extended to the application of coordination mechanism, dynamic contract by stages, risk identification and control etc. As the dynamic developing, examine the running status continuously, and improve the process according to the feedback. Organization disbandment: The disbandment of VE takes place after the disappearance of market opportunity. There is the assets liquidation among partner enterprises. The knowledge management runs through the whole operation management of VE.

TABLE I. THE OPERATION MANAGEMENT MODE OF ESC BASED ON VE

	Opportunity identifying
✓	information collection
✓	data mining
✓	analysis and estimate
	Organization configuration
✓	the core competency identifying
✓	evaluating and selecting partners
✓	the information system and ESC network
✓	estimating the holistic performance
	Enterprise running
✓	coordination mechanism
✓	dynamic contract
✓	risk identification and control
✓	monitor system and improvement
	Enterprise disbandment
✓	the assets liquidation
✓	knowledge management

It is easy to see, depending on VE, every chance of ESC can be held in developing market. However, considering ESC evolves at all times, the operation management based on VE do not end after disbandment. Contrarily, it is the beginning of the new VE. Facing the uninterrupted opportunities the independent enterprises broke from one VE, then take part in another dynamic alliance immediately. In fact, the VE is that organization of the older members left and the newer members'enter. So the VE for ESC is the dynamic durative process organization from the phase of opportunity identifying to the phase of enterprise disbandment.

IV. EVALUATION METHOD

The evaluation of VE for ESC operation is based on the firms' multi-criteria which are qualitative or quantitative. AHP is often used in such problems (Saaty, 1990). But, the unbalanced estimations, unconsidered the uncertainty and risk, the subjective judgment error etc., those show the technique exists some disadvantages. Based on those reasons, we integrate the concept of fuzzy set theory with the AHP to overcome some above disadvantages in our proposed model (Huo J. et al., 2005). Fuzzy AHP approach is applied in some practical problems widely. In order to facilitate comparison, all elements of the judgment matrix and weight vectors are represented by the triangular fuzzy values. The VE for ESC selection process are as follows:

(1)Determine alternative firms and construct the evaluating hierarchical structure. ESC first chooses the alternative VE from those which can build reverse activities, based on the basic requirements, such as Quality Certificated. Then, the hierarchical structure is constructed by the criteria of SCOR model and the chain which is linked by the product flow, the alternative VEs are considered as similar types on the similar phase.

(2) Evaluate the alternative VEs. According to the defied scope, the experts begin to evaluate those alternative firms, based on the criteria of SCOR model. The quantitative criteria can be gained by the VEs historical data and the alternative degree measured by five scales from the worst to the best, here we use 1-9 triangular fuzzy number (from (1,1,3) to (7,9,9)).The qualitative criteria are obtained by the experts evaluating values. To reducing the experts' subjective effect, the following approach is adopted for the qualitative criteria. Suppose that there are S_i experts to score on level i, $\tilde{C}_{ijts}$ is a basic value which Expert s scores VE j on level i about Sub-criteria t ($i=1,2,\cdots,N$, N is the total number of levels in the ESC; $j=1,2,\cdots,M_i$, M_i is the total number of firms on the level i in ESC; $t\in Q$, Q is the subscript set of the qualitative criteria, then $\bar{Q}$ is the subscript set of the quantitative criteria). The expert's lingual descriptions from the worst to the best are relevant to the fuzzy number from (1, 1, 3) to (7, 9, 9) using by five scales. Let $\tilde{C}_{ijts}=(l_{ijts},m_{ijts},u_{ijts})$,

$L_{ijt}=\min(l_{ijts})$, $M_{ijt}=\frac{\sum_{s=1}^{S_i}m_{ijts}}{S_i}$, $U_{ijt}=\max(u_{ijts})$, then the integrated fuzzy number is $\tilde{C}_{ijt}=(L_{ijt},M_{ijt},U_{ijt})$ based on the S_i experts' evaluating result on level i.

(3) Evaluate the VEs relationship. The ESC is constructed by selecting firm from VEs and the relationship among the firms is evaluated. The basic values in step (2) may be considered the average value of the VEs criteria, and that the effect of the upstream and downstream to the firms may be positive or negative. But the relationship among the firms is not determinant factor to some performance criteria. It happens that the double effect of performance. In addition, the negative effects produced by the relationship to the performance criteria can not reach zero. Herein, these two situations need not discussed. The relationship Coefficients are from 0 to 2 ranked by 9, which are relevant to some sub-criteria from descending by 100% to ascending by 100%. Assume that S experts score the relationship among the firms, and let r_{ikjs} denotes that the relationship coefficient which expert s scores the relationship between firm k on level $i-1$ and firm j on level i and let r_{ijls} denotes that relationship coefficient which Expert s scores the relationship between firm j on level i and firm l on level $i+1$. Therefore, by integrated S experts' evaluations, the values are $r_{ikj}=\frac{\sum_{s=1}^{S}r_{ikjs}}{S}$ and $r_{ijl}=\frac{\sum_{s=1}^{S}r_{ijls}}{S}$, respectively.

(4) Integrate the basic value of the criteria of the firms with relationship coefficients. Relationship coefficients just effect on the exterior correlated criteria and not on the interior correlated criteria. Let Z denotes that the subscript set of the exterior correlated criteria and let $\bar{Z}$ denotes that the subscript set of the interior correlated criteria. Relationship coefficients are measured the relationship between the firm and its nearness firms, thus the upstream firm and the downstream firm both effect on it. To integrating two relationship coefficients, the Integrated Relationship Coefficients are $r_{ikjl} = \sqrt{r_{ikj} r_{ijl}}$. On the boundary of the defined supply chain, let $r_{ikj} = 1$ while $i = 1$ and let $r_{ijl} = 1$ while $i = N$. The Integrated Sub-criteria based on effect of the upstream and downstream firms satisfy $\tilde{C}_{ikjlt} = \begin{cases} (L_{ijt} r_{ikjl}, M_{ijt} r_{ikjl}, U_{ijt} r_{ikjl}) & t \in Z \\ \tilde{C}_{ijt} & t \in \bar{Z} \end{cases}$.

Then Integrated Criteria are $\tilde{G}_{ikjl1} = \sum_{t=1}^{3} \tilde{C}_{ikjt}$, $\tilde{G}_{ikjl2} = \sum_{t=4}^{6} \tilde{C}_{ikjt}$, $\tilde{G}_{ikjl3} = \sum_{t=7}^{10} \tilde{C}_{ikjt}$, $\tilde{G}_{ikjl4} = \sum_{t=11}^{13} \tilde{C}_{ikjt}$, respectively.

(5) Evaluate the fuzzy weight vector. The industrial experts evaluate the four criteria of the firms and the weight of any levels, then the weighted vectors are obtained $W_i = (\tilde{w}_{i1}, \tilde{w}_{i2}, \tilde{w}_{i3}, \tilde{w}_{i4})$ and $W = (\tilde{w}_1, \tilde{w}_2, \cdots, \tilde{w}_n)$, respectively.

(6) Synthesize the criteria and the weighted values, after that select the optimal VEs. The total fuzzy score of Chain x among X supply chains is expressed as follows: $\tilde{H}_x = \sum_{i=1}^{N} \left[\tilde{w}_i \otimes \sum_{q=1}^{4} (\tilde{G}_{ikjlq} \otimes \tilde{w}_{iq}) \right]$. The supply chain has the greatest finial score is the best one using by compared the finial score which is deduced by the following steps: Let $\tilde{H}_x = (L_x, M_x, U_x)$, consider that $h_{xl}^{\lambda} = L_x + \lambda(M_x - L_x)$ and $h_{xr}^{\lambda} = U_x - \lambda(U_x - M_x)$ (where λ ($0 < \lambda < 1$) is the degree of confidence), and define that $H_x^{\lambda} = \left[h_{xl}^{\lambda}, h_{xr}^{\lambda} \right]$, then the finial score is calculated by $H_{x\beta}^{\lambda} = \beta h_{xl}^{\lambda} + (1-\beta) h_{xr}^{\lambda}$ (where β ($0 < \beta < 1$) is the risk index).

Now, a case study will illustrate our results. A three-stage network of the electronic industry is incorporated by two VEs (denoted by F11 and F12), two manufactories (denoted by F21 and F22) and one retailer. The VEs implement the reverse activities, and the manufactories perform assembly line work to achieve the finial products. The retailer sells these products. According to their historical data, our aim intends to evaluate every VE. Let $\lambda = 0.5$ and $\beta = 0.5$, By using abovementioned processes, and the solution is presented in Table 2. It is easy to see the best VEs that formed chain is F11-F21-F31. At the same time, we can find that the chain relationship effect on the order of finial scores, i.e., VEs should pay attention to the chain relationship in course of constructing the ESC. In addition, VEs can comprehend the important degree of every criterion in the different industries by using the criteria weight evaluation, thus performance can be improved efficiently. In the same time, such technique can be used as a decision support system in VEs. VEs can provide more consulting service and realize the integrative optimization of ESC.

TABLE II. THE FINAL SCORES OF VES

Supply chain	$H_{x0.5}^{0.5}$	
	No considering the relationship	Considering the relationship
F11-F21-F31	52.67244	57.22441
F11-F22-F31	41.74084	56.32318
F12-F21-F31	49.99745	50.00566
F12-F22-F31	50.42136	48.44038

REFERENCES

[1]Ayres RU, Ayres LU. Industrial ecology: towards closing thematerials cycle, Cheltenham (UK): Edward Elgar; 1996, pp. 278–280.

[2]Gattorna, J.L. The Gower Handbook of Logistics and Distribution Management, Gower, Vermont, USA, 1997.

[3]Guojun Ji "Market-Motivated Value Systems, Reverse Logistics and the Evaluation Model for the Third Party Reverse Logistics Providers",Journal of International Logistics and Trade, 2006,4 (1), pp.53-92.

[4]Guojun Ji. "Complaint Management and Virtual Enterprise in Closed-loop Supply Chains and its Performance Evaluation by Using Exergoeconomics and Extenics", International Journal of Service and Operation Management, UK, 2008, 2(2),pp.23-44.

[5]Guojun Ji. "Design Principles and Evaluation for Closed-loop Supply Chains", Proceedings of 1st International Conference on Operations and Supply Chain Management in China, Chinese University of Hong Kong, 2007,pp.66-69.

[6]Handfield, R., Nichols, E. Introduction to Supply Chain Management, Prentice-Hall, Englewood Cliffs, NJ.,1999.

[7]Hawken, P., Lovins, A.B., Lovins, L.H., Natural Capitalism: Creating the Next Industrial Revolution, Little, Brownand Company, Boston, MA. Engineering. Massachusetts Institute of Technology, Cambridge, MA, 1995.

[8]I. Henriques and P. Sadorsky "The relationship between environmental commitment and managerial perceptions of stakeholder importance", Academy of Management Journal, 1999, 42 (1), pp.87-99.

[9]Jie Chen and Wei Xiong, "Ecological supply chain and Eco-design", City Environment and Ecology, 2003,16(2), pp.74-76.

[10]Leenders, M. R. and Blenkhorn, D. L. Reverse Marketing: The New Buyer-Supplier Relationship, The Free Press, New York, 1998.

[11]Liu Jia-shun,Wang Guang-feng. "Game's Analysis on Enterprise's Polluting Behavior: Based on the Assumption of 'Ecological and Economic Man'", Ecological Economy, 2007, (3), pp.64-66.

[12]S.C. Lenny Koh, Frank Birkin, Linda Lewis, Adrian Cashman. "Current issues of sustainable production, eco-supply chains and eco-logistics for sustainable development", International Journal of Global Environmental Issues, 2007, 7(1), pp.88-101.

[13]Stephen F. Hamilton and David Zilberman. "Green markets, ecocertification, and equilibrium fraud", Journal of Environmental Economics and Management, 2006, 52(3), pp.627-644.

[14]United Nations Environmental Program (UNEP). Ecodesign : a promising approach to sustainable production and consumption. United Nations Environmental Program (UNEP), 1997.

[15]Yang, Q.Z., Song, B. Eco-Design for Product Lifecycle Sustainability, 2006 IEEE International Conference on Industrial Informatics, pp.548-554.

[16]Yongli Yao, Study on Ecological Consumed Problems [D], China: Northeast Forestry University ,2007.