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Managerial decision making applications in logistics and information management

Guest Editor: Cengiz Kahraman

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Managerial decision making applications in logistics and information management

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Contents

Abstracts & keywords

Multi-criteria supplier selection using fuzzy AHP

Cengiz Kahraman, Ufuk Cebeci and Ziya Ulukan

Keywords Supplier evaluation, Fuzzy logic, Analytic hierarchy process, Group decision support systems, Decision making, Turkey

A supplier selection decision inherently is a multi-criterion problem. It is a decision of strategic importance to companies. The nature of this decision usually is complex and unstructured. Management science techniques might be helpful tools for these kinds of decision-making problems. The aim of this paper is to use fuzzy analytic hierarchy process (AHP) to select the best supplier firm providing the most satisfaction for the criteria determined. The purchasing managers of a white good manufacturer established in Turkey were interviewed and the most important criteria taken into account by the managers while they were selecting their supplier firms were determined by a questionnaire. The fuzzy AHP was used to compare these supplier firms.

An integrated approach for supplier selection

Ferhan Çebi and Demet Bayraktar

Keywords Supply chain management, Supplier evaluation, Programming, Analytic hierarchy process, Turkey

Competitive international business environment has forced many firms to focus on supply chain management to cope with highly increasing competition. Hence, supplier selection process has gained importance recently, since most of the firms have been spending considerable amount of their revenues on purchasing. The supplier selection problem involves conflicting multiple criteria that are tangible and intangible. Hence, the purpose of this study is to propose an integrated model for supplier selection. In order to achieve this purpose, supplier selection problem has been structured as an integrated lexicographic goal programming (LGP) and analytic hierarchy process (AHP) model including both quantitative and qualitative conflicting factors. The application process has been accomplished in a food company established in Istanbul, Turkey. In this study, the model building, solution and application processes of the proposed integrated model for supplier selection have been presented.

Linguistic assessment approach for managing nuclear safeguards indicator information

Da Ruan, Jun Liu and Roland Carchon

Keywords Fuzzy logic, Decision making, Nuclear safety, Modelling, Linguistics, Algebra

A flexible and realistic linguistic assessment approach is developed to provide a mathematical tool for synthesis and evaluation analysis of nuclear safeguards indicator information. This symbolic approach, which acts by the direct computation on linguistic terms, is established based on fuzzy set theory. More specifically, a lattice-valued linguistic algebra model, which is based on a logical algebraic structure of the lattice implication algebra, is applied to represent imprecise information and to deal with both comparable and incomparable linguistic terms (i.e. non-ordered linguistic values). Within this framework, some weighted aggregation functions introduced by Yager are analyzed and extended to treat these kinds of lattice-value linguistic information. The application of these linguistic aggregation operators for managing nuclear safeguards indicator information is successfully demonstrated.

Supplier selection using activity-based costing and fuzzy present-worth techniques

Ibrahim Dogan and Ugur Sahin

Keywords Supplier evaluation, Fuzzy logic, Modelling, Activity based costing, Cash flow

The relationship between a supplier and a purchaser is one of the most essential issues for viability of both sides. The well-built relationship is especially related to the healthy selection of suppliers. The changing customer preferences also make this selection process important. Many different selection approaches have been published in the purchasing literature. In these studies, the working conditions of suppliers and purchasers and selection criteria are considered constant and precise at the beginning of the selection process by the purchaser during the relationship period. However, this selection process should be considered dynamically because of the changing working conditions of supplier-purchaser and lifecycle of the product or a project. Therefore, the relationship between suppliers and purchasers is multi-period and the factors that affect the selection process are considered as fuzzy

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parameters in this study. The activity based costing (ABC) approach is used for selection method.

Viability of e-commerce as an alternative distribution channel

Muhamad Jantan, Nelson Oly Ndubisi and Ong Boon Yean

Keywords Electronic commerce, Distributors, Malaysia, Semiconductors, Technology led strategy

This paper proposes a framework for evaluating the impact of e-commerce on the roles of distributors in the semiconductor industry for four different types of products, namely differentiated products, architectural products, technological products, and complex products. Questionnaire and the purposive sampling method were used to collect data from respondents in the distribution industry. The results of the study show that the salience of the roles is increasing. In addition, there is strong likelihood of e-commerce replacing the traditional distributors, more so for less standardized products such as complex, technological, and architectural products.

Evaluating IS usage in Malaysian small and medium-sized firms using the technology acceptance model

Nelson Oly Ndubisi and Muhamad Jantan

Keywords Information systems, Small to medium-sized enterprises, Malaysia

The current research investigates the impact of persona-system characteristics, technical backing, and computing skill on information systems (IS) usage by Malaysian small and medium firms (SMF) using the TAM. The study hypothesizes that persona-system characteristics (such as perceived usefulness and perceived ease of use) and usage of systems will be greater when there is greater computing skill and strong technical backing. A total of 177 firms responded to the survey and the results show that there is a positive relationship between computing skill and technical backing on one hand and IS usage directly, and indirectly via perceived usefulness and ease of use on the other. Usage is influenced directly by usefulness and indirectly (via usefulness) by ease of use. These findings are particularly crucial to system designers and vendors targeting SMF, as well as, to information systems management in SMF. Important theoretical and practical implications are discussed.

A case study of supplier selection for lean supply by using a mathematical model

Semra Birgün Barla

Keywords Cellular manufacturing, Just in time, Lean production, Supplier evaluation

The role of purchasing departments has changed significantly in today's competitive environment. In order to keep the promises to customers; an effective material procurement system becomes necessary beside the improved manufacturing methods and technology. It becomes a necessity to work with the suppliers to provide quality and just in time delivery by supplying raw materials, parts and products. A purchasing department can take on both the active and effective role by applying the lean supply principles as much as possible. Single sourcing provides to easy control of procurement for achieving the lean supply objectives. In this paper, the supplier selection and evaluation for a manufacturing company is studied under lean philosophy. In order to reduce the supplier base, the supplier selection and evaluation study is conducted by multi-attribute selection model (MSM) in five basic steps. Consequently, the selected two suppliers are proposed to top management.

Guest Editorial

About the Guest Editor

Cengiz Kahraman is an Associate Professor in the Department of Industrial Engineering, Istanbul Technical University (ITU), Turkey. He received his BSc, MSc, and PhD degrees in industrial engineering from ITU. He is currently the assistant head of the department and his research areas include engineering economics, statistics, quality control, and the applications of fuzzy sets theory on these areas. He has published several international conference papers, journal papers, and book chapters.

In this special issue on "Managerial decision making applications in logistics and information management", seven application papers are presented on a range of topics from supplier selection to viability of e-commerce.

Managerial decision making includes four quite dissimilar operations: the construction of problem models; the selection of numerical input for these models; the derivation of model output from inputs; and the interpretation and use of this output as a guide to choice. Only one of these operations – derivation of model output from inputs – can generally be accomplished by the routine application of formulas and mechanical procedures or by the use of a computer. The remaining phases of decision analysis call for judgment and discretion, which can not be reduced to rote procedures. Managerial decision making cannot yet be accomplished by a set of series of steps that leads to the "one right answer".

One of the main problems of managerial decision making in supply chain management is the problem of supplier selection. The objective of supplier selection is to identify suppliers with the highest potential for meeting a firm's needs consistently and at an acceptable cost. Selection is a broad comparison of suppliers using a common set of criteria and measures. The special issue includes four different methods of supplier selection: fuzzy analytic hierarchy process (AHP); a multi-attribute selection model based on expected utilities; an integrated approach using lexicographic goal programming and AHP; and a model of activity based costing with fuzzy capital budgeting. These methods require different inputs and operations and the decision maker may not select the same supplier alternative at the end of each analysis for the same problem.

The other three papers of this special issue are on: viability of e-commerce as an alternative distribution channel; the impact of persona-system characteristics, technical backing, and computing skill on information system usage; and linguistic assessment for synthesis of nuclear safeguards indicator information. These papers also include the applications of some models on information management.

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Multi-criteria supplier selection using fuzzy AHP

Cengiz Kahraman
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Keywords

Supplier evaluation, Fuzzy logic, Analytic hierarchy process, Group decision support systems, Decision making, Turkey

Abstract

A supplier selection decision inherently is a multi-criterion problem. It is a decision of strategic importance to companies. The nature of this decision usually is complex and unstructured. Management science techniques might be helpful tools for these kinds of decision-making problems. The aim of this paper is to use fuzzy analytic hierarchy process (AHP) to select the best supplier firm providing the most satisfaction for the criteria determined. The purchasing managers of a white good manufacturer established in Turkey were interviewed and the most important criteria taken into account by the managers while they were selecting their supplier firms were determined by a questionnaire. The fuzzy AHP was used to compare these supplier firms.

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Introduction

The objective of supplier selection is to identify suppliers with the highest potential for meeting a firm's needs consistently and at an acceptable cost. Selection is a broad comparison of suppliers using a common set of criteria and measures. However, the level of detail used for examining potential suppliers may vary depending on a firm's needs. The overall goal of selection is to identify high-potential suppliers.

To select prospective suppliers, the firm judges each supplier's ability to meet consistently and cost-effectively its needs using selection criteria and appropriate measures. Criteria and measures are developed to be applicable to all the suppliers being considered and to reflect the firm's needs and its supply and technology strategy. It may not be easy to convert its needs into useful criteria, because needs are often expressed as general qualitative concepts while criteria should be specific requirements that can be quantitatively evaluated. The firm can set measures while it is developing selection criteria to ensure that the criteria will be practical to use. Often, developing criteria and measures overlaps with the next step, gathering information. Gathering information may offer insight into the number and type of criteria that will be required for the evaluation and the type of data that is available. However, gathering information without specific criteria and measures in place can lead to extraneous effort. Selection criteria typically fall into one of four categories: supplier criteria, product performance criteria, service performance criteria, or cost criteria.

Some criteria may be impractical to evaluate during selection. Information may be difficult to obtain, complex to analyze, or there may not be sufficient time. The firm's criteria should be appropriate to its planned level of effort. Also, the firm may initially develop criteria or measures that it eventually finds are inapplicable to some suppliers or certain products and services. Applying common criteria to all suppliers makes objective comparisons possible.

Supplier criteria

A firm uses supplier criteria to evaluate whether the supplier fits its supply and technology strategy. These considerations are largely independent of the product or service sought. Supplier criteria are developed to measure important aspects of the supplier's business: financial strength, management approach and capability, technical ability, support resources, and quality systems:

- *Financial.* The firm should require its suppliers to have a sound financial position. Financial strength can be a good indicator of the supplier's long-term stability. A solid financial position also helps ensure that performance standards can be maintained and that products and services will continue to be available.
- *Managerial.* To form a good supplier relationship, companies need to have compatible approaches to management, especially for integrated and strategic relationships. Maintaining a good supplier relationship requires management stability. The firm should have confidence in its supplier's management's ability to run the company. It is also important that the supplier's management be committed to managing its supply base. The supplier's level of quality, service, and cost are directly affected by its suppliers" ability to meet its needs.
- *Technical.* To provide a consistently high-quality product or service, promote successful development efforts, and ensure future improvements, a firm needs competent technical support from its suppliers. This is particularly important when the firm supply and technology strategy includes development of a new product or technology or access to proprietary technology. Technical criteria may motivate a firm to move into the global marketplace. Sometimes a desirable technology has been developed overseas and is not available to domestic suppliers.
- *Support resource.* The supplier's resources need to be adequate to support product or service development (if necessary), production, and delivery. Criteria need to consider the supplier's facilities, information systems, and provisions for education and training. When considering international suppliers, a firm needs to carefully examine the industrial infrastructure that supports the supplier. With international suppliers, a firm also needs to establish appropriate mechanisms to handle financial transactions and product deliveries, as well as any related legal and regulatory matters. Some form of global customer service may be required to support project implementation and day-to-day operations.
- *Quality systems and process.* The supplier's quality systems and processes that maintain and improve quality and delivery performance are key factors. Selection criteria may consider the supplier's quality assurance and control procedures, complaint handling procedures, quality manuals, ISO 9000 standard registration status, and internal rating and reporting systems. As the customer, a firm especially wants to examine the supplier's programs or processes for assessing and addressing customer needs.
- *Globalization and localization.* A firm's sourcing strategy may recognize definite advantages or disadvantages associated with choosing suppliers in a particular region or country. The firm's risk assessment should have identified potential risks, such as currency fluctuations, shifts in political policy, and the accompanying domestic or international regulatory and market changes that result.

Product performance criteria

A firm can use product performance criteria to examine important functional characteristics and measure the usability of the product being purchased. The exact criteria depend on the type of product being considered. A firm may need to examine conformance to specifications in any of the following areas:

- *End use:* quality, functionality (speed, capacity, etc.), reliability, maintainability, compatibility, durability/damage tolerance.
- *Handling:* packaging, shelf-life, storage requirements.
- *Use in manufacturing (components):* quality, testability, manufacturability, compatibility, end-use performance.
- *Other business considerations:* environmentally-friendly features such as recycled product content, ergonomic

features, product availability, stage of the technology life cycle, market trends.

If the product or service is yet to be developed, the firm's supplier criteria needs to examine whether the supplier has the basic management, technical, and quality support necessary to develop the product or service. In the international market, technical standards may vary between countries. The firm either needs to become familiar with manufacturer's standards or test the product using its own standards. Products may have to be reworked to be compatible or interchangeable with domestic products.

Service performance criteria

A firm can use service performance criteria to evaluate the benefits provided by supplier services. When considering services, a firm needs to clearly define its expectations since there are few uniform, established service standards to draw upon. Because any purchase involves some degree of service, such as order processing, delivery, and support, a firm should always include service criteria in its evaluation. If the supplier provides a solution combining products and services, the firm should be sure to adequately represent its service needs in the selection criteria. The service aspect can easily be lost amid product specifications when purchasing a highly technical product. Some of the concepts employed to judge products also apply to services, however, the terminology is often different, and services require other considerations. When assessing the fitness of services, a firm may need to examine the following areas:

- *Customer support:* accessibility, timeliness, responsiveness, dependability.
- *Customer satisfiers*: value-added.
- *Follow-up:* to keep customer informed, to verify satisfaction.
- *Professionalism:* knowledge, accuracy, attitude, reliability.

Cost criteria

Cost criteria recognize important elements of cost associated with the purchase. The most obvious costs associated with a product are "out of pocket" expenses, such as purchase price, transportation cost, and taxes. These are typically considered during selection. Operational expenses, such as transaction processing and cost of rejects, may also be included, although these require more effort to estimate. Although a firm can express any criteria in terms of estimated cost, in some cases, obtaining reliable estimates may be too involved for the level of analysis in selection. A firm should re-evaluate cost in more detail during qualification.

To evaluate suppliers based on a firm's selection criteria it needs to develop measures of supplier performance, product or service performance, and cost. There should be consensus within the team or organization on the measures, standards, and methods used to rate or compare suppliers. A firm needs to develop effective measures for each of its selection criteria. A firm can evaluate the effectiveness of a measure of quality by determining the degree to which it is: related to customer requirements, developed with inputs from and consensus with work groups, specific, easy to understand, practical to implement, able to drive desired behavior.

The organization of this paper is as follows. First, supplier selection applications in literature are given, and then fuzzy sets theory and fuzzy AHP, fuzzy AHP applications in literature, extent analysis method on fuzzy AHP, a case study, and finally a conclusion are given.

Supplier selection applications in literature

Choy and Lee (2002) propose a case-based supplier management tool (CBSMT) using the case-based reasoning (CBR) technique in the areas of intelligent supplier selection and management that will enhance performance as compared to using the traditional approach. Cebeci and Kahraman (2002) and Cebeci (2001) measure customer satisfaction of catering service companies in Turkey by using fuzzy AHP. Ghodsypour and O'Brien (2001) present a mixed integer non-linear programming model to solve the multiple sourcing problem, which takes into account the total cost of logistics, including net price, storage, transportation and ordering costs. Buyer limitations on budget, quality, service, etc. can also be considered in the model. Feng *et al.* (2001) present a stochastic integer programming approach for simultaneous

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selection of tolerances and suppliers based on the quality loss function and process capability indices. Boer *et al.* (2001) present a review of decision methods reported in the literature for supporting the supplier selection process. The review is based on an extensive search in the academic literature. Masella and Rangone (2000) propose four different vendor selection systems (VSSs) depending on the time frame (short-term versus long-term) and on the content (logistic versus strategic) of the co-operative customer/supplier relationships. Liu *et al.* (2000) compare suppliers for supplier selection and performance improvement using data envelopment analysis (DEA). Braglia and Petroni (2000) describe a multi-attribute utility theory based on the use of DEA, aiming at helping purchasing managers to formulate viable sourcing strategies in the changing market place. Dowlatshahi (2000) focuses on facilitating ah interface and collaboration among designer at three planning horizons: strategic, tactical, and operational with respect to supplier relations. To accomplish this interface, nine propositions for all areas of interface at three levels of planning are presented. Motwani *et al.* (1999) attempt to fill a void in supplier selection research by developing a model for sourcing and purchasing in an international setting, particularly in developing countries. Ittner *et al.* (1999) examine whether supplier selection and monitoring practices affect the association between supplier strategies and organizational performance. Ganeshan *et al.* (1999) examine the dynamics of a supply chain that has the option of using two suppliers-one reliable, and the other unreliable. They analyze the cost economics of two suppliers in a broader inventory-logistics framework, one that includes in-transit inventories and transportation costs. Verma and Pullman (1998) examine the difference between managers" rating of the perceived importance of different supplier attributes and their actual choice of suppliers in an experimental setting. Boer *et al.* (1998) show by means of a supplier selection example, that an outranking approach may be very well suited as a decision-making tool for initial purchasing decisions. O'Brien and Ghodsypour (1998) propose an integration of an analytical hierarchy process and linear programming to consider both tangible and intangible factors in choosing the best suppliers and placing the optimum order quantities among them such that the total value of purchasing becomes maximum. Noci (1997) designs a conceptual approach that first identifies measures for assessing a supplier's environmental performance and, secondly, suggests effective techniques for developing the supplier selection procedure according to an environmental viewpoint. Choi and Hartley (1996) compare supplier selection practices based on a survey of companies at different levels in the auto industry. Mummalaneni *et al.* (1996) report the results of an exploratory study examining the trade-offs made by Chinese purchasing managers among the six attributes identified earlier. Swift (1995) examines the supplier selection criteria of purchasing managers who have a preference for single sourcing and those who have a preference for multiple sourcing. Chao *et al.* (1993) highlight six key criteria of supplier selection and describes the responses of a sample of Chinese purchasing managers. They segment the respondents into three clusters, based on similarities in their supplier evaluation processes and differentiate these clusters in terms of whether the managers emphasize reliable deliveries, price/cost considerations, or product quality. Weber and Ellram (1993) explore the use of a multi-objective programming approach as a method for supplier selection in a just-in-time (JIT) setting. Partovi *et al.* (1990) review the published applications of AHP in supplier selection. Willis and Huston (1990) discuss the various attributes that are important in implementing JIT into the purchasing process and introduce a new dimensional analysis model that has certain advantages over the traditional methods.

Fuzzy sets theory and fuzzy AHP

To deal with vagueness of human thought, Zadeh (1965) first introduced the fuzzy set theory, which was oriented to the rationality of uncertainty due to imprecision or vagueness. A major contribution of fuzzy set theory is its capability of representing vague data. The theory also allows mathematical operators and programming to apply to the fuzzy domain. A fuzzy set is a class of objects with a continuum of grades of membership. Such a set is characterized by a membership (characteristic) function, which assigns to each object a grade of membership ranging between zero and one. A tilde " $\sim$ " will be placed above a symbol if the symbol represents a fuzzy set. Therefore, $\tilde{P}$, $\tilde{r}$, $\tilde{n}$ are all fuzzy sets. The membership functions for these fuzzy sets will be denoted by $\mu(x|\tilde{P})$, and $\mu(x|\tilde{n})$ respectively. A triangular fuzzy number (TFN), $\tilde{M}$, is shown in Figure 1. A TFN is denoted simply as $(m_1/m_2, m_2/m_3)$ or (m_1, m_2, m_3). The parameters m_1, m_2 and m_3 respectively denote the smallest possible value, the most promising value, and the largest possible value that describe a fuzzy event.

Each TFN has linear representations on its left and right side such that its membership function can be defined as:

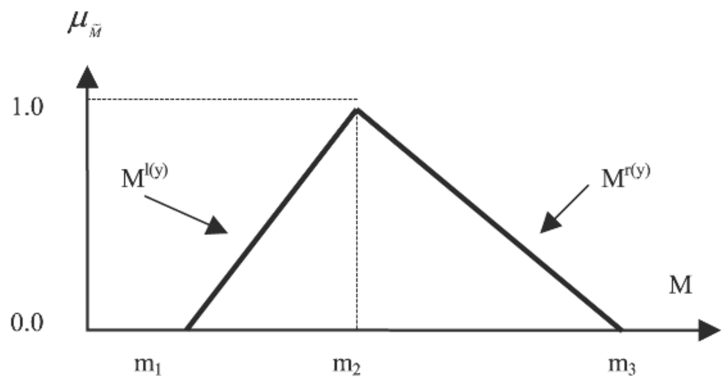
$$\mu(x|\tilde{M}) = \begin{cases} 0 & , x < m_1 \\ (x - m_1)/(m_2 - m_1) & , m_1 \leq x \leq m_2 \\ (m_3 - x)/(m_3 - m_2) & , m_2 \leq x \leq m_3 \\ 0 & , x > m_3 \end{cases} \tag{1}$$

A fuzzy number can always be given by its corresponding left and right representation of each degree of membership:

$$\begin{aligned} \tilde{M} &= (M^{l(y)}, M^{r(y)}) \\ &= (m_1 + (m_2 - m_1)y, m_3 + (m_2 \\ &\quad - m_3)y). y \in [0, 1], \end{aligned} \tag{2}$$

where $l(y)$ and $r(y)$ denotes the left side representation and the right side representation of a fuzzy number respectively. Many ranking methods for fuzzy numbers have been developed in the literature. These methods may give different ranking results and most methods are tedious in graphic manipulation requiring complex mathematical calculation. The algebraic operations with fuzzy numbers are given in Appendix 1.

Figure 1 A triangular fuzzy number, $\tilde{M}$



Many decision-making and problem-solving tasks are too complex to be understood quantitatively, however, people succeed by using knowledge that is imprecise rather than precise. Fuzzy set theory resembles human reasoning in its use of approximate information and uncertainty to generate decisions. It was specifically designed to mathematically represent uncertainty and vagueness and provide formalized tools for dealing with the imprecision intrinsic to many problems. By contrast, traditional computing demands precision down to each bit. Since knowledge can be expressed in a more natural by using fuzzy sets, many engineering and decision problems can be greatly simplified. Fuzzy set theory implements classes or groupings of data with boundaries that are not sharply defined (i.e. fuzzy). Any methodology or theory implementing "crisp" definitions such as classical set theory, arithmetic, and programming, may be "fuzzified" by generalizing the concept of a crisp set to a fuzzy set with blurred boundaries. The benefit of extending crisp theory and analysis methods to fuzzy techniques is the strength in solving real-world problems, which inevitably entail some degree of imprecision and noise in the variables and parameters measured and processed for the application. Accordingly, linguistic variables are a critical aspect of some fuzzy logic applications, where general terms such a "large," "medium," and "small" are each used to capture a range of numerical values. Fuzzy set theory encompasses fuzzy logic, fuzzy arithmetic, fuzzy mathematical programming, fuzzy topology, fuzzy graph theory, and fuzzy data analysis, though the term fuzzy logic is often used to describe all of these.The analytic hierarchy process (AHP) is one of the extensively used multi-criteria decision-making methods. One of the main advantages of this method is the relative ease with which it handles multiple criteria. In addition to this, AHP is easier to understand and it can effectively handle both qualitative and quantitative data. The use of AHP does not involve cumbersome mathematics. AHP involves the principles of decomposition, pair-wise comparisons, and priority vector generation and synthesis. Though the purpose of AHP is to capture the expert's knowledge, the conventional AHP still cannot reflect the human thinking style. Therefore, fuzzy AHP, a fuzzy extension of AHP, was developed to solve the hierarchical fuzzy problems.

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The decision-maker can specify preferences in the form of natural language expressions about the importance of each performance attribute (hygiene, quality of meals, quality of service). The system combines these preferences using fuzzy-AHP, with existing data (from industrial surveys and statistical analysis) to re-emphasize attribute priorities. In the fuzzy-AHP procedure, the pairwise comparisons in the judgment matrix are fuzzy numbers that are modified by the designer's emphasis. Using fuzzy arithmetic and α-cuts, the procedure calculates a sequence of weight vectors that will be used to combine the scores on each attribute. The procedure calculates a corresponding set of scores and determines one composite score that is the average of these fuzzy scores.

Fuzzy AHP applications: literature review

There are many fuzzy AHP methods proposed by various authors. These methods are systematic approaches to the alternative selection and justification problem by using the concepts of fuzzy set theory and hierarchical structure analysis. Decision makers usually find that it is more confident to give interval judgments than fixed value judgments. This is because usually he/she is unable to explicit about his/her preferences due to the fuzzy nature of the comparison process.

The earliest work in fuzzy AHP appeared in van Laarhoven and Pedrycz (1983), which compared fuzzy ratios described by triangular membership functions. Buckley (1985) determines fuzzy priorities of comparison ratios whose membership functions trapezoidal. Stam *et al.* (1996) explore how recently developed artificial intelligence techniques can be used to determine or approximate the preference ratings in AHP. They conclude that the feed-forward neural network formulation appears to be a powerful tool for analyzing discrete alternative multi-criteria decision problems with imprecise or fuzzy ratio-scale preference judgments. Chang (1996) introduces a new approach for handling fuzzy AHP, with the use of triangular fuzzy numbers for pairwise comparison scale of fuzzy AHP, and the use of the extent analysis method for the synthetic extent values of the pairwise comparisons. Ching-Hsue (1997) proposes a new algorithm for evaluating naval tactical missile systems by the fuzzy analytical hierarchy process based on grade value of membership function. Weck *et al.* (1997) present a method to evaluate different production cycle alternatives adding the mathematics of fuzzy logic to the classical AHP. Any production cycle evaluated in this manner yields a fuzzy set. The outcome of the analysis can finally be defuzzified by forming the surface center of gravity of any fuzzy set, and the alternative production cycles investigated can be ranked in order in terms of the main objective set. Kahraman *et al.* (1998) use a fuzzy objective and subjective method obtaining the weights from AHP and make a fuzzy weighted evaluation. Deng (1999) presents a fuzzy approach for tackling qualitative multi-criteria analysis problems in a simple and straightforward manner. Lee *et al.* (1999) review the basic ideas behind the AHP. Based on these ideas, they introduce the concept of comparison interval and propose a methodology based on stochastic optimization to achieve global consistency and to accommodate the fuzzy nature of the comparison process. Cheng *et al.* (1999) propose a new method for evaluating weapon systems by analytical hierarchy process based on linguistic variable weight. Zhu *et al.* (1999) make a discussion on extent analysis method and applications of fuzzy AHP. Chan *et al.* (2000a) present a technology selection algorithm to quantify both tangible and intangible benefits in fuzzy environment. They describe an application of the theory of fuzzy sets to hierarchical structural analysis and economic evaluations. By aggregating the hierarchy, the preferential weight of each alternative technology is found, which is called fuzzy appropriate index. The fuzzy appropriate indices of different technologies are then ranked and preferential ranking orders of technologies are found. From the economic evaluation perspective, a fuzzy cash flow analysis is employed. Chan *et al.* (2000b) report an integrated approach for the automatic design of FMS, which uses simulation and multi-criteria decision-making techniques. The design process consists of the construction and testing of alternative designs using simulation methods. The selection of the most suitable design (based on AHP) is employed to analyze the output from the FMS simulation models. Intelligent tools (such as expert systems, fuzzy systems and neural networks) are developed for supporting the FMS design process. Active X technique is used for the actual integration of the FMS automatic design process and the intelligent decision support process. Leung and Cao (2000) propose a fuzzy consistency definition with consideration of a tolerance deviation. Essentially, the fuzzy ratios of relative importance, allowing certain tolerance deviation, are formulated as constraints on the membership values of the local priorities. The fuzzy local and global weights are determined via the extension principle. The alternatives are ranked on the basis of the global weights by application of maximum-minimum set ranking method. Kuo *et al.* (2002) develop a decision support system for locating a new convenience store. The first component of the proposed system is the hierarchical structure development for fuzzy analytic process.

Extent analysis method on fuzzy AHP

In the following, first the outlines of the extent analysis method on fuzzy AHP are given and then the method is applied to a supplier selection problem.

Let $X = \{x_1, x_2, \ldots, x_n\}$ be an object set, and $U = \{u_1, u_2, \ldots, u_m\}$ be a goal set. According to the method of Chang's (1992) extent analysis, each object is taken and extent analysis for each goal is performed respectively. Therefore, m extent analysis values for each object can be obtained, with the following signs:

$$M^1_{g_i}, M^2_{g_i}, \ldots, M^m_{g_i}, i = 1, 2, \ldots, n, \quad (3)$$

where all the $M^j_{g_i} (j = 1, 2, \ldots, m)$ are triangular fuzzy numbers.

The value of fuzzy synthetic extent with respect to the ith object is defined as:

$$S_i = \sum_{j=1}^{m} M^j_{g_i} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M^j_{g_i} \right]^{-1} \quad (4)$$

The degree of possibility of $M_1 \geq M_2$ is defined as:

$$V(M_1 \geq M_2) = \sup_{x \geq y} \lfloor \min(\mu_{M_1}(x), \mu_{M_2}(y) \rfloor. \quad (5)$$

When a pair (x, y) exists such that $x \geq y$ and $\mu_{M_1}(x) = \mu_{M_2}(y)$, then we have $V(M_1 \geq M_2) = 1$. Since M_1 and M_2 are convex fuzzy numbers we have that:

$$V(M_1 \geq M_2) = 1 \quad \text{iff} \quad m_1 \geq m_2, \quad (6)$$

$$V(M_1 \geq M_2) = \text{hgt}\ (M_1 \cap M_2) = \mu_{M_1}(d), \quad (7)$$

where d is the ordinate of the highest intersection point D between μ_{M_1} and μ_{M_2} (see Figure 2).

When $M_1 = (l_1, m_1, u_1)$ and $M_2 = (l_2, m_2, u_2)$, the ordinate of D is given by equation (8):

$$V(M_2 \geq M_1) = \text{hgt}\ (M_1 \cap M_2)) = \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)}. \quad (8)$$

To compare M_1 and M_2, we need both the values of $V(M_1 \geq M_2)$ and $V(M_2 \geq M_1)$.

The degree possibility for a convex fuzzy number to be greater than k convex fuzzy numbers M_i $(i = 1, 2, \ldots k)$ can be defined by:

$$V(M \geq M_1, M_2, \ldots, M_k) = V[(M \geq M_1) \text{ and } (M \geq M_2) \text{ and } \ldots \text{ and } (M \geq M_k)] = \min V(M \geq M_i), i = 1, 2, 3, \ldots, k. \quad (9)$$

Assume that:

$$d'(A_i) = \min V(S_i \geq S_k). \quad (10)$$

For $k = 1, 2, \ldots, n$; $k \neq i$. Then the weight vector is given by:

$$W' = (d'(A_1), d'(A'_2), \ldots, d'(A_n))^T, \quad (11)$$

where $A_i (i = 1, 2, \ldots, n)$ are n elements.

Via normalization, the normalized weight vectors are:

$$W = (d(A_1), d(A_2), \ldots, d(A_n))^T, \quad (12)$$

where W is a nonfuzzy number.

A numerical example

One of the biggest white good manufacturers in Europe, established in Turkey, needs to select a supplier for a new model of aspirators. The firm should take into account a lot of criteria because the competition is very high. The firm wants to make an existing supplier produce a plastic part, scroll housing. A scroll housing is used in aspirators and produced in plastic injection machines. The number of the existing suppliers considered in the

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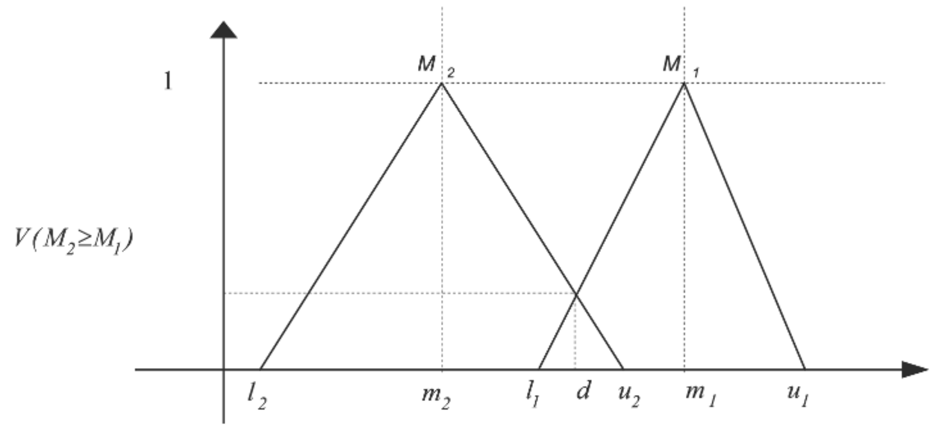
Figure 2 The intersection between M_1 and M_2



comparison is three. The criteria taken into account are the ones given in Introduction. The hierarchy is given in Figure 3.

From Table I, the following values are obtained:

$S_{SC} = (3.17, 4.00, 5.00) \otimes (1/12.34, 1/10.00, 1/8.14) = (0.26, 0.40, 0.61)$,

$S_{PP} = (2.90, 3.50, 4.17) \otimes (1/12.34, 1/10.00, 1/8.14) = (0.24, 0.35, 0.51)$,

$S_{SP} = (2.07, 2.50, 3.17) \otimes (1/12.34, 1/10.00, 1/8.14) = (0.17, 0.25, 0.39)$.

Using these vectors, $V(S_{SC} \geq S_{PP}) = 1.0$, $V(S_{SC} \geq S_{SP}) = 1.0$, $V(S_{PP} \geq S_{SC}) = 1.0$, $V(S_{PP} \geq S_{SP}) = 0.84$, $V(S_{SP} \geq S_{SC}) = 0.47$, and $V(S_{SP} \geq S_{PP}) = 0.61$ are obtained. Thus, the weight vector from Table I is calculated as $W'G = (0.43, 0.37, 0.20)^T$. The decision-making group then compares the sub-attributes with respect to main-attributes. The other tables will not be given in the paper because the calculation is similar. The questionnaires to obtain the preference weights among main-attributes, sub-attributes and alternatives are given in Appendix 2. The combination of priority weights for sub-attributes, attributes, and alternatives to determine priority weights for the best supplier firm are given in Tables II-V. FXM is the supplier firm selected.

Conclusions

Decisions are made today in increasingly complex environments. In more and more cases the use of experts in various fields is necessary, different value systems are to be taken into account, etc. In many of such decision-making settings the theory of fuzzy decision-making can be of use. Fuzzy group decision-making can overcome this difficulty.

Figure 3 Hierarchy of the numerical example

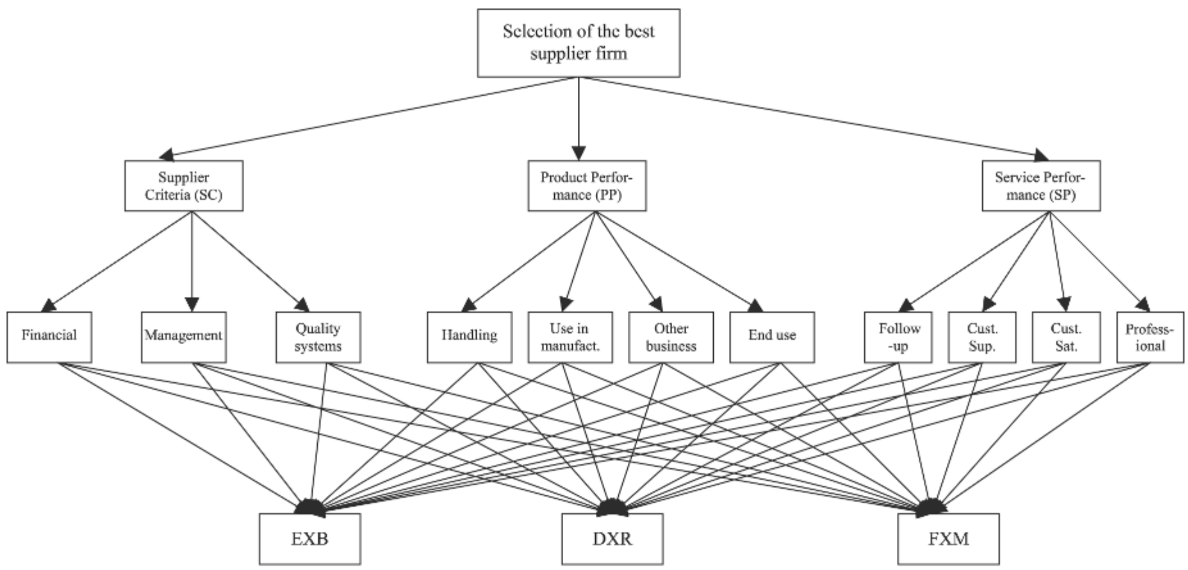


Table I The fuzzy evaluation matrix with respect to the goal

	SC	PP	SP
SC	(1, 1, 1)	(3/2, 2, 5/2)	(2/3, 1, 3/2)
PP	(2/5, 1/2, 2/3)	(1, 1, 1)	(3/2, 2, 5/2)
SP	(2/3, 1, 3/2)	(2/5, 1/2, 2/3)	(1, 1, 1)

Table II Summary combination of priority weights: sub-attributes of supplier criteria

	Financial	Management	Quality Sys.	Alternative priority weight
Weight	0.70	0.15	0.15	
Alternative				
EXB	0.66	0	0	0.46
DXR	0	0	0	0.00
FXM	0.34	1	1	0.54

Table III Summary combination of priority weights: sub-attributes of product performance criteria

	Hand.	Use in	Other	End use	Alternative priority weight
Weight	0.19	0.04	0.77	0.00	
Alternative					
EXB	0	0.87	0	0.27	0.03
DXR	0	0	0.31	0.18	0.24
FXM	1	0.13	0.69	0.55	0.73

Table IV Summary combination of priority weights: sub-attributes of service performance criteria

	Fol.-up	C. Sup.	C. Sat.	Prof.	Alternative priority weight
Weight	0.00	0.05	0.00	0.95	
Alternative					
EXB	1	0.05	0.72	0	0.003
DXR	0	0.64	0	0	0.032
FXM	0	0.31	0.28	1	0.965

Table V Summary combination of priority weights: main attributes of the goal

	SC	PP	SP	Alternative priority weight
Weight	0.43	0.37	0.20	
Alternative				
EXB	0.46	0.03	0.003	0.21
DXR	0	0.24	0.032	0.10
FXM	0.54	0.73	0.965	0.69

In general, many concepts, tool and techniques of artificial intelligence, in particular in the field of knowledge representation and reasoning, can be used to improve human consistency and implementability of numerous models and tools in broadly perceived decision-making and operations research. In this paper, supplier firms were compared using fuzzy AHP. Humans are often uncertain in assigning the evaluation scores in crisp AHP. Fuzzy AHP can capture this difficulty. There are many other methods to use in comparing csupplier firms. These are multi-attribute evaluation methods such as ELECTRE, DEA, and TOPSIS. These methods have been recently developed to use in a fuzzy environment. Further research may be the application of these methods to the supplier selection problem and the comparison of the results.

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Appendix 1

One of the most basic concepts of fuzzy set theory which can be used to generalize crisp mathematical concepts to fuzzy sets is the extension principle. Let X be a Cartesian product of universes $X = X_1 \ldots X_r$, and $\tilde{A}_1, \ldots, \tilde{A}_r$ be r fuzzy sets in $X_1, \ldots, X_r$, respectively. f is a mapping from X to a universe Y, $y = f(x_1, \ldots, x_r)$. Then the extension principle allows us to define a fuzzy set $\tilde{B}$ in Y by Zimmerman (1994):

$$\tilde{B} = \{(y, \mu_{\tilde{B}}(y)|y = f(x_1, \ldots, x_r), (x_1, \ldots, x_r) \in X\}, \tag{A1}$$

where:

$$\mu_{\tilde{B}}(y) = \begin{cases} \sup\limits_{(x_1,\ldots,x_r)\in f^{-1}(y)} \min\{\mu_{\tilde{A}1}(x_1), \ldots, \mu_{\tilde{A}_r}(x_r)\}, & \text{if } f^{-1}(y) \neq \emptyset \\ 0 & \text{, otherwise} \end{cases} \tag{A2}$$

where f^{-1} is the inverse of f.

Assume $\tilde{P} = (a, b, c)$ and $\tilde{Q} = (d, e, f)$. a, b, c, d, e, f are all positive numbers. With this notation and by the extension principle, some of the extended algebraic operations of triangular fuzzy numbers are expressed in the following.

Changing sign

$$-(a, b, c) = (-c, -b, -a), \tag{A3}$$

or

$$-(d, e, f) = (-f, -e, -d) \tag{A4}$$

Addition

$$\tilde{P} \oplus \tilde{Q} = (a + d, b + e, c + f), \tag{A5}$$

and

$$k \oplus (a, b, c) = (k + a, k + b, k + c), \tag{A6}$$

or

$$k \oplus (d, e, f) = (k + d, k + e, k + f), \tag{A7}$$

if k is an ordinary number (a constant).

Subtraction

$$\tilde{P} - \tilde{Q} = (a - f, b - e, c - d), \tag{A8}$$

and

$$(a, b, c) - k = (a - k, b - k, c - k), \tag{A9}$$

or

$$(d, e, f) - k = (d - k, e - k, f - k), \tag{A10}$$

if k is an ordinary number.

Multiplication

$$\tilde{P} \otimes \tilde{Q} = (ad, be, cf), \tag{A11}$$

and

$$k \otimes (a, b, c) = (ka, kb, kc), \tag{A12}$$

or

$$k \otimes (d, e, f) = (kd, ke, kf), \tag{A13}$$

if k is an ordinary number.

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Appendix 2

Figure A1 Questionnaire forms used to facilitate comparisons of main and sub-attributes

With respect to: the Best supplier firm	Importance (or preference) of one main-attribute over another									
Attribute	(7/2, 4, 9/2) Absolute	(5/2, 3, 7/2) Very strong	(3/2, 2, 5/2) Fairly strong	(2/3, 1, 3/2) Weak	(1, 1, 1) Equal	(2/3, 1, 3/2) Weak	(3/2, 2, 5/2) Fairly strong	(5/2, 3, 7/2) Very strong	(7/2, 4, 9/2) Absolute	Attribute
SC										PP
SC										SP
PP										SP

With respect to: SP	Importance (or preference) of one sub-attribute over another									
Sub-attribute	(7/2, 4, 9/2) Absolute	(5/2, 3, 7/2) Very strong	(3/2, 2, 5/2) Fairly strong	(2/3, 1, 3/2) Weak	(1, 1, 1) Equal	(2/3, 1, 3/2) Weak	(3/2, 2, 5/2) Fairly strong	(5/2, 3, 7/2) Very strong	(7/2, 4, 9/2) Absolute	Sub-attribute
F										M
F										QS
M										QS

With respect to: PP	Importance (or preference) of one sub-attribute over another									
Sub-attribute	(7/2, 4, 9/2) Absolute	(5/2, 3, 7/2) Very strong	(3/2, 2, 5/2) Fairly strong	(2/3, 1, 3/2) Weak	(1, 1, 1) Equal	(2/3, 1, 3/2) Weak	(3/2, 2, 5/2) Fairly strong	(5/2, 3, 7/2) Very strong	(7/2, 4, 9/2) Absolute	Sub-attribute
H										UM
H										OBC
H										EU
UM										OBC
UM										EU
OBC										EU

With respect to: SP	Importance (or preference) of one sub-attribute over another									
Sub-attribute	(7/2, 4, 9/2) Absolute	(5/2, 3, 7/2) Very strong	(3/2, 2, 5/2) Fairly strong	(2/3, 1, 3/2) Weak	(1, 1, 1) Equal	(2/3, 1, 3/2) Weak	(3/2, 2, 5/2) Fairly strong	(5/2, 3, 7/2) Very strong	(7/2, 4, 9/2) Absolute	Sub-attribute
FU										CSo
FU										CSa
FU										P
Cso										CSa
CSo										P
Csa										P

Figure A2 Two of the 11 questionnaire forms used to facilitate comparisons of alternatives

With respect to: F	Importance (or preference) of one alternative over another									
Alternative	(7/2, 4, 9/2) Absolute	(5/2, 3, 7/2) Very strong	(3/2, 2, 5/2) Fairly strong	(2/3, 1, 3/2) Weak	(1, 1, 1) Equal	(2/3, 1, 3/2) Weak	(3/2, 2, 5/2) Fairly strong	(5/2, 3, 7/2) Very strong	(7/2, 4, 9/2) Absolute	Alternative
EXB										DXR
EXB										FXM
DXR										FXM

With respect to: Professional	Importance (or preference) of one alternative over another									
Alternative	(7/2, 4, 9/2) Absolute	(5/2, 3, 7/2) Very strong	(3/2, 2, 5/2) Fairly strong	(2/3, 1, 3/2) Weak	(1, 1, 1) Equal	(2/3, 1, 3/2) Weak	(3/2, 2, 5/2) Fairly strong	(5/2, 3, 7/2) Very strong	(7/2, 4, 9/2) Absolute	Alternative
EXB										DXR
EXB										FXM
DXR										FXM

An integrated approach for supplier selection

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Keywords

Supply chain management, Supplier evaluation, Programming, Analytic hierarchy process, Turkey

Abstract

Competitive international business environment has forced many firms to focus on supply chain management to cope with highly increasing competition. Hence, supplier selection process has gained importance recently, since most of the firms have been spending considerable amount of their revenues on purchasing. The supplier selection problem involves conflicting multiple criteria that are tangible and intangible. Hence, the purpose of this study is to propose an integrated model for supplier selection. In order to achieve this purpose, supplier selection problem has been structured as an integrated lexicographic goal programming (LGP) and analytic hierarchy process (AHP) model including both quantitative and qualitative conflicting factors. The application process has been accomplished in a food company established in Istanbul, Turkey. In this study, the model building, solution and application processes of the proposed integrated model for supplier selection have been presented.

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Introduction

Increases and varieties of customer demands, advances of recent technologies in communication and information systems, competition in global environment, decreases in governmental regulations, and increases in environmental consciousness have forced companies for focusing on supply chain management (Tracey and Tan, 2001). The "supply chain management" term has been used for almost 20 years and is defined as the integration of activities to procure materials, transforms them into intermediate goods and final products, and delivers to customers (Heizer and Render, 2001). The supply chain consists of all links from suppliers to customers of a product. Goffin *et al.* (1997) have stated that supplier management is one of the key issues of supply chain management because the cost of raw materials and component parts constitutes the main cost of a product and most of the firms have to spend considerable amount of their sales revenues on purchasing. Hence, supplier selection is one of the most important decision making problems, since selecting the right suppliers significantly reduces the purchasing costs and improves corporate competitiveness (Ghodsypour and O'Brien, 2001).

On the other hand, supplier selection decision-making problem involves trade-offs among multiple criteria that involve both quantitative and qualitative factors, which may also be conflicting (Ghodsypour and O'Brien, 1998). In other words, buyer-supplier relationships based on only the price factor has not been appropriate in supply chain management recently. Considerations have been given also to the other important strategic and operational factors such as quality, delivery, flexibility, and etc. Supplier selection decisions must include strategic and operational factors as well as tangible and intangible factors in the analysis (Sarkis and Talluri, 2002). Hence, supplier selection problem can be modeled and solved by means of utilizing multi-criteria decision analysis. Furthermore, Ghodsypour and O'Brien (2001) have stated that only a few mathematical programming models have been published to this date those analyze supplier selection problems involving multiple sourcing with multiple criteria and with supplier's capacity constraints.

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This study aims to show the usage of integrated lexicographic goal programming (LGP) and analytic hierarchy process (AHP) model for decision-making problem and so how the mathematical programming techniques could evaluate the multiple objectives in determining the best compromise solution for supplier selection demonstrated by means of using integrated LGP and AHP model. Therefore, the purpose of this study is to propose an integrated model for supplier selection decision problem. In this study, the model building, solution and application processes of the proposed integrated model for supplier selection are presented.

Dickson (1966) presented 23 supplier selection criteria that were taken into consideration during the decision making process in his earlier study (Weber *et al.*, 2000). Later, Wind and Robinson (1968) reported that most vendor selection decisions involved multiple criteria (Weber *et al.*, 2000) and since then, several articles have been published for supplier selection. Verma and Pullman (1998) stated that supplier selection literature is rich in terms of conceptual and empirical works and decision support methods for purchasing managers as well. Weber and Ellram (1993) used multi-objective programming for supplier selection. Ghodsypour and O'Brien (1998) proposed an integrated AHP and linear programming (LP) approach as a supplier-selection decision-support system. In their recent work, Ghodsypour and O'Brien (2001) proposed mixed integer non-linear programming model to solve the multiple sourcing problem, with multiple criteria and with suppliers" capacity. Chen (2001) presented a multiple-criteria decision-making model based on fuzzy-set theory for supplier selection. Akbari Jokar *et al.* (2001) presented several necessary elements for a multiple criteria approach for strategic supplier selection and proposed a mathematical model maximizing the total utility of the supplier with respect to supplier and buyer constraints. In addition to these articles, data envelopment analysis (DEA) was used as a mathematical programming tool for supplier selection (Weber, 1996; Liu *et al.*, 2000; Weber *et al.*, 2000). On the other hand, Choi and Hartley (1996), Verma and Pullman (1998), Humphreys *et al.* (2001) and Tracey and Tan (2001) presented empirical studies related to supplier selection.

Development of the integrated model

As mentioned above, this study aims to propose an integrated model for supplier selection. For this purpose, a Turkish manufacturing company, which has been operating for almost 40 years, was chosen. The company produces dry mixed food and drink products. The company works with a number of suppliers for its raw materials. Some of the raw materials have been supplied from multiple sources while some of the others have been supplied from single source. In this study, the raw materials, which were selected by the firm, have been taken into consideration. The purchasing cost of these raw materials constitutes the important part of the total purchasing cost of the firm. Additionally, there have been alternative suppliers for each raw material. Hence, certain type of raw materials purchased from different suppliers have been involved in this study.

In the food company, the most important factors, which are taken into consideration in supplier selection, are in the order of quality, delivery, and cost. In the literature, these factors are also taken into consideration in supplier selection decision making process, especially those utilizing both mathematical programming approaches and decision support systems (Weber and Ellram, 1993; Ghodsypour and O'Brien, 1998; Ghodsypour and O'Brien, 2001; Akbari Jokar *et al.*, 2001). Because the company emphasizes qualitative factors regarding to its supplier selection strategy, it was required to develop a model, which includes factors such capacity, reputation, flexibility, communication, etc. In this pursuit, an integrated LGP and AHP model for supplier selection was developed. Quality, delivery, and cost factors have been selected as the objective functions. In addition, a utility function, coefficients representing the supplier scores, has been added to the model as the fourth objective function. In order to obtain supplier scores, which are the coefficients of the fourth objective function, an AHP model including several important factors that also effects the supplier decisions except quality, delivery, and cost has been developed. Quality, delivery, and cost factors are excluded in the model in order to prevent duplication in the proposed integrated model. The reason for including the supplier score objective function to the integrated proposed model is the enhance importance of supplier management.

Good suppliers can help manufactures during the development of new products and processes, with long-term quality improvements and cost reductions and can provide enhanced delivery performance (Goffin *et al.*, 1997). Therefore, maximizing the supplier's score is the other challenging factor that should be taken into consideration during the decision processes.

The initial AHP model was developed by means of utilizing the previous literature in supplier selection reported by Narasimhan (1983), Lambert and Stock (1993), Choi and Hartley (1996), Ghodsypour and O'Brien (1998), Verma and Pullman (1998), Vonderembse and Tracey (1999), Yahya and Kingsman (1999), Masella and Rangone (2000), Akbari Jokar *et al.* (2001) and Humphreys *et al.* (2001). After reviewing the initial model with the managers from R&D, purchasing, production, logistics, and quality departments, a four level AHP model is developed. The model encompasses criteria and sub-criteria, which may influence supplier evaluation. The overall objective, which is "supplier evaluation", takes place at the top of the hierarchy. The criteria, which may influence supplier evaluation, take place at the second level and the sub-criteria at the third level. Finally, alternative suppliers take place at the lowest level as shown in Figure 1. The criteria and sub-criteria developed in this study are the following:

- *Logistics criterion:* delivery lead time, supply lots, flexibility in changing the order, and delivery in good condition.
- *Technologic criterion:* capacity to meet the demand, involvement to formulating a new product or developing the current products, improvement efforts in their products and processes, etc., and problem solving capability.
- *Business criterion:* reputation and position in the sector, financial strength, and management skills and compatibility.
- *Relationship criterion:* easy communication, past experience, and sales representative's competence.

Finally, alternative suppliers determined by company management for the selected raw materials take place at the lowest level. This hierarchical model has been utilized for each product. Thus, eight AHP models have been processed.

On the other hand, buyer's demand and capacity of the suppliers have been determined as constraints. Also, another constraint was added to the model based on the purchasing strategy of the company. The company has split its suppliers into two categories according to their payment terms. The company pays first group (G-1) supplier in the short-term and the second group (G-2) supplier in the longer term. The purchasing cost of raw materials from second group supplier constitutes at least 45 percent of the total purchasing cost. Furthermore, the company prefers to buy some of the raw materials from at least two suppliers as the purchasing strategy:

- *Decision variables.* The decision variables, which are represented as X_{ij}, are the amount of raw material i to be purchased from supplier j. Y_{ij} equals "1" if supplier j is chosen for raw material i, and "0" otherwise.
- *Objective functions.* The objective functions of the LGP model are in the order of maximization of quality objective function, minimization of delivery objective function, minimization of cost objective function, and maximization of utility objective function. While the quality objective function (equation (1)) is maximized, the delivery and the purchasing cost objective functions (equations (2) and (3)) are minimized and the utility objective function is maximized (equation (4)). The coefficients of the fourth objective function have been calculated based on each product from the AHP model.
- *Constraints.* The constraints of the decision problem are buyer's demand (equation (5)), minimum and maximum order quantity of each supplier for each raw material (equations (6) and (7)), number of suppliers (equation (8)), and percentage of purchasing cost of G-2 (equation (9)).

$$Z_{\max.} = \sum_i \sum_j A_{ij} * X_{ij} \tag{1}$$

(Quality objective function),

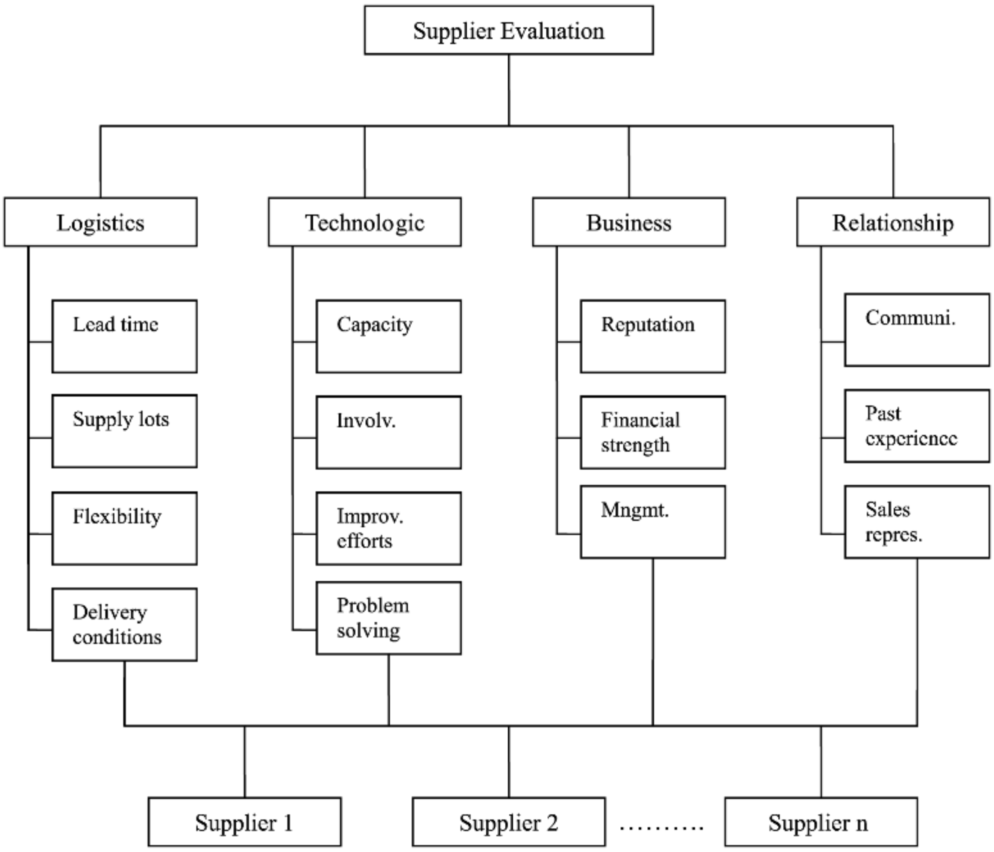
$$Z_{\min.} = \sum_i \sum_j L_{ij} * X_{ij} \tag{2}$$

(Delivery objective function),

$$Z_{\min.} = \sum_i \sum_j P_{ij} * X_{ij} \tag{3}$$

(Cost objective function),

Figure 1 The proposed AHP model for determining supplier scores



$$Z_{\max.} = \sum_i \sum_j S_{ij} * X_{ij} \quad (4)$$

(Utility objective function),

subject to:

$$\sum_j X_{ij} = D_i \forall i, \quad (5)$$

$$Q_{ij\min.} * Y_{ij} \leq X_{ij} \forall i, j, \quad (6)$$

$$Q_{ij\max.} * Y_{ij} \geq X_{ij} \forall i, j, \quad (7)$$

$$\sum_j Y_{ij} \geq n_i \exists i, \quad (8)$$

$$\frac{\sum\sum_{ij\in G2} P_{ij} * X_{ij}}{\sum_i \sum_j P_{ij} * X_{ij}} \geq k, \quad (9)$$

$$X_{ij} \geq 0 \text{ and integer} \quad \forall i, j, \quad (10)$$

$$Y_{ij} = 0 \quad \text{or} \quad 1 \quad \forall i, j. \quad (11)$$

The constants are:

A_{ij} = rate of perfect raw material i from supplier j.

L_{ij} = rate of raw material i late from supplier j.

P_{ij} = purchasing cost (acquisition, transportation, etc.) of raw material i from supplier j.

S_{ij} = score of supplier j for raw material i.

D_i = demand of raw material i.

$Q_{ij\min.}$ = minimum order quantity from supplier j for raw material i.

$Q_{ij\max.}$ = maximum order quantity from supplier j for raw material i.

n_i = number of supplier to be selected for raw material i.

k = percentage of purchasing cost of G-2.

The variables are:

Y_{ij} = "1" if supplier j is chosen for raw material i, "0" otherwise.

X_{ij} = amount of raw material i to be purchased from supplier j.

Application and solution of the integrated model

As mentioned earlier, the proposed integrated model has been applied in a food company established in Istanbul. Eight raw materials and three suppliers for each raw material, and thus 13 suppliers in total have been taken into consideration in the application process of the proposed integrated model. All the data except supplier scores in the problem have been collected from the company and calculated for determining the parameters in the integrated proposed model. The data have not been given in this study to ensure the confidence of the company. On the other hand, a group has been constituted from the same members who attended the AHP model building process in the food company in order to elucidate the pairwise comparison judgments. The judgments in Saaty's (1988) scale were obtained from the group members after the achievement of the consensus. Then, the judgments were used to obtain supplier scores by means of utilizing Expert Choice for Windows software package. Additionally, the proposed integrated LGP and AHP model building process has been performed interactively with the manager of the company. LGP model was solved by WinQSB, which uses lexicographical optimum. The results of the solution process of the proposed model are given in Table I.

As it is seen in Table I, the solution results of the model indicate that raw material 1 should be procured from the suppliers 1 and 2. Raw material 2 should be procured from the suppliers 4 and 5. Raw material 3 should be procured from the supplier 7. Raw material 4 should be procured from the supplier 8. Raw material 5 should be procured from suppliers 11 and 12. Raw material 6 should be supplied from the suppliers 1 and 13. Raw material 7 should be procured from the suppliers 12 and 13. Finally, raw material 8 should be procured from the supplier 12. Within the conflicting objectives of the firm that are quality maximization, late order percentage minimization, purchasing cost minimization, and also utilization maximization the best compromise purchasing quantity of each raw material from the suppliers are listed in Table I. The results of the model have been presented to the manager of the company. The results have been found to be consistent and reliable by the management.

Table I The results of the integrated model

Decision variables	Solution values (unit)
$X_{1,1}$	6.000
$X_{1,2}$	4.000
$X_{2,4}$	15.000
$X_{2,5}$	15.000
$X_{3,7}$	20.000
$X_{4,8}$	25.000
$X_{5,11}$	7.000
$X_{5,12}$	3.000
$X_{6,1}$	50.000
$X_{6,13}$	50.000
$X_{7,12}$	25.000
$X_{7,13}$	5.000
$X_{8,12}$	10.000

Notes: maximized objective function value=232,380; minimized objective function value = 5,300; minimized objective function value = 989,833,920; maximized objective function value = 69,374

On the other hand, according to the solution results among the 13 suppliers, nine suppliers have been proposed to be in relationship. This result is also in accordance with the fact that working with a small number of suppliers allows collaborative partnership. Organizations for whom buying are tending to be in collaborative partnership rather than adversarial competition. Hence, this kind of relationship can be managed with a small number of suppliers. Therefore, the organization can work with limited strategic suppliers in order to maintain its collaborative relationship and also to cope with global competition in its supply chain.

Conclusions and future work

Supplier management is one of the most important parts in supply chain management that gains importance increasingly in the globalization process. Most of the companies can improve their competitive advantage by means of good supplier management. Hence, supplier selection should be performed by a systematic and scientific approach. During the supplier selection process, the purchasing manager should take into consideration strategic and operational factors as well as tangible and intangible factors. In this study, an integrated LGP and AHP model was proposed for selecting suppliers among the conflicting objectives that are quality, delivery, cost, and utility.

One of the most important advantages of the proposed integrated model is that it includes both tangible and intangible factors in supplier selection decision-making process. Additionally, the decision maker can analyze

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the supplier selection decision in a systematic and scientific approach by means of utilizing the proposed model. Since an extensive analysis is needed in the entire decision making process, the proposed comprehensive and systematic approach would help purchasing managers in the evaluation of supplier selection.

Although integrated models have been reported in the literature previously, this study differs from the literature in terms of developing AHP model and also adding a constraint related to the financial strategy of the company. The developed AHP model consists of qualitative factors except quality, delivery, and cost. These factors have been grouped in four main criteria such as logistics, technologic, business, and relationship factors. These criteria should also be taken into consideration during the supplier selection decision process in order to be successful in supplier management. However, some of the criteria and sub-criteria may be eliminated or some other criteria may be included to the AHP model. Additionally, it has to be pointed out that the proposed integrated model can easily be adapted to any kind of applications and can easily be expanded as well.

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Linguistic assessment approach for managing nuclear safeguards indicator information

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Keywords

Fuzzy logic, Decision making, Nuclear safety, Modelling, Linguistics, Algebra

Abstract

A flexible and realistic linguistic assessment approach is developed to provide a mathematical tool for synthesis and evaluation analysis of nuclear safeguards indicator information. This symbolic approach, which acts by the direct computation on linguistic terms, is established based on fuzzy set theory. More specifically, a lattice-valued linguistic algebra model, which is based on a logical algebraic structure of the lattice implication algebra, is applied to represent imprecise information and to deal with both comparable and incomparable linguistic terms (i.e. non-ordered linguistic values). Within this framework, some weighted aggregation functions introduced by Yager are analyzed and extended to treat these kinds of lattice-value linguistic information. The application of these linguistic aggregation operators for managing nuclear safeguards indicator information is successfully demonstrated.

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1. Introduction

Assurance of non-diversion of nuclear materials is the ultimate goal of safeguards. Many countries, concluding comprehensive safeguards agreements (INFCIRC/153 type) with the International Atomic Energy Agency (IAEA), are currently discussing the new additional protocol (INFCIRC/540). The protocol will make them to provide more information to the IAEA. Compared to the traditional regime, additional measures are taken into consideration in this strengthened safeguards regime. The new measures will essentially consist in having access to more information that can be very qualitative in nature.

The information collected by the IAEA comes from mainly three different sources: information provided by the state, information collected by the IAEA, and information obtained from open sources (like media, studies, provided by third parties, etc.). It is obvious that the amount of data is enormous and that not all information contributes to a better knowledge of the situation in a particular state. This information can be of very different nature: it can be relevant, or it can be uncertain, like fuzzy or vague (due to the imprecise boundary), incomplete (due to lack of information), abundant (due to the limited ability of human beings to perceive and process simultaneously large amounts of data), conflicting (due to different sources), fragmentary (the information usually related to a fragment of the problem, and different fragments can be covered by various information sources), not fully reliable (due to different sources for different purposes), and deficient. This information does not directly contribute to a better knowledge of the facts, nor does it facilitate decision making.

The final conclusion on the non-proliferation commitment and on the absence of any undeclared activities of a state has to result from the balancing of all information in an integrated way. The IAEA has to process and evaluate a large amount of data, which is available from the different sources as described above.

Hence, there is an important need to establish a mathematical framework that provides a basis for synthesis across multidimensional information of varying quality, and provides an evaluation method that enables the IAEA to derive a final estimation on the possibility degree that "No nuclear material in a certain country is used for manufacture of nuclear weapons".

Traditional study of such issues is conducted using probabilistic tools and techniques. However, it is not difficult to see that aspects related to imprecision or vagueness clearly have a non-probabilistic character since they are related to imprecision of meanings.

Usually, in a quantitative setting the information is expressed by means of numerical values. However, when we work in a qualitative setting, that is, with vague or imprecise knowledge, this cannot be estimated with an exact numerical value. Then, a more realistic approach may be to use linguistic assessments instead of numerical values, i.e. to suppose that the variables that participate in the problem are assessed by means of linguistic terms.

Fuzzy logic as a modern computational tool provides a systematic way to interpret linguistic variables rather than numerical variables as well as a rule-based expert system in a natural decision-making procedure in nuclear safeguards applications. It can be viewed as complementary to traditional methods and can be a powerful tool to deal with imprecise information, especially linguistic information. Therefore, an important issue in the development of automated decision aids for safeguard is to handle fuzziness, since the evaluation involves human expertise and knowledge. This would enable the system to better emulate human evaluation processes.

Accordingly, a flexible and realistic approach of linguistic assessment based on fuzzy set theory is presented in this paper. In section 2, some mathematical and technological bases are analysed and provided. Section 3 is an application of those mathematical methods to evaluation of information on State's nuclear activities. A case study is illustrated for the proposed approach in managing nuclear safeguards indicator information.

2. Mathematical and technological bases

2.1 Linguistic assessment instead of numerical assessment

The linguistic approach is an approximate technique appropriate for dealing with qualitative aspects of problems. It models linguistic values by means of linguistic variables. Since words are less precise than numbers, the concept of a linguistic variable serves the purpose of providing a measure for an approximate characterization of the phenomena, which are too complex or ill-defined to be amenable to their description by conventional quantitative terms. Its application is beneficial because it introduces a more flexible framework for representing the information in a more direct and suitable way when it is not possible to express it accurately. Thus, the burden of quantifying a qualitative concept is eliminated and the systems can be simplified.

Within the proposed linguistic approach, two main different approaches can be found in order to aggregate linguistic values:

(1) an approximation approach uses the associated membership functions (Lee, 1996; Yager, 1992; Bonissone and Decker, 1986);
(2) a symbolic approach acts by the direct computation on labels (Delgado *et al.*, 1993).

Most available techniques belong to the former kind. However, those methods require the definition of the membership functions or fuzzy numbers associated with the linguistic terms, and the final results of them require the linguistic approximation. Both of these steps are usually the burden steps implying the investigation of human factor, semantics of the linguistic terms, subjective beliefs, etc. The latter kind of methods work assuming that the linguistic term set is an ordered structure uniformly distributed on a scale. These methods seem natural when the linguistic approach is used, because the linguistic assessments are just approximations that are given and handled when it is impossible or unnecessary to obtain more accurate values. Thus, in this case, the use of membership functions associated to the linguistic terms is unnecessary. Furthermore, they are computationally simple and quick (Delgado *et al.*, 1993).

The issue of aggregation has been studied extensively in many applications of fuzzy sets as multi-criteria decision making, pattern recognition, diagnosis and fuzzy logic control (Delgado *et al.*, 1993; Dubois and Prade, 1985; Ruan *et al.*, 1999; Yager, 1993a). In this section, we focus on the aggregation of linguistic information provided for different

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criteria, which are not equally important, i.e. weighted linguistic information.

To manipulate the linguistic information in this context, we shall work with operators for combining the linguistic un-weighted and weighted values by the direct computation on labels. Specifically, we shall present and analyse the weighted operators of combination of the linguistic values based on the direct computation, like min-type and max-type weighted aggregation operators and median aggregation operators, which are all introduced by Yager (1978, 1981, 1993b, 1994, 1998).

2.2 Weighted linguistic aggregation operators based on transformation function

The aggregation of weighted information involves the transformation of the weighted information under the degree of importance. The transformation form depends upon the type of aggregation of weighted information being performed. Yager (1981; 1993b; 1994) discussed the effect of the degree of importance in the types of aggregation max and min and suggested a class of functions for importance transformation in both types of aggregation, i.e.:

- min-type aggregation:

$$D = \min(g(w_1, a_1), g(w_2, a_2), \ldots, g(w_n, a_n)). \tag{1}$$

- max-type aggregation:

$$D(x) = \max(g(w_1, a_1), g(w_2, a_2), \ldots, g(w_n, a_n)). \tag{2}$$

Here, $g: H \times H \rightarrow H$ is a weight transformation function, and $H$is a finite ordered set. For the min-type aggregation he suggested a family of t-conorms acting on the weighted information and the negation of the weights, which presents the non-increasing monotonic property in the weights. For the max-type aggregation he suggested a family of t-norms acting on weighted information and the weight, which presents the non-decreasing monotonic property in the weights. Yager proposed a general specification of the requirements that any importance transformation function g must satisfy for any type of the aggregation operator. The function $g: L \times L \rightarrow L$ must have the following properties:

I. if $a > b$ then $g(w, a) \geq g(w, b)$.
II. $g(w, a)$ is monotone in w.
III. $g(0, a) = ID$.
IV. $g(1, a) = a$:.

with $a, b \in L$ expressing the satisfaction with regard to a criterion, $w \in L$ the weight associated to the criterion, and ID an identity element such that if we add it to our aggregations it does not change the aggregated value.

Condition I means that the function g is monotonically non-decreasing in the second argument, that is, if the satisfaction with regard to the criteria is increased the overall satisfaction should not decrease.

Condition II may be viewed as a requirement that the effect of the importance be consistent. It does not specify the monotonicity of g in the first argument, which depends on the type of aggregation operator. That is, if the aggregation operator is the min type, then g is monotonically non-increasing in the first argument. The effect of this is that the satisfactions with respect to lower importance criteria are increased relative to higher importance criteria. If the aggregation operator is the max type, then g is monotonically non-decreasing in the first argument. The effect of this is that the satisfactions with respect to lower importance criteria are decreased relative to higher importance criteria.

Condition III is a manifestation of the imperative that zero importance items do not effect the aggregation process. Concretely, $ID = 0$ for the max-aggregation and $ID = 1$ for the min-aggregation. Condition IV is essentially a boundary condition, which states that the assumption of all importance equal to 1 effectively is like not including importance at all.

Note that conditions I-IV are in fact a subset of general axioms required by a fuzzy implication operator (Klir and Yuan, 1995). As analysed in (Klir and Yuan, 1995; Ruan and Kerre, 1990) for the axioms hold by different fuzzy implication operators, some implication operators satisfy conditions I-IV are listed as follows:

- Łukasiewicz:

$$I_a(x, y) = \min(1, 1 - x + y).$$

- Standard strict:

$$I_s(x, y) = \begin{cases} 0 & x > y \\ 1 & x \leq y \end{cases}.$$

- Standard star (Gödel):

$$I_g(x,y) = \begin{cases} y & x > y \\ 1 & x \leq y \end{cases}.$$

- Kleene-Dienes:

$$I_b(x,y) = \max(1 - x, y).$$

- Adjusted Kleene-Dienes implication:

$$I_{b*} = \begin{cases} \max(1 - x, y) & x > y \\ 1 & x \leq y \end{cases}.$$

- Gaines:

$$I_\Delta(x,y) = \begin{cases} y/x & x > y \\ 1 & x \leq y \end{cases}.$$

- Kleene-Dienes-Łukasiewicz:

$$I_*(x,y) = 1 - x + x \cdot y.$$

- Yager:

$$I_E(x,y) = y^x.$$

Here, $x, y \in [0,1]$. Moreover, we can easily see that I_s is not feasible for characterizing the transformation function g. Hence, except for the I_s, the above implication operators can be suggested as the manifestation of the transformation function g, which are used for the min-type aggregation operator.

Considering the aforementioned ideas and assuming a linguistic framework, that is a label set L_0, to express the information and the weights. Let $L_0 = \{0 = s_0 < s_1 < s_2 \ldots < s_n = 1\}$ be a finite set of linguistic terms, $n \in \{0\} \cup \mathrm{N}$. Accordingly, a general form of the overall fused function can be given by:

$$D = \mathrm{Agg}(g(w_1, a_1).g(w_2, a_2), \ldots, g(w_n, a_n)), \tag{3}$$

where $w_i, a_i \in L_0 (i = 1, \ldots, n)$. Yager (1981) suggested a possible g function for the min aggregation which only needs a linear scale, i.e. the Kleene-Dienes implication I_b:

$$I_b(w, a) = \max(\mathrm{Neg}(w), a), \tag{4}$$

where $w, a \in L_0$, and $\mathrm{Neg}(s_i) = s_{n-i}$, $i, j \in \{0, \ldots, n\}$.

Furthermore, we consider the additional examples of g for the min-type aggregation operator on a finite linear ordinal scale L_0, only the following implication can be used, i.e.:

- I_g(Gödel implication):

$$I_g(s_i, s_j) = \begin{cases} s_j & i > j \\ 1 & i \leq j \end{cases}. \tag{5}$$

- $I_{b^\star}$ (adjusted Kleene-Dienes implication):

$$I_{b*}(s_i, s_j) = \begin{cases} \max(n(s_i), s_j) & i > j \\ 1 & i \leq j \end{cases}. \tag{6}$$

- $I_{a^\star}$(Łukasiewicz implication (Pavelka, 1979; Novak, 1982; Bolc and Borowik, 1992)):

$$I_a(s_i, s_j) = s_{\min(n, n-i+j)}, i, j \in \{0, \ldots, n\}. \tag{7}$$

Here $I_{g^\star}$ is an equivalent form of I_g on the finite ordinal scale.

The other two examples of g for the max-type aggregation operator on L_0 are:

- $T_\wedge$ (minimum):

$$T_\wedge(s_i, s_j) = s_i \wedge s_j. \tag{8}$$

- T_a: bounded difference (Klir and Yuan, 1995):

$$T_a(s_i, s_j) = s_{\max(0, i+j-n)}. \tag{9}$$

In addition, the corresponding t-conorm of $T_\wedge$ for a linear scale L_0, are $\vee$ = maximum and the corresponding t-conorm of T_a, i.e.:

$$S_a(s_i, s_j) = s_{\min(n, i+j)}. \tag{10}$$

According to equation (3), we have the following two more general fused function forms:

- min-type aggregation:

$$D = T(g(w_1, a_1), g(w_2, a_2), \ldots, g(w_n, a_n)), \tag{11}$$

  where $w_i, a_i \in L_0$ $(i = 1, \ldots, n)$, g is an implication-type transform function given in equations (4)-(7). T is a t-norm. It is the aggregation rule used in the pessimistic strategy. For a linear scale here, T can be taken as $\wedge$ or T_a.
- max-type aggregation:

$$D(x) = S(g(w_1, a_1), g(w_2, a_2), \ldots, g(w_n, a_n)). \tag{12}$$

  Here $w_i, a_i \in L_0$ $(i = 1, \ldots, n)$, g is a t-norm-type transform function given in (8) and (9), and S is the corresponding t-conorm. It is the aggregation rule used in the optimistic strategy. For a linear scale here, accordingly, S can be taken as $\vee$ = maximum or S_a.

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In the following subsection, we will consider the more general linguistic cases, i.e. lattice-valued linguistic terms by using the logical algebraic structure-lattice implication operation. And the detailed comparative analysis of the transformation function *g* will be given in section 2.5.

2.3 Lattice structure and lattice implication algebras

Lattice structures (Birkhoff, 1967) have been successfully applied to many fields, such as reliability theory, rough theory, knowledge representation and so on. We can at least trace two important applications in the past. First of all, recent developments in the theory of mathematical morphology show that the general framework of lattice theory is almost indispensable in explaining complex phenomena in an easy way. Second, the introduction of *L*-fuzzy sets by Goguen (1967, 1968/1969) provides a general framework for Zadeh's fuzzy set theory.

In general, lattice structures apply whenever ordinal information must be represented. Some claim that chains, i.e. totally ordered sets, can be applied in most cases. But very often this assumption is an oversimplification of reality, since we cannot deal with incomparable elements. We meet difficulties hard to solve, which deal with complex non-single criterion based problems, where the system state itself is evaluated according to various criteria.

In fact, there is much incomparable information in the evaluation and decision making of real-life systems. We give some concrete examples: consider a particular manufactured product; it can be very difficult to define a linear order when comparing the "quality" of products made by different people, since "quality" refers to many aspects of the manufactured product; we can also note that in general an expert's knowledge of certain information is only approximate because the information is often incomplete. The ability to evaluate information and draw conclusions can differ among experts and may be comparable or incomparable in the sense that one expert may be more capable in some particular situation than others. In general, decision-making relations are rarely linear. Hence, a partial ordered structure or a lattice structure (with much more better properties than partially ordered structures) should be the suitable tool to order objects.

In fuzzy set theory, instead of the underlying membership set being a two-valued set it is a multi-valued set that generally has the structure of a lattice L with a minimal element O and maximal element I. Furthermore, if $\wedge$, $\vee$, $\rightarrow$, $'$ are defined in the set L, then we can use these operations to define, as in the ordinary set theory, operations on fuzzy subsets.

The only question left is the extension of two-valued logic operation to multi-valued logic. Two important cases of L are of interest and often being used: when L is a finite simple ordered set; and when L is the unit interval $[0, 1]$. More general, L should be a lattice with suitable operations like $\wedge$, $\vee$, $\rightarrow$, $'$. The question of the appropriate operation and lattice structure has generated much literature (Pavelka, 1979; Novak, 1982; Bolc and Borowik, 1992; Goguen, 1967, 1968/1969). Goguen (1967) extended the concept of fuzzy sets to *L*-fuzzy sets in which membership grades form a partially ordered set instead of a linearly ordered set as $[0, 1]$. Moreover, according to such an extension; Goguen (1968/1969) established *L*-fuzzy logic of which truth value set is a complete lattice-ordered monoid, which is also called a complete residuated lattice in Pavelka and Novak's *L*-fuzzy logic (Pavelka, 1979; Novak, 1982). Since this algebraic structure is quite general, it is relevant to ask whether one can specify the structure. In this note, we specify the algebraic structure to lattice implication algebras introduced by Xu (1989), which was established by combining lattice and implication algebra with the attempt to model and deal with the comparable and incomparable information. There have been much work about lattice implication algebra, as well as the corresponding lattice valued logic system, lattice-valued approximate reasoning theory and lattice-valued resolution-based automated reasoning theory and methods (Xu, 1989; Xu and Qin, 1993; Liu and Xu, 1999; Qin and Xu, 1994; Xu *et al.*, 1999, 2000a, b). The lattice implication algebra is defined axiomatically as follows (Xu, 1989).

Definition 2.1 (LIA)

Let $(L, \vee, \wedge, ')$ be a bounded lattice with an order-reversing involution "$'$" and the universal bounds O, I, $\rightarrow: L \times L \rightarrow L$ be a mapping. $(L, \vee, \wedge, ', \rightarrow)$ is called a lattice implication algebra (LIA) if the following axioms hold for all $x, y, z \in L$:

(A_1) $x \to (y \to z) = y \to (x \to z)$ (exchange property).
(A_2) $x \to x = I$ (identity).
(A_3) $x \to y = y' \to x'$ (contraposition or contrapositive symmetry).
(A_4) $x \to y = y \to x = I$ implies $x = y$ (equivalency).
(A_5) $(x \to y) \to y = (y \to x) \to x$.
(A_6) $(x \vee y) \to z = (x \to z) \wedge (y \to z)$.
(A_7) $(x \wedge y) \to z = (x \to z) \vee (y \to z)$.

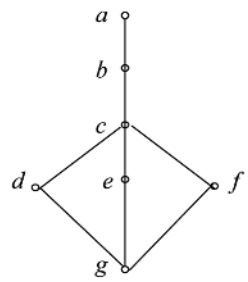
Some basic concepts and properties of lattice implication algebras can be obtained in (Xu, 1989; Xu and Qin, 1993; Liu and Xu, 1999; Qin and Xu, 1994; Xu *et al.*, 1999, 2000a, b). The lattice implication algebra structure will be used to characterize the set of linguistic truth values.

2.4 Lattice-valued linguistic terms

There is much qualitative information in the area of evaluation process and decision making, like subjective judgement of experts, etc. In fact, human beings cannot be seen as a precision mechanism. They usually express their knowledge about the world using linguistic variable in natural language with full of vague and imprecise concepts. A linguistic term differs from a numerical one in that its values are not numbers, but words or sentences in a natural or artificial language. On the other hand, these words, in different natural language, seem difficult to distinguish their boundary sometime, but their meaning of common usage can be understood. Moreover, there are some "vague overlap districts" among some words, which cannot be strictly linearly ordered, as given in Figure 1 of example 2.1.

Example 2.1
See Figure 1 for the ordering relationships in some linguistic terms. Note that d = approximately true, e = possibly true, f = more or less true are incomparable. One cannot collapse that structure into a linearly ordered structure, because then one would impose an ordering on d, e, and f, which was originally not present.

Figure 1 Linguistic terms in an ordering



Note: *a = very true, b = more true, c = true, d = approximately true, e = possibly true, f = more or less true, g = little true*

This means the set of linguistic values may not be strictly linearly ordered. It is shown that linguistic term can be ordered by their meanings in natural language. Naturally, it should be suitable to represent the linguistic values by a partially ordered set or lattice.

According to the feature of linguistic variables, we need to find some suitable algebras to characterize the values of linguistic variables. There is a good basic to believe that this approach would provide us with simple algorithms for reasoning and decision making. To attain this goal we characterize the set of linguistic truth values by a LIA structure, i.e. use the LIA to construct the structure of value sets of linguistic variables.

In general, the value of a linguistic variable can be a linguistic expression involving a set of linguistic terms such as "high", "middle", and "low", modifiers such as "very", "more or less" (called hedges (Zadeh, 1975; Cat Ho and Wechler, 1990) and connectives (e.g. "and", "or"). Let us consider the domain of the linguistic variable "truth": domain (truth) = {true, false, very true, more or less true, possibly true, very false, possibly false, ...}, which can be regarded as a partially ordered set whose elements are ordered by their meanings and also regarded as an algebraically generated set from the generators G = {true, false} by means of a set of linguistic modifiers M = {very, more or less, possibly, ...}. The linguistic modifiers play a vital role in the representation of fuzzy sets. They are strictly related to the notion of vague concept. The generators G can be regarded as the prime term, different prime terms correspond to the different linguistic variables.

Taking into account the above remarks, construction of an appropriate set of linguistic values for an application can be carried out step by step. Consider a set of linguistic hedges, e.g. H^+= {very, more or plus}, H = {approximately, possibly, more or less, little}, where H^+ consists of hedges which strengthen the meanings of "true" and the hedges in H weaken it. Put $H = H^+ \cup H$. H^+, H can be ordered by the degree of strengthening or weakening. For example,

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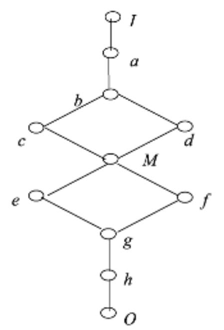
one may assume that very > more, little > approximately, possibly, and more or less, and "approximately", "possibly", "more or less" are incomparable. We say that $a \leq b$ if and only if a(true) $\leq b$(true) in the natural language, where a and b are linguistic hedges.

Applying the hedges of H to the primary term "true" or "false" we obtain a partially ordered set or lattice. For example, as represented in Figure 2, we can obtain a lattice generated from "true" or "false" by means of operations in H. We add these three special elements I, M, O called "absolutely true", "medium", and "absolutely false" to the obtaining set so that they have natural ordering relationship with the linguistic truth values. The set of linguistic truth values obtained by the above procedure is a lattice with the boundary. And one can define $\wedge$, $\vee$, implication $\rightarrow$ and complement operation $'$ on this lattice according to LIA structure.

Example 2.2
See Figure 2 for the lattice-valued algebra of linguistic terms with 11 elements. Note that $c =$ approximately true, $d =$ possibly true are incomparable. We set $L = \{O, a, b, c, d, M, e, f, g, h, I\}$. The operations "$\wedge$" and "$\vee$"can be shown in the Hasse diagram of Figure 2. The complement operation, the implication operation, the corresponding t-norm $\otimes$ and the t-conorm $\oplus$ can be given as shown in Tables I-IV, according to the lattice implication algebra structure and properties.

As we can show that $(L, \vee, \wedge, ', \rightarrow)$ is a lattice implication algebra, all the properties of lattice implication algebra will hold in L. So the finite set of linguistic values can be characterized by a finite lattice implication algebra.

Figure 2 The lattice-ordering structure of linguistic terms with 11 elements



Note: I = *absolutely true*, a = *very true*, b = *true*, c = *approximately true*, d = *possibly true*, M = *medium*, f = *possibly false*, e = *approximately false*, g = *false*, h = *very false*, O = *absolutely false*

Table I Operation "$'$"

x	*x'*
O	*I*
a	*h*
b	*g*
c	*e*
d	*f*
M	*M*
e	*c*
f	*d*
g	*b*
h	*a*
I	*O*

Table II Operation "$\rightarrow$"

$\rightarrow$	*O*	*A*	*b*	*c*	*d*	*M*	*e*	*f*	*g*	*h*	*I*
O	I	I	I	I	I	I	I	I	I	I	I
a	h	I	a	b	b	c	M	M	e	g	I
b	g	I	I	a	a	b	c	c	M	e	I
c	e	I	I	I	a	a	b	c	c	M	I
d	f	I	I	a	I	a	d	b	c	M	I
M	M	I	I	I	I	I	a	a	b	e	I
e	c	I	I	I	I	I	I	a	a	b	I
F	d	I	I	I	I	I	a	I	a	b	I
g	b	I	I	I	I	I	I	I	I	a	I
h	a	I	I	I	I	I	I	I	I	I	I
I	O	a	b	c	d	M	e	f	g	h	I

Remarks

- Given the number of the linguistic terms L, and the ordering structure of L, the complement operation, the implication, the corresponding t-norm $\otimes$ and the s-norm $\oplus$ can be given.
- The implication operation in LIA satisfies the conditions I-IV of the importance transformation function. Hence the implication operation in LIA can be used to capture the transformation between the weight and the individual ratings in the min-type aggregation.
- The corresponding t-norm $\otimes$ in LIA can be taken as the transformation function in the max-type aggregation. It can also be taken as the min-type aggregation operator.
- The t-conorm $\oplus$ can be taken as the max-type aggregation operator.

Accordingly, we can deal with some more general linguistic information, i.e. from a linear ordered linguistic label set to lattice-

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Table III Operation "⊗"

⊗	**O**	**a**	**b**	**C**	**d**	**M**	**e**	**f**	**g**	**h**	**I**
O	O	O	O	O	O	O	O	O	O	O	O
a	O	a	c	M	M	e	M	g	h	O	a
b	O	c	M	E	e	g	c	h	O	O	b
c	O	M	e	G	e	h	b	h	O	O	c
d	O	M	e	O	g	h	d	O	O	O	d
M	O	c	g	H	h	O	a	O	O	O	M
e	O	g	h	O	h	O	I	O	O	O	e
f	O	g	h	H	O	O	a	O	O	O	f
g	O	h	O	O	O	O	I	O	O	O	g
h	O	O	O	O	O	O	I	O	O	O	h
I	O	a	b	C	d	M	e	f	g	h	I

Table IV Operation "⊕"

⊕	**O**	**a**	**b**	**C**	**d**	**M**	**e**	**f**	**g**	**h**	**I**
O	O	a	b	C	d	M	e	f	g	h	I
a	a	I	I	I	I	I	I	I	I	I	I
b	b	I	I	I	I	I	I	I	I	a	I
c	c	I	I	I	a	a	b	c	c	M	I
d	d	I	I	I	I	I	a	I	a	b	I
M	M	I	I	I	I	I	a	a	b	e	I
e	c	I	I	I	a	a	b	c	c	M	I
f	f	I	I	a	I	a	d	b	c	M	I
g	g	I	I	a	a	b	c	c	M	e	I
h	H	I	a	b	b	c	M	M	e	g	I
I	I	I	I	I	I	I	I	I	I	I	I

valued linguistic label set. According to equation (3), we have the following two extended fused function forms for lattice-valued linguistic terms:

- min-type aggregation:

$$D = T(g(w_1, a_1), g(w_2, a_2), \ldots, g(w_n, a_n)), \tag{13}$$

  where $w_i, a_i \in L$, L is the finite set of linguistic values characterized by a finite LIA. g is an implication operation in LIA, $T = \wedge$ or $\otimes$ in LIA.
- max-type aggregation:

$$D(x) = S(g(w_1, a_1), g(w_2, a_2), \ldots, g(w_n, a_n)). \tag{14}$$

  Here w_i, $a_i \in L$, L is the finite set of linguistic values characterized by a finite LIA. $g = \wedge$ or $\otimes$ in LIA. S can be taken as $\vee$ or $\oplus$.

2.5 Remarks on the weighted aggregation function and the transformation functions

In the following, we assume that g is defined on $L_0 \times L_0$. Now we consider some intuitive properties for these fused functions:

- In the case of min-type aggregation, due to the conditions I-IV for the g and implication-type feature, $g(w_i, a_i)$ can be intuitively interpreted as a measure of the degree to which a criteria satisfies the statement "all important criteria are satisfied" or "if important, then the observation or judgement is valid".
- If the aggregation operator is the min-type, we also note that $g(w, a) \geq a$. From the fact that $g(s_n, a) = a$ and the fact $g(w_1, a) \leq g(w_2, a)$ for $w_1 > w_2$, the satisfaction in the values of D of equation (11) tends to be higher than those in the component a_j. Hence, the Gödel implication does not seem suitable in general cases. Because of the definition of the Gödel implication that if $w > a$, then $g(w, a)$ always is the a, the importance weight does not effect the overall fused value when $w > a$.
- Note that there is an order relation among the four implication operations (Klir and Yuan, 1995), i.e.:

$$I_{a*}(w, a) \geq I_{b*}(w, a) \geq I_b(w, a) \geq I_g(w, a),$$

  where $w, a \in L_0$, which means there would be the same relative ordering on the overall fused values D using the corresponding implication operations. It means the Łukasiewicz implication provides a bigger positive compensation than other three implications.
- When g is taken as the Łukasiewicz implication, the Gödel implication and the adjusted Kleene-Dienes implication in the min-type aggregation, if $w_i \leq a_i$ holds for all $i \in \{1, \ldots, n\}$, then $w_i \rightarrow a_i = s_n$ holds for the above three implications, i.e. $D = s_n$. And if $w_i \leq a_i$ holds for some $i \in \{1, \ldots, n\}$, the ith criteria does not effect the overall satisfaction D. In this case, $g(w_i, a_i) = w_j \rightarrow a_i$ can also be intuitively seen as a measure of the degree to which a criteria satisfies the statement "All the valid degree of observation or judgement is bigger than or equal to the importance". This property shows that there are much more emphasis put on the criteria with a high importance, where the importance that is lower than the satisfaction does not effect the overall fused value. This property is also hold for the implication operator in the LIA.

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If we need to consider the importance weight as a threshold to the satisfaction, then the Łukasiewicz implication, the adjusted Kleene-Dienes implication and the implication in LIA will simplify the process of aggregation and would be a suitable selection. Otherwise, the Kleene-Dienes implication should be more suitable.

For the implication operator $I : H \times H \rightarrow H$, here $H = [0, 1]$, L_0 (the set of the linearly order linguistic terms) or L (the set of the lattice-order linguistic terms based on LIA), we consider the following properties of I:

I. $I(w, a)$ is non-decreasing in a, i.e. if $a > b$ then $I(w, a) \geq I(w, b)$.
II. $I(w, a)$ is non-increasing in w, i.e. if $w_1 < w_2$, then $I(w_1, a) \geq I(w_2, b)$.
III. $I(0, a) = 1$.
IV. $I(1, a) = a$.
V. $w \leq a$ if and only if $I(w, a) = 1$.
VI. $I(w, a) \geq a$ for any w, a.

Table V gives a comparison among different implication operators on the properties for characterizing the transformation function g.

Assume L is the finite set of elements used to indicate preference information. Furthermore assume that the structure available on S is a lattice ordering. Let $Y = \{A_1, A_2, \ldots, A_p\}$ be the set of criteria to be satisfied and X be the set of alternatives. Assume that each objective is represented by a fuzzy subset of X with grades selected from L. Thus, for any $x \in X$, $A_i(x) \in L$ indicates the degree to which x satisfies the criteria specified by A_i. Let G be a fuzzy subset of Y in which $G(A_i) = w_i \in L$ indicates the importance of the objective A_i; Yager conjectured a general form for this type of decision function (Yager, 1981) based on the max-min principle of the Bellman and Zadeh approach (Bellman and Zadeh, 1970):

$$D(x) = g(A_1(x), w_1) \text{ and } g(A_2(x), w_2) \text{ and } \ldots \text{ and } g(A_p(x), w_p), \quad (15)$$

where $g(A_i(x), w_i)$ indicate objective evaluated at alternative x, modified by its importance. The optimal alternative is the $x \in X$ that maximizes D.

2.6 Weighted median aggregation for the ordinal scale

It should be note that neither the min-type nor max-type aggregation allow any compensation, i.e. a higher degree of satisfaction of one of the criteria cannot compensate for a lower degree of satisfaction of another criteria. Averaging operators or ordered weighted averaging operators (OWA) (Yager, 1992) have a positive compensation between ratings, but it can only be used in numerical value. Hence we consider the following median aggregation operator for ordinal scale introduced by Yager (1994, 1998). Some OWA-like aggregation operators for the ordinal scale, like LOWA operator (Herrera *et al.*, 1996; Herrera and Herrera-Viedma, 2000) and WOWA operator (Torra, 1997), but we do not consider them here due to their somewhat complex formulation and the fact that they are not available in our applications.

2.6.1 Un-weighted median aggregation

Assume $C = \{a_1, \ldots, a_n\}$ is a collection of element drawn from L_0. If we order the elements in C and denoted this as $\{b_1, \ldots, b_n\}$ such that b_j is the jth largest of the a_i in C, then:

Table V Fulfillment of some conditions for the selected implication operators used for the transformation function

	I_a	I_s	I_g	I_b	I_{b^*}	I_Δ	I_*	I_{a^*}	I_E	I_{LIA}
I	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
II	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
III	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
IV	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
V	Y	Y	Y	N	Y	Y	N	Y	N	Y
VI	Y	N	Y	Y	Y	N	Y	Y	Y	Y
Feasible for g on [0,1]	Y	Y	N	Y	Y	Y	Y	Y	Y	Y
Feasible for g on L_0	N	N	N	Y	Y	N	N	Y	N	Y
Feasible for g on L	N	N	N	Y	Y	N	N	N	N	Y
The order relation	$I_a \geq I_{b^*} \geq I_b \geq I_g$, $I_{LIA} \geq I_{b^*} \geq I_b$									

Notes: Y = yes, N = no

$$\mathrm{med}\,(C) = \begin{cases} b_{(n+1)/2} & \text{if } n \text{ is odd,} \\ b_{n/2} & \text{if } n \text{ is even.} \end{cases} \quad (16)$$

Note that this operation, like min and max, is simple based on the ordering of the element, it is also like the average in that it is a mean-type aggregation.

The process of taking the median requires an ordering of the arguments, as does the min and max aggregation, and then taking the element in the middle. We note that in the process of taking the median the values at the extremes play little role in the determination of the median. It is the elements in the middle that are significant.

If n is even we shall call $b_{n/2}$ the lower median and $b_{(n/2)+1}$ the upper median. In this situation, we have two ways to define the median:

$$\mathrm{med}\,(C) = \min(\text{lower, upper median}),$$

or:

$$\mathrm{med}\,(C) = \max(\text{lower, upper median}).$$

The adjudication of the situation when n is even depending upon the context of the problem. When $n$is odd, then:

$$\text{Upper median} = \text{lower median} = b_{(n/2)+1}.$$

Now let us look at some properties of this median operation:

- The median operation is monotonic in its argument if $a_i' \geq a_i$ for all a_i then:

$$\mathrm{med}\,(a_i', \ldots, a_n') \geq \mathrm{med}\,(a_i, \ldots, a_n).$$

- The median is commutative, the indexing of the arguments doesn't effect the aggregation:

$$\min i(a_i) \leq \mathrm{med}_{\,i}(a_i) \leq \max{}_i(a_i).$$

  As noted by Dubois and Prade (1985), any operation satisfying these three properties is a mean-type operator.
- The median operator is idempotent:

$$\mathrm{med}\,(e, \ldots, e) = e.$$

We note that all the above properties are shared by min and max. The following properties clearly distinguish it from min and max. Assume:

$$\mathrm{med}\,(a_i, \ldots, a_n) = a.$$

Then:

$$\begin{aligned} &\mathrm{med}\,(a_i, \ldots, a_n, a_{n+1}) \geq a && \text{if } a_{n+1} > a, \\ &\mathrm{med}\,(a_i, \ldots, a_n, a_{n+1}) \leq a && \text{if } a_{n+1} < a, \\ &\mathrm{med}\,(a_i, \ldots, a_n) = a && \text{if } a_{n+1} = a. \end{aligned}$$

We recall that the min is monotontically decreasing in cardinality – it cannot increase if we add elements to the aggregation. The max operation is monotonetically increasing in cardinality – it cannot decrease if we add elements to the aggregation. Especially, we note that the placement of pair of elements 1 at the top and 1 at the bottom does not effect the median. From this we see that the identity element from the median aggregation is the pair 0, 1. Thus for any n, $\mathrm{med}(a_i, \ldots, a_n) = \mathrm{med}\,(0, a_i, \ldots, a_n, 1)$.

2.6.2 Weighted median aggregation for the ordinal scale with value and weights

The procedure is similar in spirit to that used in obtaining the weighted max and min operations. First, based on the associated weights, transform the values of a_i into new values and then take the median of these new values. Since it is the elements in the middle of the ordered elements that play a crucial role in the median aggregation one imperative in doing the transformation is to get the elements with low importance out the middle. Recalling the observation that the "identity object" for the median is the pair of element 0 and 1, based upon the importance, we can replace each of the original objects, the values of a_i by two element a_i^+ and a_i^- in such way that if the importance is low one object goes to the value 1 and the other goes to the value 0. In doing this we are essentially converting low importance elements into identity objects.

Replacing a_i in C by two elements a_i^+ (called the upper replacement) and a_i^- (called the lower replacement) such that:

$$a_i^+ = w_i \rightarrow a_i, \text{ and } a_i^- = T(w_i, a_i).$$

$\rightarrow$ is given by the Łukasiewicz implication. T is a Łukasiewicz t-norm (bounded difference T_a) on L_0. Then the weighted median aggregation is:

$$\mathrm{med}(a_1^+, a_1^- a_2^+, a_2^-, \ldots, a_p^+, a_p^-). \quad (17)$$

We consider the properties of the operation:

- Obviously $a_i^+ = w_i \rightarrow a_i \geq a_i^- = T(w_i, a_i)$ for any pair of w_i and a_i.
- We have if $a > b$, then $a^+ > b^+$ and $a^- > b^-$, and the median increases. Thus

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we get increasing aggregation for increasing satisfaction.

- We see that for $w = 0$, we get:

  $$a_i^+ = 0 \rightarrow a_i = 1 \text{ and } a_i^- = T(0, a_i) = 0,$$

  and hence zero importance converts this to an identity item.
- For $w = 1$, then:

  $$a_i^+ = 1 \rightarrow a_i = a_i, a_i^- = T(1, a_i) = a_i.$$

  Thus, the situation with all one importance effectively acts as if we have the importance median.
- Since $w_i \rightarrow a_i \geq a_i$ is monotonically non-increasing as w_i increases and $T(w_i, a_i)$ is monotonically non-decreasing as w_i increase. Thus as w_i decrease then $a_i{}^+ = w_i \rightarrow a_i$ is getting bigger while $a_i{}^- = T(w_i, a_i)$ is getting smaller and hence the spread between increases, and the more likely 1 is at the top of the ordering and 1 is at the bottom of the ordering, making them less likely to effect the median selection.

The problem here is how to choose an appropriate model from all of these models for a particular application. In general, it should obey the following principles:

- If there is no need to distinguish the weighted conjunction from the weighted disjunction, or neither of them is sufficient to model the real situation, we can select the weighted averaging-type model, like median aggregation.
- If there is a need to take the point of optimistic conjunction and a pessimistic disjunction view, we use the relative weighted model based on the Zadeh's operators ($\wedge$, $\vee$).
- According to the emphasis on the importance in the aggregation process, we can select the implication among the Łukasiewicz implication, the adjusted Kleene-Dienes implication, the Kleene-Dienes implication.
- If there is a need to consider comprehensively information from all components, we can employ other relative weighted models. Furthermore, we can select an appropriate pair of *t*-norms and *s*-norms according to the degree to which we need to distinguish weighted conjunction from the weighted disjunction.

3. Application for evaluation of information on state's nuclear activities

3.1 The structure of state's nuclear activities

A State's nuclear activity could be evaluated from a single aspect such as especially designed and dual-use equipment or nuclear and non-nuclear materials, and so on. However such a single-aspect evaluation simply does not reflect the overall facilities and activities about undeclared nuclear materials. Nuclear material suitable for the manufacture of weapons does not exist in nature. It must be manufactured from source materials through a series of discrete and definable steps (e.g. mining and milling, conversion, enrichment, fuel fabrication, irradiation in nuclear reactor, etc.). To provide an effective evaluation, it is necessary to establish a systematic and comprehensive indicator system, the hierarchy structure of the evaluation model of state's nuclear activities should be established.

During the design of the model structure, the following requirements have to be taken into account. The model should:

- adequately reflect the connections between the elements of the subject area;
- provide the link among the elements;
- represent the performance of the subject area with different levels of details;
- be used for qualitative evaluation of the performance of the subject area.

The IAEA (1999) physical model of the nuclear fuel cycle will be taken as the basis (a case study) for this task. It includes all the main activities that may be involved in the nuclear fuel cycle from source materials acquisition to the production of weapons-usable materials. The structure of the physical model of the nuclear fuel cycle is well developed, i.e. its elements and the interconnections between them are clearly defined. It contains detailed narratives describing every known process for accomplishing each given nuclear activity represented in the fuel cycle and the links between them, i.e. it can take into account all the possible technological chains of production of Pu and HEU. It also identifies and describes indicators of the existence or development of a particular process. The indicators include especially designed and dual-use equipment, nuclear and non-nuclear

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materials, technology/training R&D, and many others.

The IAEA physical model of the nuclear fuel cycle provides a convenient structure for organizing the safeguard relevant information, which will be used by IAEA analysts and inspectors to better evaluate the safeguards-related significance of information on a state's activities. It is a comprehensive indicator system, as illustrated in Figure 3.

It can be seen that the physical model is a complex system consisting of a number of individual subsystems, such as mining and milling (O_1), conversion I (O_2), conversion II (O_3), enrichment of uranium (O_4), fuel fabrication (O_5), nuclear reactors (O_6), deuterium/heavy water production (O_7), reprocessing of irradiated fuel (O_8). Each of them is determined by different subsystems. For example, in the context of enrichment uranium (O_4), there are three similar sub-processes determined by the nature of the raw material, i.e. by UF_6 (O_{41}), UCl_4 (O_{42}), and U metal (O_{43}); Moreover, O_{41} is used for gas centrifuge (O_{411}), gaseous diffusion (O_{412}), aerodynamic (O_{413}), and molecular laser (O_{414}); O_{42} is used for electromagnetic (O_{421}), chemical exchange (O_{422}), and ion exchange (O_{423}); O_{43} is used for atomic vapour laser (O_{431}), and plasma (O_{432}). Finally, each sub-factor is determined by many indicators including especially designed and dual-use equipment, nuclear and non-nuclear materials, technology/training/R&D, and so on.

Evaluation of the safeguards-effectiveness is to estimate a possibility degree to what extent the objective is attained. In this case, the assurance degree that "no attempt in a country toward to the manufacture of nuclear explosive devices" should be estimated, for instance, the assurance degrees of "No undeclared acquisition of highly enriched uranium (in short HEU)". The possibility degree of "no undeclared acquisition of HEU" can be determined by some other sub-factors, like "no diversion of declared HEU", "no undeclared import of HEU" and "no undeclared production of HEU" and so on.

Accordingly, the overall evaluation should be a multi-layer comprehensive evaluation. The resultant evaluation structure generally follows the steps that would be involved in the nuclear fuel cycle from source material acquisition to the production of weapons-usable material, and then beyond the fuel cycle to weaponization. The general evaluation structure is illustrated in Figure 4.

3.2 The strength of indicators

The physical model identifies and describes indicators for a particular process that already exists or that is under development. The indicators include nuclear and non-nuclear materials, operation specific materials, dual-use items, by-products of the process. The specificity or relevance of each indicator is attributed to a given nuclear activity, and is used to determine the importance of an indicator.

Up to 914 indicators were identified within the IAEA study throughout the whole fuel cycle, from mining to reprocessing, and they are evaluated as the strength degree, but they are in one way or another signs for on-going activities. Moreover, the specificity of each indicator has been designated to a given nuclear activity and is used to determine the strength of an indicator. An indicator that is present only if the nuclear activity exists or is under development, or whose presence is

Figure 3 Hierarchy structure of the physical model

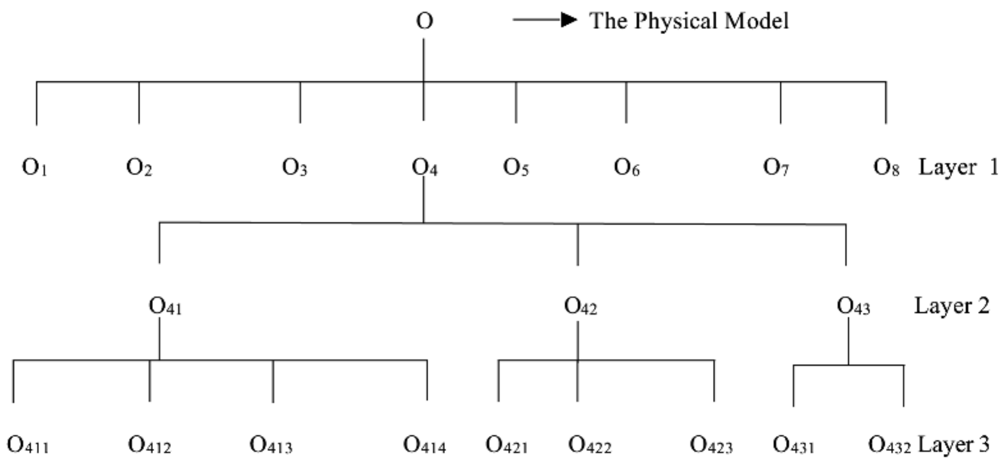
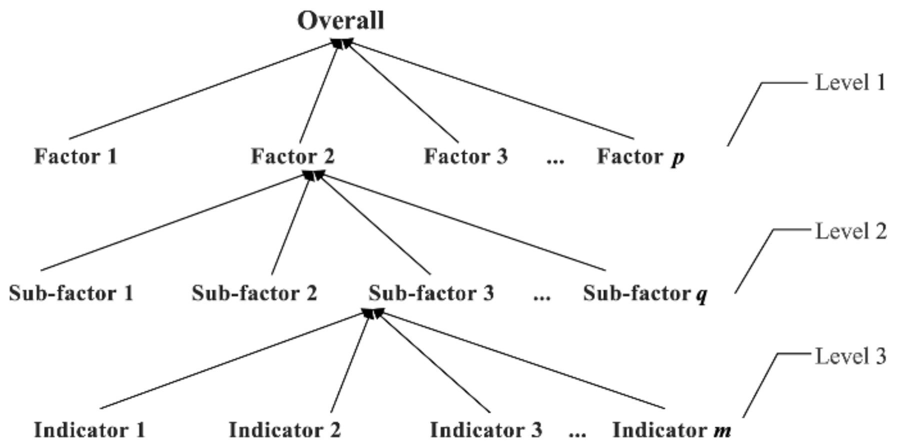


Figure 4 The structure of the overall evaluation



almost always accompanied by a nuclear activity is a strong indicator of that activity. Conversely, an indicator that is present for many other reasons, or is associated with many other activities, is a weak indicator. In between are medium indicators. In fact, the strength of an indicator should not be limited to "strong, medium and weak" but more descriptions like "very strong, very weak, somewhat strong, more or less weak, etc.". In addition, those linguistic terms, such as "approximately strong, possibly strong, and more or less strong" being incomparable, are not strictly linearly ordered.

Hence, an overall evaluation needs to take into account all the indicators related to the given process and the strength of each indicator.

3.3 Methods for evaluation of information on State's nuclear activities

As descried in section 3.1, the evaluation model is designed to include all known pathways for the production of weapons-usable material and subsequent weaponization. The structure of the model has several levels ranging from the technologies to specific facilities. Each succeeding level, depending on the order taken, is a detailed version or generalization of the previous level:

- *Level 1.* At this level the stage of processing of nuclear materials, i.e. the technologies are considered. It contains all the main activities that may be involved in proliferation. The elements of the structure of the model of this level are linked. At this level they are generalized and little suited for performing a specific analysis. This level is intended to represent the general performance of nuclear activity of a State: the level of development of technology, general directions of possible production of Pu and HEU, an overall evaluation of nuclear activity. The first level of elements of the evaluation model reflects the possible presence in a country of a specific technology. The value of any element of this level is expressed by a fuzzy linguistic variable. For example, very high possibility, low possibility, medium, etc. The value of this level will be obtained from the level 2 by using the fuzzy aggregation.
- *Level 2 (separate processes)*. At this level the links between the different technologies for processing nuclear material are clearly seen. Each activity in the top level is broken down into more specific routes or processes in this level. For example, enrichment is broken down into nine possible enrichment processes (gas centrifuge, electromagnetic, aerodynamic, gaseous diffusion, molecular laser, atomic vapor laser, plasma separation, chemical exchange, and ion exchange). The value of any element of this level reflect the State's capability to conduct a specific process at the qualitative and is expressed by a fuzzy linguistic variable. The value of this level will be obtained from the level 3 by using the fuzzy aggregation.
- *Level 3.* This is a detailed description of the level 2 and reflects the existence of specific capacity for processing nuclear materials, i.e. indicator level. The value of this level qualitatively reflects the potential of the specific facilities used by a

country to conduct a specific process for treating nuclear material at a qualitative level. The value of any element of this level reflects the possible presence or underdevelopment in a country of a specific indicator and is expressed by a fuzzy linguistic variable, which is described and provided by inspectors.

The evaluation structure for the special technology A is illustrated in Figure 5.

The proposed method gives an overall evaluation of a possibility degree to what extent the objective is attained, like undeclared acquisition of HEU, a special nuclear technology or process, under consideration of different levels, the importance of different factors in a level, the conflict in the observation by different inspector, the strength of every indicator.

Here, linguistic variables will be used to represent assurance degrees of different levels, importance degrees of every factor, as well as the strength of every indicator.

Suppose we have had some knowledge about the importance of every factor consulted and the strength of each indicator, this knowledge is based on the experience and expertise in the safeguards group.

Now we consider some more general case that the importance degree, the strength degree, and the possibility degree are all represented by lattice-valued linguistic terms and directly used in the procedure without transforming them into fuzzy number or the membership functions. We take the linguistic terms based on the lattice implication algebra.

As for the convenience to illustrate, we suppose the evaluation set is a finite lattice-valued linguistic variable set $L = \{O, a, b, c, d, M, e, f, g, h, I\}$ as given in example 2.2 in section 2.4, where the prime terms {true, false} are changed to {high, medium, low}. The complement and the implication operation are defined in Tables I and II in example 2.2 in section 2.4.

Consequently, we have the following evaluation steps.

The first step (level 3)

The first step is to obtain the possibility degree of each process P_s $(s = 1,\ldots, p)$.

At first, let $E = \{E_1, \ldots, E_q\}$ be the set of inspectors, $I_i = \{I_{1s}, \ldots, I_{ns}\}$ be the collection of indicator related to a process P_s, $A_{st} = \{a_{1s,t}, \ldots, a_{ns,t}\}$ be the set of the possibility degree of indicators, like $a_{is,t}$ $(i = 1,\ldots, n)$ is the possibility degree of the possible presence or underdevelopment in a country of a specific indicator I_{is} for the process P_s described by the inspector E_t, $W_s = \{w_{1s}, \ldots, w_{ns}\}$ be the set of the corresponding strength of indicators. $D_t(P_s)$ be the possibility degree of the process P_s by the inspector E_t. $D(P_s)$ be the consensus possibility degree of the process P_s by all inspectors. $\theta = \{\theta_1, \ldots, \theta_q\}$ be the importance weight of each inspector.

Due to this evaluation involved several inspectors, the evaluation at this level can be divided into the following two sub-steps:

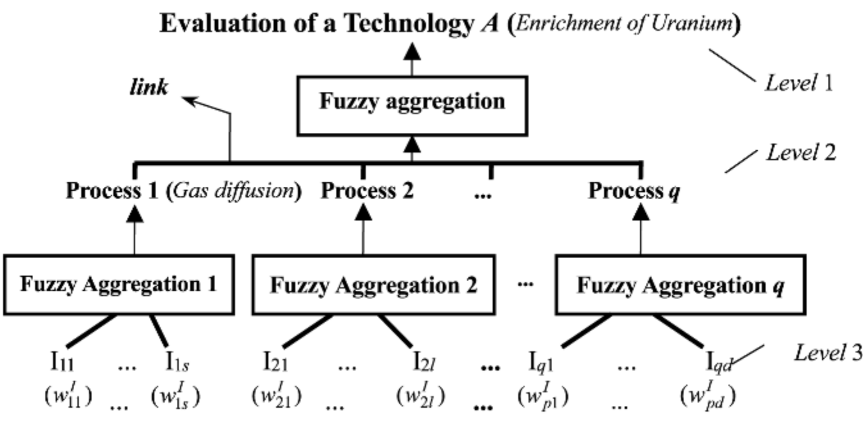
(1) *Sub-step 1:* the possibility degree of the process P_s by the inspector E_t $(s = 1,\ldots, p;\ t = 1,\ldots, q)$:

$$D_t(P_s) = \mathrm{Agg}_{i\in\{1,\ldots,n\}}(g_1(w_{is}, a_{is,t})),\quad i = 1,\ldots,n. \tag{18}$$

(2) *Sub-step 2:* the consensus possibility degree of the process P_s by all inspectors:

$$D(P_s) = \mathrm{Agg}_{t\in\{1,\ldots,q\}}(g_2(q_t, D_t(P_s))),\quad t = 1,\ldots,q. \tag{19}$$

Figure 5 The hierarchy structure of evaluation model for a technology A



For the detail discussion for this level, such as for the selection of Agg and the transformation function g_j $(j = 1, 2)$ can be seen in case study 2 in section 3.4.

Step 2 (level 2)
Considering all the process P_s $(s = 1,\ldots, p)$ corresponding to the technology A and the strength of each process as well, we have the following overall evaluation function:

$$D(P_1, \ldots, P_p) = \mathrm{Agg}_{s\in\{1,\ldots,q\}}(g_3(\lambda_s, D(P_s)), \quad s = 1, \ldots, p, \tag{20}$$

where λ_s $(s = 1,\ldots, p)$ represents the important weight of the process P_s $(s = 1,\ldots, p)$ for the technology A. $D(P_s)$ is determined by equation (19) and represents the overall possibility degree of the process P_s with different indicators. The result equation (20) is an assessment (possibility degree) of the possible presence in a country of a specific technology A.

Here, the selection of Agg and g_3 are suggested based on some practical experience.

Remarks
In the above illustration, the overall evaluation of a technology (or a general nuclear activity) can be determined by some processes (or sub-factor), and every process is determined by some different indicators with strength. We consider the relation among these processes (or sub-factors). In equation (20), we suppose that the overall result is determined by every process (or sub-factor) with different weights.

Considering the evaluation of the possibility degree of "no undeclared production of HEU" as an example. Note that "undeclared production of HEU" needs "undeclared acquisition of X". Here, X is a feed nuclear material needed for producing HEU. Generally, the feed materials are either UF_6 (F_1) or UCl_4 (F_2) or uranium metal (F_3). Hence, "Undeclared production of HEU" requires either "undeclared acquisition of UF_6" or "undeclared acquisition of UCl_4" or "undeclared acquisition of U metal".

Accordingly, high assurance of "no undeclared production of HEU" can be gained by the high assurance of "no undeclared acquisition of UF_6" and "no undeclared acquisition of UCl_4" and "no undeclared acquisition of U metal".

In this case, the overall evaluation should be the intersection of the evaluation of every factor.

Moreover, these factors are determined by many sub-factors like F_1 is used for some processes: gas centrifuge (F_{11}), gaseous diffusion (F_{12}), aerodynamic (F_{13}), molecular laser (F_{14}); Similarly, each one contributes to the production of $F_1(UF_6)$. It seems they have the same weights. In this case, the overall evaluation of the possibility degree of "no undeclared production of UF_6" should be the intersection of the evaluation of each process.

Consequently, in equation (20), we can suppose that the overall result is the intersection of every factor (or sub-factor) with different important weights. Hence, the aggregation operation Agg can be taken as "and" operation. In a special case as "$\wedge$" given in section 2.2, i.e.:

$$D(P_1, \ldots, P_p) = \wedge_{s\in\{1,\ldots,q\}} (g_3(\lambda_s, D(P_s)), \quad s = 1, \ldots, p, \tag{21}$$

where g_3 can be taken as the I_b (Kleene-Dienes implication) and the I_a(Łukasiewicz implication in the case of the linear ordered linguistic terms and taken as the implication operation in the LIA in the case of lattice-valued linguistic terms based on the LIA.

However, in some real cases, the overall evaluation should be the unification of the evaluation of every factor (or sub-factor) with the same weights. For instance, the high assurance of "undeclared acquisition of HEU" is determined by the high assurance of "diversion of declared HEU" or "undeclared import of HEU" or "undeclared production of HEU". The overall evaluation can be determined by one of some factors, every factor is also determined by one of some sub-factors with different indicators, i.e. each one is enough to contribute to the overall result. In this case, equation (20) can be changed into the following one:

$$D(P_1, \ldots, P_p) = \vee_{s\in\{1,\ldots,q\}}(g_3(\lambda_s, D(P_s)), \quad s = 1, \ldots, p, \tag{22}$$

where g_3 can be taken as the $T_\wedge$ (minimum) and T_a (bounded difference) in the linearly ordered case and taken as the $\otimes$ in LIA in the lattice-valued case.

Consequently, the aggregation operation Agg in equation (20) can be taken according to the different practical situations.

3.4 Case study for the evaluation of safeguards information based on the physical model

Evaluation of the nuclear process is to estimate an possibility degree to what extent the objective is attained. At the lowest level, the value of possibility degree, which reflects the capacity of "no conducting a specific process at a given nuclear facility" should be firstly evaluated. It depends on the possibility degree of "no abnormal indicator exists", which is observed or determined by the inspectors. Here fuzzy linguistic variables are used to characterize the possibility degree and the strength weights.

Every indicator could be inspected or described by different inspectors. Therefore it is desirable to have assurances that the different experts describe the same object in the most "uniform" way.

Based on the above analysis, we now introduce the multi-criteria, multi-expert evaluation method to get the overall linguistic value of possibility degree for a given process with consideration of information about all indicators related to this process evaluated by several inspectors, as shown in Table VI.

Here $E = \{E_1, \ldots, E_p\}$ represents the inspectors, $\theta = \{\theta_1, \ldots, \theta_p\}$ represents the importance weight of each inspector, $I = \{I_{s1}, \ldots, I_{st}, I_{m1}, \ldots I_{mr}, I_{w1}, \ldots, I_{wk}\}$ represents the indicators related to the process P, $a_{i,j}$ denotes the possibility degree value of the indicator I_i by an inspector E_j, F_s represents the set of all *strong* indicators related to the process P, F_m represents the set of all medium indicators related to P, and F_m represents the set of all weak indicators related to P. $W = \{w_s, w_m, w_w\}$ represents the strength of indicators. $D_i(P)$ means the overall possibility degree of F_sF_m, and F_m by the inspector E_i under consideration of the strength of indicators. $D(P)$ means the overall assurance of $D_i(P)$ under consideration of the importance of each inspector.

Specially, we assume that the linguistic term evaluation set $L$for the possibility degree, the importance degree of inspectors and the strength of indicators is:

$$L = \{\text{none, very low, low, medium, high, very high, perfect}\}.$$

The procedure will be summarized as follows:

- *Step 1.* Classification of indicators related to a given process P according to the different strength, i.e. the indicators are divided into three classes, i.e. F_s, F_m, and F_w.
- *Step 2.* Aggregation of the indicators within each class. For class 1 (aggregation of F_s), the strength of each indicator is strong. According to the assumptions on strong indicators, we can use the min-type un-weighted aggregation operator in equation (1). It is intuitive to aggregate the value on the premise of "minimum possibility degree". Hence we have:

$$D_i(F_s) = \min(a_{s1,i}, a_{s2,i}, \ldots, a_{sp,i}), \quad (23)$$

where $a_{sj,i}$ means the possibility degree of $I_{sj,i}$.

For class 2 (aggregation of F_m), the strength of each indicator is medium. According to the assumptions about medium indicators, we can use the median-type un-weighted aggregation operator by equation (16). It is intuitive to aggregate the value on the premise of "medium possibility degree":

$$D_i(F_m) = \text{med}\,(a_{m1,i}, a_{m2,i}, \ldots, a_{mq,i}). \quad (24)$$

For class 3 (aggregation of F_w), due to the great number of indicators, the LOWA or WOWA operator understates the aggregation value, and from the assumption about the weak indicators, we use the max-type aggregation operator in equation (2). It is intuitive to aggregate the value on the premise of "maximal possibility degree",, i.e.:

$$D_i(F_w) = \max(a_{w1,i}, a_{w2,i}, \ldots, a_{wr,i}). \quad (25)$$

Table VI Multi-expert, multi-indicator (classified) evaluation matrix for a process P

		θ_1 E_1	θ_2 E_2	θ_3 $E3$	... ...	θ_p E_p
$F_s(w_s)$	I_{s1}	$a_{s1,1}$	$a_{s1,2}$	$a_{s1,3}$	...	$a_{s1,p}$
	I_{s2}	$a_{s2,1}$	$a_{s2,3}$	$a_{s2,3}$	...	$a_{s2,p}$
	...	...	...	...	...	...
	I_{st}	$a_{st,1}$	$a_{st,2}$	$a_{st,3}$	...	$a_{st,p}$
$F_m(w_m)$	I_{m1}	$a_{m1,1}$	$a_{m1,2}$	$a_{m1,3}$	...	$a_{m1,p}$
	I_{m2}	$a_{m2,1}$	$a_{m2,2}$	$a_{m2,3}$	...	$a_{m2,p}$
	...	...	...	...	...	...
	I_{mr}	$a_{mr,1}$	$a_{mr,2}$	$a_{mr,\ 3}$	...	$a_{mr,\ p}$
$F_w(w_w)$	I_{w1}	$a_{w1,1}$	$a_{w1,2}$	$a_{w1,3}$	...	$a_{w1,p}$
	I_{w2}	$a_{w2,1}$	$a_{w2,2}$	$a_{w2,3}$	...	$a_{w2,p}$
	...	...	...	...	...	...
	I_{wk}	$a_{wk,1}$	$a_{wk,2}$	$a_{wk,\ 3}$	...	$a_{wk,\ p}$
		$D_1(P)$	$D_2(P)$	$D_3(P)$	...	$D_p(P)$
				$D(P)$		

- *Step 3.* Aggregation of F_s, F_m, and F_w considering the corresponding strength weights. We use the weighted min-type weighted aggregation operator in equation (1), It is intuitive to aggregate the value on the premise of "minimum possibility degree under consideration of the strength",, i.e.:

$$D_i(P)_{\min} = \min(w_s \to D_i(F_s), w_m \to D_i(F_m), w_w \to D_i(F_w)), \quad (26)$$

  where $\to$ is I_b (not selecting I_a, which can be explained in the following remarks). On the other hand, we can also use the weighted median aggregation operator by equation (17) (where $\to$ can be taken as I_b, T is taken as min on L) to get the final possibility degree $D_i(P)_{\text{med}}$. It is intuitive to aggregate the value on the premise of "medium possibility degree under consideration of the strength".
- *Step 4.* Aggregation of several inspectors" opinions. Steps 1-3 are the procedure to get the overall possibility degree by each inspector. In this step, we consider the group evaluation about the possibility degree of process P with consideration of different importance weight of every inspector. Obviously, unlike steps 1-3, the min or max aggregation operator will overstate fused value due to the lose of too much information. It should be a consensus degree of all inspectors. To do this, we use the weighted median aggregation operator by equation (17) (where $\to$ can be taken as I_b, T is taken as min on L) to get the final consensus degree $D(P)_{\text{med}}$.

As an example, let it be required to evaluate the possibility degree of "no conducting a specific process gaseous diffusion enrichment" within the evaluation of production of highly enriched uranium (in short HEU)" as shown in Table VII based on the formulation from steps 1-4.

Remarks

First, in the median aggregation by equation (17), we use the med(C)=min(lower median, upper median) with the intuitive means of the minimum possibility degree.

Second, we consider the aggregation process of F_w. If there exists $a_w i j = s_6$ by the inspector E_j, then the max-type aggregation operator is also not suitable for F_w. Because in this case $D_j(F_w)$ and even $w_w \to D_j(F_w)$ are always equal to s_6, it means F_w will not effect the fused value $D_j(P)_{\min}$. Hence in this extreme case, we should use the median aggregation operator for $D_i(F_w)$.

Third, when the possibility degrees of indicators are taken as the extreme values, like s_0 or s_6, what is the role of strong indicator plays on the overall fused value $D_i(P)$?

- *Case 1.* If there exists $a_{si,j} = s_0$ by the inspector E_j, then from equation (23), $D_j(F_S) = s_0$. Due to the logical relation between the strong indicator and the process P, we can directly conclude that $D_j(P) = s_0$. Moreover, note that:

$$w \to a = s_0 \text{ if and only if } w = s_6 \text{ and } a = s_0,$$

  holds for both I_b and I_a, the "min" in equation (23) cannot be suitable for $D_i(P)$ in this extreme case. For example:

$$\min(s_4 \to_L s_0, s_3 \to_L s_0, s_2 \to_L s_0) = \min(s_2, s_3, s_4) = s_2,$$

$$\min(s_4 \to_K s_0, s_3 \to_K s_0, s_2 \to_K s_0) = \min(s_2, s_3, s_4) = s_2.$$

  It does not seem reasonable.
- *Case 2.* If $a_{si,j} = s_6$ for all i obtained by the inspector E_j, then from equation (25), $D_j(F_S) = s_6$. Due to the logical relation between the strong indicator and the process P, we can directly conclude that $D_j(P)_{\min} = s_6$. Moreover, note that $x \to s_6 = s_6$ for any x for both I_b and I_a. Hence in this extreme case, it is not suitable and not necessary to use equation (23), e.g.:

$$\min(s_4 \to s_6, s_3 \to s_6, s_2 \to s_0) = \min(s_6, s_6, s_4) = s_4.$$

  It does not seem reasonable.

These two cases also hold for the weighted median aggregation operator for $D_i(P)_{\text{med}}$.

Fourth, on the one hand, there is an order: $I_b < I_a$, and we have the intuitive assumption to aggregate the value on the premise of "minimum possibility degree" for $D_i(A)$. On the other hand, I_b does not satisfy the bounded condition about the implication. This condition is not suitable for the application here. Considering the following examples:

$$\min(s_4 \to_a s_4, s_3 \to_a s_4, s_2 \to_a s_5) = \min(s_6, s_6, s_6) = s_6.$$

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Table VII Evaluation of the process P (gaseous diffusion enrichment)

		s_3 E_1	s_5 E_2	s_4 E_3	s_2 E_4
$F_s(s_4)$	Compressor for pure UF6	s_1	s_1	s_3	s_5
	Gaseous diffusion barrier	s_5	s_4	s_3	s_5
	Heat exchanger for cooling pure UF6	s_4	s_2	s_5	s_5
$D(F_s)$		s_1	s_1	s_3	s_5
$F_m(s_3)$	Diffuser housing/vessel	s_2	s_2	s_4	s_2
	Gas blower for UF6	s_2	s_1	s_1	s_1
	Rotary shaft seal	s_3	s_2	s_4	s_2
	Special control value (large aperture)	s_2	s_1	s_4	s_1
	Special shut-off value (large apertue)	s_5	s_2	s_3	s_1
	Chlorine trifluoride	s_2	s_1	s_4	s_1
	Nickel powder, high purity	s_1	s_1	s_2	s_1
$D(F_m)$		s_2	s_1	s_4	s_1
$F_w(s_2)$	Gasket, large	s_1	s_2	s_4	s_1
	Feed system/product and tails withdrawal	s_0	s_2	s_1	s_3
	Expansion bellows	s_6	s_5	s_5	s_4
	Header piping system	s_4	s_2	s_5	s_3
	Vacuum system and pump	s_2	s_1	s_0	s_1
	Aluminium oxide powder	s_1	s_1	s_1	s_2
	Nickel powder	s_3	s_2	s_5	s_3
	PTFE (teflon)	s_2	s_2	s_2	s_1
	Large electrical switching yard	s_2	s_5	s_4	s_4
	Large heat increase in air or water	s_5	s_2	s_5	s_3
	Larger specific powder consumption	s_3	s_2	s_4	s_5
	Larger cooling requirements (towers)	s_2	s_0	s_1	s_0
$D(F_w)$		s_6	s_5	s_5	s_6
$D_E(P)_{\min}$ (minimum case)		s_2	s_2	s_3	s_3
$D(P)_{\min}$			s_2		
$D_E(P)_{\text{med}}$ (median case)		s_2	s_2	s_3	s_3
$D(P)_{\text{med}}$			s_2		

This result does not seem reasonable.

$$\min(s_4 \rightarrow_b s_5, s_3 \rightarrow_b s_4, s_2 \rightarrow_b s_5) \\ = \min(s_5, s_4, s_5) = s_4.$$

It seems reasonable. Hence in this case study, I_b is more suitable than I_a.

Fifth, here we only consider the three possible cases for the aggregation on F_s, F_m, F_w, two cases for $D_i(P)$ as well as one case for $D(P)$. There are still other cases that can be considered based on different application assumptions.

4. Conclusions

To manipulate the linguistic information of nuclear safeguards indicators, we worked with aggregation operators for combining the linguistic un-weighted and weighted values by the direct computation on labels, which may be linear-ordered or lattice-ordered. We presented the multi-criteria, multi-expert evaluation method to get the overall linguistic assurance value for a given process, taking into account the particular nature of the indicators and the specific differences among the experts" activities through the aggregation process. The approach is computationally simple and quick. A case study on the application of these aggregation operators to the fusion of safeguards relevant information is given. A sensitivity study is made to detect in what sense the overall assessment is influenced by the choice of the aggregation operators.

By using this evaluation model of states' nuclear activities, we can assess, in a qualitative level, the states' capabilities on processing nuclear materials. If we focus on the indicators of undeclared nuclear activities, then we can get an assurance of undeclared nuclear activities or misuse of declared facilities in a state.

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Supplier selection using activity-based costing and fuzzy present-worth techniques

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Keywords

Supplier evaluation, Fuzzy logic, Modelling, Activity based costing, Cash flow

Abstract

The relationship between a supplier and a purchaser is one of the most essential issues for viability of both sides. The well-built relationship is especially related to the healthy selection of suppliers. The changing customer preferences also make this selection process important. Many different selection approaches have been published in the purchasing literature. In these studies, the working conditions of suppliers and purchasers and selection criteria are considered constant and precise at the beginning of the selection process by the purchaser during the relationship period. However, this selection process should be considered dynamically because of the changing working conditions of supplier-purchaser and lifecycle of the product or a project. Therefore, the relationship between suppliers and purchasers is multi-period and the factors that affect the selection process are considered as fuzzy parameters in this study. The activity-based costing (ABC) approach is used for selection method.

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Introduction

In this study, we proposed a method for vendor selection using activity-based costing (ABC) approach under the fuzzy variables by considering multi-period of supplier-purchaser relationship. The suppliers play an important role in the production chain and in the long-term viability of a company. With the increasing significance of the purchasing function, purchasing decisions become critical in the profitability of a company. Changing customer preferences, environmental concerns, government regulations, globalization of trade, internet and spreading of purchasing function are the developments which have impact on the complexity and the importance of purchasing decisions (de Boer *et al.*, 2001).

While the criteria selection and evaluation the vendors change from firm to firm, traditional supplier selection problems are based on only invoice cost. Many decision makers used countable and uncountable criteria such as quality, delivery, flexibility, cost, and response in the selection and evaluation process in the following studies. The main questions in the determination of the criteria on the selection process are the needs of the firm in its practice and the level of the success of the selection criteria to fulfill these needs (Swift Owens, 1995; Brown, 1998)

A classification of vendor selection models can be made mainly as single item and multiple items models. Subclasses of this classification are the models which take into account inventory management over time and which ignore it. Rating/linear weighting, mathematical programming, total cost approaches and statistical methods are the approaches used in the selection problems in the literature (Degraeve *et al.*, 2000, de Boer *et al.*, 2001).

In basic linear weighting models, weights are given to the criteria according to the importance. A larger weight indicates a higher importance. Then the ratings of the criteria are multiplied by their weights and the supplier with the highest score is selected. Total cost models select the vendors in line with the all quantifiable cost incurred throughout the purchasing cycle. Given an appropriate decision setting, mathematical programming approaches allow the decision makers to formulate the decision problem in

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terms of a mathematical objective function that subsequently needs to be maximized (maximize profit) or minimized (minimize cost) by varying the values of the variables in the objective function. Statistical models deal with uncertainty related to the vendor selection.

There are several advantages of the use of an ABC system for vendor selection and evaluation, not only for the purchasing company but also for the supplier. Roodhooft and Konings (1996) listed these advantages as follows:

- The purchasing company is able to see the internal production costs caused by the vendor and quantify the non-financial criteria.
- It offers an alternative approach for the multi-objective optimizing problem.
- Since the system allows identifying relative importance of cost components, the purchasing company can design different scenarios by reducing the different cost drivers.
- The system allows the vendor to review its strategy by the objective indication of customer's satisfaction and the different importance of criteria involved in the purchasing process.
- The system offers improvement of the relationships between vendor and purchaser.

In the literature, the length of supplier-purchaser relationship is always considered (as) one phase for vendor selection process. In other words, the conditions of working with the selected vendor are assumed to be unchanged along the supplier-purchaser relationship. However, the life cycle of a product in the market and the changing conditions of vendors imply that the selecting process should be considered multi-period. In this study by considering these changes, we divided the length of supplier-purchasing relationship into N periods using the fuzzy variables and an ABC approach. The criteria quality, selling price, delivery time and quantity are taken into account during the selection process. These criteria are assumed to vary during the N period for m vendors. The present worth of costs incurred by each vendor for each period are calculated by employing capital budgeting. Then the vendor with the smallest cost is selected.

Fuzzy sets

In real life, the modeling process of many phenomena may not be performed sufficiently and exactly, because the available data and information are vague, inexact, imprecise and uncertain by nature. The decision making process dealing with the modeling phenomenon should be based on these uncertain and ill-defined information. The fuzzy set theory offers a natural tool for these sorts of data.

In fuzzy set theory, the variables have a membership function that represents uncertainty. A membership function is defined from universe of discourse to [0,1]. This function depends on the problem and the decision makers. If such a function can be identified, the information contained in this function can be very useful in the decision making process.

A fuzzy subset of a universe X is always determined by a membership function $\mu_A(x)$ which maps each element of X to a real number in the interval [0,1].

A fuzzy subset A of a universal set R is called a fuzzy number if $\exists x_0 \in R$, $\mu_A(x_0) = 1$ and $\forall \alpha \in [0,1]$, $A_\alpha = x|\mu_A(x_0) \geq \alpha\}$ is a closed interval.

A triangular fuzzy number is a fuzzy number with its membership function:

$$\mu_A(x) = \begin{cases} \frac{x-a}{b-a}, & x\in[a,b] \\ \frac{x-c}{b-c}, & x\in[b,c] \\ 0, & \text{otherwise} \end{cases} \tag{1}$$

where $a \leq b \leq c$, a and c stand for the end points of A. The triangular fuzzy number can be characterized by (a,b,c) in which $\mu_A(b) = 1$.

This representation is useful for arithmetic operation on fuzzy numbers. With this notation, the arithmetic operations on fuzzy numbers are defined as follows.

Let $A_1 = (a_1, b_1, c_1)$ and $A_2 = (a_2, b_2, c_2)$ be positive triangular fuzzy numbers, then (Klir *et al.*, 1997):

Addition:

$$(a_1, b_1, c_1) \oplus (a_2, b_2, c_2) = (a_1 + a_2, b_1 + b_2, c_2 + c_2), \tag{2}$$

Substraction:

$$(a_1, b_1, c_1)\ \Theta\ (a_2, b_2, c_2) = (a_1 - c_2, b_1 - b_2, c_1 - a_2), \tag{3}$$

Multiplication:

$$(a_1, b_1, c_1) \otimes (a_2, b_2, c_2) \cong (a_1.a_2, b_1.b_2, c_1.c_2), \quad (4)$$

$$(k, k, k) \oslash (a_2, b_2, c_2) = (ka_2, kb_2, kc_2), k \in R^+, \quad (5)$$

Image:

$$(a_1, b_1, c_1)^{-1} \cong (1/c_1, 1/b_1, 1/a_1), \quad (6)$$

Division:

$$(a_1, b_1, c_1)(a_2, b_2, c_2) \cong (a_1/c_2, b_1/b_2, c_1/a_2) \text{ if } a_1 \geq 0, a_2 > 0. \quad (7)$$

In vendor selection process, a decision maker should decide to have the lowest total present cost represented by the triangular fuzzy numbers. Therefore, a method to rank the fuzzy triangular numbers is required. The total integral value method for ranking fuzzy numbers is one of the several ranking methods in the literature. The total integral value of a triangular fuzzy number $A = (a, b, c)$ is defined as:

$$\delta^{\alpha}(A) = 1/2[\alpha c + b + (1 - \alpha)a], \alpha \in [0, 1].$$

Here, α is an optimism index representing the degree of optimism of the decision maker. For two given fuzzy numbers A_i and A_j:

- If $\delta_T^{\alpha}(A_i) < \delta_T^{\alpha}(A_j)$ then $A_i < A_j$.
- If $\delta_T^{\alpha}(A_i) = \delta_T^{\alpha}(A_j)$ then $A_i = A_j$.
- If $\delta_T^{\alpha}(A_i) > \delta_T^{\alpha}(A_j)$ then $A_i > A_j$.

The lower values of A_i, the higher appropriateness of the decision alternative to the decision criteria (Moon and Kang, 2001).

Fuzzy cash flows analysis

Suppose that $\mu_{A_j}(x)$ is a membership function of triangular fuzzy number (TFN), $A_j = (A_{ja}, A_{jb}, A_{jc})$, and r is a positive triangular fuzzy number denoted by $r = (r_a, r_b, r_c)$. Equation (8) is used to derive the present worth of the fuzzy cash flows, where $\mu_{PW}(A_j)$ is the membership function of the present worth of the N period fuzzy cash flows and r is the fuzzy periodic interest rate.

$$\mu_{PW}(x) = \mu_{A_0}(x) + \left((\mu_{A_1}(x) * (1 + \mu_r(x)^{-1})\right) + \cdots + \left((\mu_{A_{N-1}}(x) * (1 + \mu_r(x)^{-(n-1)})\right). \quad (8)$$

If A_j is positive, PW of A_j can be given as:

$$PW(A_j) \cong \left(\frac{A_{ja}}{(1 + r_c)^j}, \frac{A_{jb}}{(1 + r_b)^j}, \frac{A_{jc}}{(1 + r_a)^j}\right). \quad (9)$$

If A_j is negative, PW of A_j can be given as:

$$PW(A_j) \cong \left(\frac{A_{ja}}{(1 + r_a)^j}, \frac{A_{jb}}{(1 + r_b)^j}, \frac{A_{jc}}{(1 + r_c)^j}\right). \quad (10)$$

Two representations of fuzzy numbers can be put together by using the maximum and minimum operators. The present worth of all fuzzy cash flows is obtained as (Karsak and Tolga, 2001; Kahraman, 2001; Kahraman *et al.*, 2002):

$$PW(A_j) \cong \left(\sum_{j=1}^{N-1}\left[\left(\frac{\max(A_{ja}, 0)}{(1 + r_c)^j} + \frac{\min(A_{ja}, 0)}{(1 + r_a)^j}\right)\right], \sum_{j=1}^{N-1}\frac{A_{jb}}{(1 + r_b)^j}, \sum_{j=1}^{N-1}\left[\frac{\max(A_{jc}, 0)}{(1 + r_a)^j} + \frac{\min(A_{jc}, 0)}{(1 + r_c)^j}\right]\right). \quad (11)$$

Vendor selection using ABC for multi-period project incorporating fuzzy data

In this study, we analyze the vendor selection problems by dividing the supplier-purchasing relationships into N periods. The reasons of considering this approach are:

- There is a life cycle for the product following the purchase of raw materials from the vendor.
- The demand is varying and uncertain in each period along the product's life cycle.
- These demand differences and uncertainties cannot be responded identically by each vendor in the different phases. For example; If a vendor changes its production process in the future, you can not select the vendor in accordance to the actual product quality, delivery time and quantity performance. In other words, the actual performance of the vendor wouldn't be the same in the following periods.

In the multi-period working conditions, the content of ordered reasons in the previous paragraph should be taken into account under uncertainty conditions. Therefore, the parameters such as quality, delivery time and

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quantity used in computing total cost for each vendor are considered fuzzy numbers.

The occurred cost in the event that a vendor cannot meet the purchaser's request in accordance to the criteria will be calculated by the total cost approach. According to the total cost approach; Present total cost is obtained by adding the present purchasing cost to the present activity cost as follows:

$$\mu_{PTC}(x)_i^B = \mu_{PPC}(x)_i^B + \mu_{PAC}(x)_i^B, \qquad (12)$$

where:

$\mu_{PTC}(x)_i^B$ = membership function of budgeted present total cost caused by the ith vendor.

$\mu_{PPC}(x)_i^B$ = membership function of budgeted present purchasing cost for the ith vendor.

$\mu_{PAC}(x)_i^B$ = membership function of budgeted present activity cost caused by the ith vendor.

An ABC system starts with process value analysis (PVA). After the detailed examinations of PVA are completed, the activities are identified. Then, resources (expense categories) are determined and these resources are separated to direct costs and overhead costs. After separating the resources, the cost drivers are determined to distribute the overhead costs to the activities and to trace overhead costs related to these activities. Finally, overhead costs per unit cost driver are applied to cost objects.

The present purchasing cost is computed by the formula:

$$\mu_{PPC}(x)_i^B = \sum_{j=0}^{N-1} \frac{\mu_{P_{ij}}(x)\mu_{Q_j}(x)}{\left(1+\mu_R(x)\right)^j}, \qquad (13)$$

and the present activity cost is obtained as:

$$\mu_{PAC}(x)_i^B = \sum_{j=0}^{N-1} \sum_{k=1}^{M} \frac{\mu_{C_{jk}}(x)\mu_{D_{ijk}}(x)}{\left(1+\mu_R(x)\right)^j}, \qquad (14)$$

where:

$\mu_{P_{ij}}(x)$ = membership function of the selling price ith vendor for jth period.

$\mu_{Q_j}(x)$ = membership function of units purchased for jth period.

$\mu_R(x)$ = membership function of interest rate.

$\mu_{C_{jk}}(x)$ = membership function of the estimated cost per cost driver k for period j in the purchasing company.

$\mu_{D_{ijk}}(x)$ = membership function of the estimated units of cost driver k caused by vendor i for period j in the purchasing company.

N = project's life represented by the numbers of periods.

The purchasing company will choose that the vendor for which equation (12) is minimized. The first component of the equation (12) is the present invoice cost caused by vendor i. Present purchasing cost is calculated according to the invoice costs of each period for i. vendor with the cash flow analysis. The price, $\tilde{P}_{ij} = (p_{ija}, p_{ijb}, p_{ijc})$; the quantity, $\tilde{Q}_j = (q_{ja}, q_{jb}, q_{jc})$; and the interest rate, $\tilde{R} = (r_a, r_b, r_c)$ are all fuzzy numbers.

A second component of the equation (12) is the present activity cost consisting of the budgeted interval production costs caused by vendor i. The cost per cost driver, $\tilde{C}_{jk} = (c_{jka}, c_{jkb}, c_{jkc})$ and units of cost driver, $\tilde{D}_{ijk} = (d_{ijka}, d_{ijkb}, d_{ijkc})$ are all triangular fuzzy numbers. Besides the invoice cost, supplementary cost caused by quality, delivery and service problems is considered.

Case study

Tekno-Tv is a company operating just in time environment. The firm will select one of the TV tube suppliers among S_1, S_2, S_3 and S_4. A TV tube is very important for TV quality. If the quality requirements of the purchasing firm aren't satisfied, the production will stop and TV set sales decrease with the cease of production.

Tekno-Tv will expect extra costs if the product delivery time increases. In this situation, the purchasing firm should prepare its product line for a different product. The product line must be organized over again according to the number of delayed TV tubes. Hence, each delay results in one planning activity and two setups. The shortages in the delivery quantity cause two setups and one planning activity that increase the product delivery time. Moreover, the completion of the shortcomings of the delivery quantities in dispatches causes one reception activity and one administrative activity. The activities due to the shortages are displayed in Table I (Roodhooft and Konings, 1996).

Tekno-Tv will make a strategic plan to position a new type TV set in the market. Therefore, the supplier selection will be made for four periods with one year interval.

Table I Occurring activities due to the shortages of the criteria

Criteria	Activities
Delayed delivery	Two setups
	One planning activity
Quantity trouble	One planning activity
	Two setups
	One reception activity
	One administrative activity
Quality trouble	One production stop

Vendor's estimated performance of product quality, delivery time and quantity are given in Table II as fuzzy data. Table II displays all information about performance of vendors and is formed by interviewing with vendors and taking information from the market. Each vendor's performance is different for each period. For example; vendor S_1 presents better conditions in the second period than the first period according to the delivery time and quality requirements, however there is deterioration in the delivery quantity performance in the third period. The reasons of the vendor's performance differences in each period may be the changes in the production process, variability in the expected demand from the other customers, market situation, vendor's vision and mission. Therefore, the expected sale price can differentiate for each vendor and each period as displayed in Table III.

Activities related to cost driver (D_k) in the ABC vendor selection model and cost driver rates (C_{jk}) for each period are listed in Table IV. This table is formed by the information about estimated changes in production process, the expected increment of personnel salaries and purchasing firm strategies.

Table III Estimated fuzzy sale price of for each vendor in each period

Vendors	Period 1	Period 2	Period 3
S_1	(50,53,56)	(52,55,58)	(53,57,61)
S_2	(52,55,58)	(53,56,59)	(53,57,61)
S_3	(48,51,54)	(50,53,56)	(49,53,57)
S_4	(49,52,55)	(49,52,55)	(51,55,59)

Purchasing department of Tekno-Tv is planning to place "about 50" orders for TV tubes during the first period, "about 150" TV tubes for the second period and "about 50" TV tubes for the third period. These linguistic variables are quantified as triangular fuzzy numbers. The purchasing firm orders 100 parts for each order which is constant and crisp for each period. Interest rate is considered as a triangular fuzzy number during the all periods. Order quatity and interest rate for each period are shown in Table V.

In Table VI, we calculate the activity cost components according to each performance criterion for all suppliers. This table is formed by considering Table II and Table IV. For instance; the value of exceeded delivery date for vendor S_1 in the second period is obtained by multiplying the cost driver rates and the estimated units of cost drivers. Exceeded delivery date requires two setups and one planning activity. Therefore, the vendors" cost is calculated as follows:

$$(2,2,2)\times(1000,1100,1200)\times(4,6,8)$$
$$+(650,700,750)\times(4,6,8)$$
$$=(10600,17400,25200).$$

The present purchasing costs and the present activity costs are demonstrated in Table VII.

Table II Vendor's fuzzy performance according to the criteria in each period

Vendors	Criteria	Period 1	Period 2	Period 3
S_1	Delayed delivery	(6,8,10)	(4,6,8)	(3,5,7)
	Quantity trouble	(1,3,5)	(1,3,5)	(2,4,6)
	Quality trouble	(200,250,300)	(150,200,250)	(150,200,250)
S_2	Delayed delivery	(3,5,7)	(5,7,9)	(3,5,7)
	Quantity trouble	(3,5,7)	(4,6,8)	(1,3,5)
	Quality trouble	(400,450,500)	(400,450,500)	(250,300,350)
S_3	Delayed delivery	(1,3,5)	(6,8,10)	(4,6,8)
	Quantity trouble	(4,6,8)	(7,9,11)	(6,8,10)
	Quality trouble	(100,150,200)	(300,350,400)	(300,350,400)
S_4	Delayed delivery	(1,3,5)	(1,3,5)	(2,4,6)
	Quantity trouble	(5,7,9)	(6,8,10)	(6,8,10)
	Quality trouble	(300,350,400)	(200,250,300)	(300,350,400)

Table IV Cost drivers and estimated fuzzy cost driver rates for Tekno-Tv in each period

		Cost driver rate		
Activity	**Cost driver**	**Period 1**	**Period 2**	**Period 3**
Planning	Production order	(600,650,700)	(650,700,750)	(650,700,750)
Reception	Delivery	(500,550,600)	(600,650,700)	(600,650,700)
Production stop	Stop	(200,225.250)	(200,225,250)	(230,250,270)
Setting up	Setup	(800,900,1000)	(1000,1100,1200)	(1000,1100,1200)
Administration	Invoice	(300,330,360)	(320,350,370)	(350,380,410)

Table V Order quantity and interest rate for each period

	Period 1	**Period 2**	**Period 3**
Order quantity	(40,50,60)	(120,150,180)	(40,50,60)
Interest rate	(10,11,12)	(10,11,12)	(10,11,12)

These values are computed by equations (13) and (14). Present total cost (PTC) is the summation of present purchasing cost (PPC) and present activity cost (PAC). According to this table, PPC values of vendor S_3 and S_4 are less than the other vendors, however vendor S_1 has the least PAC value.

In Table VIII, we calculated total integral value for fuzzy PTC value of each alternative vendor. Since the ranks of decision alternatives may be changed according to the degree of optimism of decision makers, the total integral value for fuzzy PTC value is calculated for three different values of α in order to examine the effect of the degree of optimism on the ranks of the decision alternatives. It is noticed that regardless of optimism index value of the decision maker, the ranks of the decision alternatives don't change. Hence, S_1 with the minimum total integral value is selected by the decision maker.

While we were analyzing PPC and PAC values of vendors, we got some remarkable results. The selected vendor S_1 has greater purchasing and activity costs than S_3 for the first period, however, the following periods S_1

Table VIII Total integral value and rank for various values of optimism index α

	Optimism index of decision maker		
Vendors	**Moderate ($\alpha = 0.5$)**	**Optimistic ($\alpha = 1$)**	**Pessimistic ($\alpha = 0$)**
S_1	1.465.889,18	1.268.563,84	1.663.214,52
S_2	1.614.592,85	1.408.911,53	1.820.274,16
S_3	1.490.129,34	1.295.246,90	1.685.011,79
S_4	1.598.698,55	1.392.562,03	1.804.835,08

Table VI Vendors' costs for performance criteria in each period

Vendors	**Performance criteria**	**Period 1**	**Period 2**	**Period 3**
S_1	Exceeded delivery date	(13200,19600,27000)	(10600,17400,25200)	(7950,14500,22050)
	Quantity problems	(3000,9990,18300)	(3570,11700,21150)	(7200,15720,25560)
	Quality problems	(40000,56250,75000)	(30000,45000,62500)	(34500,50000,67500)
S_2	Exceeded delivery date	(6600,12250,18900)	(13250,20300,28350)	(7950,14500,22050)
	Quantity problems	(9000,16650,25620)	(14280,23400,33840)	(3600,11790,21300)
	Quality problems	(80000,101250,125000)	(80000,101250,125000)	(57500,75000,94500)
S_3	Exceeded delivery date	(2200,7350,13500)	(15900,23200,31500)	(10600,17400,25200)
	Quantity problems	(12000,19980,29280)	(24990,3510046530)	(21600,31440,42600)
	Quality problems	(20000,33750,50000)	(60000,78750,100000)	(69000,87500,108000)
S_4	Exceeded delivery date	(2200,7350,13500)	(2650,8700,15750)	(5300,11600,18900)
	Quantity problems	(15000,23310,32940)	(21420,31200,42300)	(21600,31440,42600)
	Quality problems	(90000,115500,144000)	(64000,87500,114000)	(105000,133000,164000)

Table VII Budgeted present purchasing cost, present activity cost and present total cost for each vendor

Vendors	**PPC budgeted**	**PAC budgeted**	**PTC budgeted**
S_1	(942479, 1239556, 1559916)	(137388, 217705, 309252)	(1.079.866, 1.457.260, 1.869.168)
S_2	(961388, 1263069, 1587987)	(250421, 342945, 446547)	(1.211.809, 1.606.013, 2.034.534)
S_3	(899438, 1186296, 1496640)	(209555, 295205, 391882)	(1.108.992, 1.481.501, 1.888.522)
S_4	(899140, 1185899, 1496135)	(296272, 403813, 523823)	(1.195.412, 1.589.711, 2.019.958)

has the least cost. If we selected the vendors only according to the first period costs, we would have to select vendor S_3. In the same way, if we analyzed the selection problem by using the traditional concept and considering only purchasing cost, we would have to select S_3 providing the least sale price.

Conclusion

In this paper we have examined supplier selection problem for multi-period under the uncertainty conditions. Vendor selection process is performed by choosing the supplier who minimizes the present total additional costs associated with the purchase decision. These include price differentials and supplementary estimated internal production costs caused by the supplier in each period. After selecting the supplier, evaluation process could be done according to the supplier performance at the end of each period.

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Viability of e-commerce as an alternative distribution channel

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Keywords

Electronic commerce, Distributors, Malaysia, Semiconductors, Technology led strategy

Abstract

This paper proposes a framework for evaluating the impact of e-commerce on the roles of distributors in the semiconductor industry for four different types of products, namely differentiated products, architectural products, technological products, and complex products. Questionnaire and the purposive sampling method were used to collect data from respondents in the distribution industry. The results of the study show that the salience of the roles is increasing. In addition, there is strong likelihood of e-commerce replacing the traditional distributors, more so for less standardized products such as complex, technological, and architectural products.

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Introduction

During the past decade, organizational theorists, telecommunication managers, business consultants, have directed our attention to the strategic role that information technology can play in the competitive strategy of firms. Throughout the 1980s, the use of telecommunication networks linking firms to their suppliers and distribution chains conveyed important first mover advantages were discussed. The Internet business-to-business (B2B) space is gaining much attention, with valuation for publicly traded B2B companies escalating rapidly. Estimates for the size of this burgeoning space vary widely from Gartner Group's prediction of $7.29 trillion by 2004 to Goldman Sachs" estimation of $1.5 trillion, the future still hold great promise (A.T. Kearney, 2000a, b). Similarly, Arthur Andersen & Co. (2000) indicated that eB2B represents 84 per cent of total
e-business revenue and the growth prospects are substantial with the revenues predicted to be anywhere from $2.7 trillion to over $7 trillion in the next three years.

In the other hand, the existence of distribution channels has helped to make society more efficient in resource allocation. Most producers use intermediaries to bring their products to market. They try to forge distribution channel – a set of interdependent organizations involved in the process of making a product or service available for use or consumption by the consumer or business users (Stern *et al.*, 1996). Bagozzi *et al.* (1998) asserted that intermediary creates economics savings for the system and the savings become more dramatic as the number of producer-consumers increases. Armstrong and Kotler (2000) argued that intermediaries play an important role in matching supply and demand. Waxman (2000a, b) argued that by servicing the thousands of indirect partners who are the customers, midrange distribution adds true value.

However, one of the constantly raised questions with the emergence of e-commerce is whether the functions of traditional distribution channel will remain. Will dis-intermediation happen with the increasing popularity of e-commerce? Will distributors be able to secure their position as the channel of promoting products to users? Or how can middlemen survive when the world is becoming more and more reliant on information technology, especially e-business oriented technologies? The purpose of the study therefore, is to unveil and generate discussion of the impact of e-commerce on the roles of traditional distribution channel. Thus, it evaluates if e-commerce can be substitute to existing distribution channel for semiconductor industry, and stretches the understanding of the likelihood of market characteristics and technology novelty in impacting distribution channel's roles with the emergence of e-commerce.

Literature

The distribution industry can be considered as one of the fragmented industries whereby no firm has a significant market share and can strongly influence the industry outcome. Porter (1980) wrote that industries are fragmented for a wide variety of reasons with greatly differing implications for competing in them. Some of the underlying economic causes of fragmentation are, low overall entry barrier, absence of economies of scale or experience curve, high transportation costs, high inventory costs or erratic sales fluctuation, etc. Consequently, the industry is usually populated by a large number of small and medium-size firms. Yet, marketing channel decision is one of the critical decisions for an organization because it will intimately affect all other marketing and overall strategic decisions on how a product is to be offered in the marketplace. Stern and El-Ansary (1988) see distribution channel as a set of independent organizations involved in the process of making a product or service available for use. In most contemporary markets, mass production and consumption have lured intermediaries into the junction between buyer and seller. Alderson (1958) wrote that the goal of marketing is the matching of segments of supply and demand. Alderson argued that intermediaries provide economies of distribution by increasing the efficiency of the process.

Porter's (1985) value chain model describes primary activities such as inbound logistics, operations, outbound logistics, marketing and sales, service, etc., and distribution channel clearly plays an important role in these (safe for operations) where they also could gain competitive advantage. Researchers have credited distribution channels with the following roles: information gathering and distribution of marketing research and intelligence information (Sawhney, 2000; Sarkar *et al.*, 1995; Stern and El-Ansary, 1988); promotion (Sarkar *et al.*, 1995; Stern and El-Ansary, 1988); contact or prospecting (Sawhney, 2000; Shapiro, 1997; Sarkar *et al.*, 1995); matching (A.T. Kearney, 2000a, b; Shapiro, 1997; Bagozzi *et al.*, 1998; Stern and El-Ansary, 1988; Reibstein, 1985); negotiation (Shapiro, 1997); physical distribution (Sawhney, 2000; A.T. Kearney, 2000a, b; Shapiro, 1997; Sarkar *et al.*, 1995; Reibstein, 1985); financing (Shapiro, 1997; Stern and El-Ansary, 1988); and risk-taking (Kearney, 2000a, b; Sarkar *et al.*, 1995; Stern and El-Ansary, 1988).

Bagozzi *et al.* (1998) categorized the distribution functions into three: functions for customers; functions for producers; and functions for both customers and producers. Two forces underlie the need for intermediaries: the discrepancy of quantity (i.e. difference between the quantity typically demanded by customers and the quantity that can be produced economically by manufacturers) and the discrepancy of assortment (difference between the varieties of products typically demanded and economically produce-able varieties (Bagozzi *et al.*, 1998). Middlemen fill these needs by carrying out what Reibstein called transactional activities, physical activities, and facilitating activities (for a review, see Reibstein, 1985).

E-commerce (particularly B2B) has revolutionized and fundamentally reshaped business relationships and has caused dramatic shifts in channel power as information and communication imbalances disappear. Online exchanges are infiltrating distribution channels at an outstanding rate. As growth in the use of Internet accelerates, distributors have been warned repeatedly that they risk being cut out of the channel by aggressive Web-savvy, and purely virtual competitors. Gates (in Adelaar, 2000) opined that in recent years, it has been widely accepted that e-commerce signifies the dawn of a friction-free market; structural changes in markets, such as dis-intermediation, would occur due to the impact of electronic trade and electronic information age, albeit, Sarkar *et al.* (1995) disagrees, stating it is

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exaggeration because different outcomes are possible such as, cyber-mediation and re-intermediation. Moreover, the high fragmentation of the distribution industry, and the nature of the product sold which differs with respect to need for inspection, personal assistance needed from the expert, etc. has been challenging the view traditional channel replacement by the Internet. Instead, distributors will compete and collaborate with a new type of Internet-based company – the online exchange (OLE). Online exchanges, which are being created in almost every vertical supply chain, bring together buyers and sellers in ways that were not possible before the advent of Internet. It is believed by many that online exchanges (of the many variations of e-commerce) pose the most important strategic challenges to the traditional intermediary, whereas Fein *et al.* (1999) believe that distributors can retain an important, and enhanced place in the channel as these exchanges mature.

The issue of place retention by traditional channels or its replacement by e-commerce will depend on a number of factors chief among them being the value-added and the cost of each channel. The transaction cost theory by Coase (in Sarkar *et al.*, 1995) is an often-employed framework in the intermediaries context since it focuses on a firm's choice between internalized, vertically integrated structures, and the use of external market agents for carrying out activities that constitute its value system. In the context of channel decisions, it can be used to articulate process whereby firms either "make or buy" an intermediary function; that is, whether the firm decides to internalize the channel activity within its organizational boundaries, or whether it chooses to rely on the market (Sarkar *et al.*, 1995). In the milieu of choice between traditional channels or e-commerce, decision makers have employed the transaction cost perspective. Wigand and Benjamin (1995) examined electronic markets and the industry value chain from a transaction and transaction cost perspective. They argued that transaction cost theory helps to understand how markets and hierarchies are chosen. In free market economies, one can observe two basic mechanisms for coordinating the flow of materials and services through adjacent steps in the value chain: markets and hierarchies. Williamson (1981) further classified transactions into those that support coordination between multiple buyers and sellers (i.e. market transactions), and those supporting coordination within the firm as well as industry value chain (i.e. hierarchy transactions). Hence, the price a product is sold consists of three elements: production costs, coordination costs, and profit margin. Wigand and Benjamin (1995) suggest that the chain of market hierarchies, which bypasses the distributor, will result in a lower purchase price for the customer. Recent research by A.T. Kearney (2000a, b) showed that production costs seem to be under control, but Web-based processes can:

- save another 10-30 per cent from operating costs;
- cut cycle times by anything up to 90 per cent; and
- virtually eliminate the supply and demand mismatches that cause inventory build-ups and stock-outs.

Porter (1985) viewed value chain as a collection of activities that add value to the product or service provided. For instance, value is added when the production process takes raw materials, transforms them into finished or semi-finished products, and distributes them to customers. At each stage, a company makes profit if the price customers are willing to pay for (value-added to) the product exceeds the cost of creating the value. It has been noted that intermediaries add significant costs to the value chain, which are reflected in a higher final price of goods and services (Sarkar *et al.*, 1995). As illustrated in Benjamin and Wigand (1995), in the high quality shirts market, it would be possible to reduce the retail price by almost 62 per cent if wholesalers and retailers could be eliminated from the traditional value chain. If intermediaries will be eliminated at all, the "also runs" or "me too" intermediaries, who neither innovate nor add any tangible value are more prone to catch pneumonia when traditional channels are threatened by cold. Moreover, since the cost of creating value is a function of how well the activities in the value chain are coordinated, and integrated (Delphi Group, 2000), intermediaries who are unable to coordinate and integrate activities at reduced cost will suffer market loss to this newer marketing arrangement – the e-commerce.

Schmitz (2000) commented that the effects of e-commerce on intermediation depend on

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the characteristics of the goods under consideration. Schmitz (2000) considers high degrees of standardization, a low complexity of valuation, and ease of description as prerequisites to distribute goods via e-commerce. King and Kang (2000) indicated that product complexity is positively correlated to an e-shopper's propensity to use a vehicle other than the Internet to close a transaction. In other words, the more complex the product is, the more likely the customer is to seek information or make the purchase using a more interactive method of communication. Connors (2000) asserted that technological advances are producing many products more complex than what came before, so it is essential to get active guidance from technicians for customizing, integrating, installing, documenting, and maintaining these systems. As new technologies create new markets and opportunities, new technologies will replace older ones (Armstrong and Kotler, 2000), just as more efficient processes will take the baton from the exhausted ones. There is no gainsaying that the cycle rate of new technologies allows the distributors to bring, newer, less matured, and often more complex product lines into the mix, nonetheless, Waxman (2000a, b) holds the view that relationship with customer (common in relationship marketing) is still required even though the Internet may migrate to an order fulfillment vehicle. Manufacturers of many types of industrial goods tend to be more engineering than marketing-oriented, therefore, it is not surprising (given this orientation) that they frequently turn marketing problems to distribution specialists. This is one of the reasons why industrial products, more so than consumer products has been a particularly viable sector of wholesaling over the years (Stern and El-Ansary, 1988). Also, distribution goals depend in part on other product characteristics namely, unit value, standardization, bulkiness, complexity, stage of product life cycle (Pelton *et al.*, 1997), which affect decision about whether intermediaries should be used or which distribution channel to use. Industrial products more so than other product categories tend to be more complex, and the relevant properties are more technical in nature, which plausibly explains why "the same man who as a customer settles for plain shaving cream if he cannot find a lemon lime, will be unwilling as an industrial buyer to accept a bolt with 30 threads to the inch when his specification calls for 28 inches" (Webster, 1984).

Whilst some researchers have argued in favour of traditional channel based intermediation, others have feared its overthrow (dis-intermediation) by e-commerce. Wigand (1996) has defined dis-intermediation as the displacement of market intermediaries, enabling direct trade between sellers and buyers without agents. Schmitz (2000) wrote that the notion that e-commerce will lead to dis-intermediation seems to be widely accepted in the scientific community and well established in the popular debates. Schmitz further argued that elimination of intermediaries will have one of two causes: there is no longer a demand for the services provided by the intermediary; or the provider of these services is integrated into another company at a different step in the value chain and the service will be produced internally. According to Benjamin and Wigand (1995) when appropriate information technology can reach the consumer directly – the manufacturer can use the national information infrastructure to leap over all intermediaries. In turn, Picot *et al.* (1997) argued that with the support of information and communication technology, principals could acquire the agent's superior problem solving capabilities, thus enabling them to fulfill the originally delegated tasks on their own. In line with above argument, Pitt *et al.* (1999) reasoned that many intermediaries will die out, while new channels and new intermediaries will take their places as a result of the emergence of Internet, and the World Wide Web will change distribution like no other environmental force since the industrial revolution. Other works (e.g. Sawhney, 2000) have studied the channel impact of e-commerce and categorized richness of physical interactions in the buying process and the intensity of information in the buying process as two main factors influencing whether a company should disintermediate its channel partners.

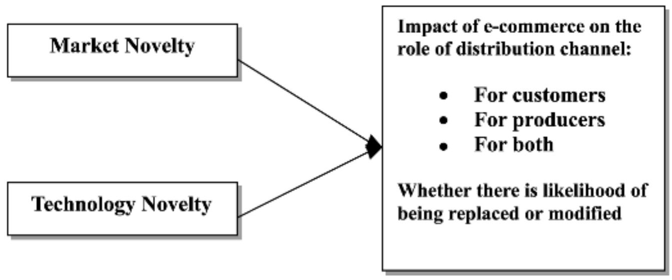
The synthesis of these divergent views is the form of collaboration between producers and channels partners with the help of advancement in information technology. Partner Relationship Management, (PRM) focuses on information that enables channels partners to quickly act on the product and customer data they receive from vendors (Connors, 2000). The PRM utilizes specialized extranets (password protected Web sites) that enable producers and their channels partners to share and jointly manage business processes to facilitate sales management and product information sharing, offering secure Web sites that afford partners access to all a producer's data – leads, profiles, and sales support documents (Connors, 2000). Survey conducted by Johnson (1999) on industrial equipment distributors unveiled that dependence, flexibility, continuity expectations, and relationship age, encouraged the distributor's strategic integration of its supplier relationship. These new intermediaries or e-marketplaces in some cases are threatening existing intermediaries, and in many other cases, they are establishing partnerships with traditional intermediaries (Weller, 2000).

In sum, some developments (e.g. increased efficiency and availability of truck transportation, increased availability and access to electronic data interchange via WWW, growth of larger retailers) threaten the overall viability of distributors, or at least limit their ability to perform certain functions profitably, whereas others create new opportunities for distributors growth and expansion, and new ways of doing business (Bagozzi *et al.*, 1998). Schmitz (2000) submits that the effects of the diffusion of e-commerce would not reduce the functions of distributors in gathering, organizing, and evaluating information, instead the informational efficiency of intermediation will prevail. Moreover, there is no indication that e-commerce would reduce the marginal efficiency gains from engaging in a principal agent relation nor increase its marginal costs to the principal. Corroborating, Amor's (2000) summation posits that the Internet has become the fourth channel for trade, after face-to-face, mail, and telephone.

Research framework and method

This study attempted to investigate the likelihood of market characteristics and technology novelty in impacting the roles of industrial distributors in the e-commerce world (see Figure 1). Based on Tidd *et al.* (1997) and Bagozzi *et al.* (1998) the research model was developed. Bagozzi *et al.*"s (1998)

Figure 1 Schema of the study model

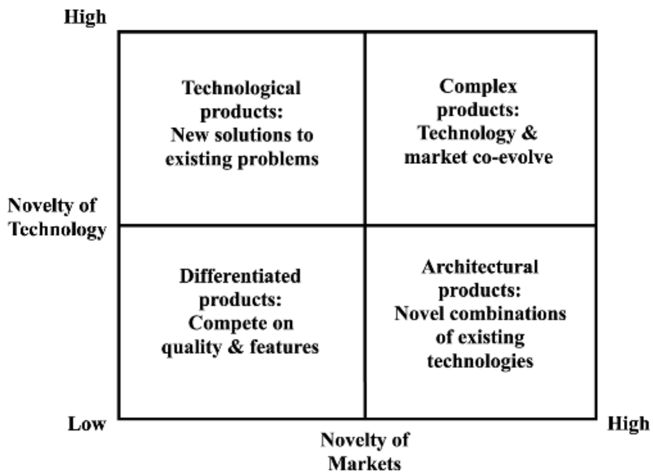


model of distribution functions was adapted to categorize distribution functions into three major groups – functions for customers, functions for producers, and functions for both customers and producers. Tidd *et al.* (1997) developed the two-by-two matrix of technological and market novelties presented in Figure 2. Market innovation includes the identification of market trends and opportunities, the translation of these requirements into new products and services, and the promotion and diffusion of these products. Clearly, understanding the maturity of the technologies and markets will provide organizations an insight of strategic or tactical marketing that the firm might adopt.

Since a number of studies (e.g. King and Kang, 2000; Schmitz, 2000) have shown that the nature of the product is important factor in determining whether or not transaction will be done online, an investigation of different product categories in the semiconductor industry is needful as there is currently no known study focusing on this sector.

For complex products, both the technologies and markets are novel, and co-evolve. In this case there is no clearly defined use of a new technology, but over time

Figure 2 Two-by-two matrix of technological and market maturity



developers work with lead users to create new applications. The development of multimedia products and services is a recent example of such a co-evolution of technologies and markets.

Technological products are novel technologies developed to satisfy known customer needs. Such products and services compete on the basis of performance, rather than price or quality. Here, innovation is mainly driven by developers.

Architectural products are existing technologies applied or combined to create novel products or services, or new applications. Competition is based on serving specific market niches and on close relations with customers. Innovation typically originates or is in collaboration with potential users.

Differentiated products are those in which both the technologies and markets are mature, and most innovations consist of the improved use of existing technologies to meet a known customer need. Products and services are differentiated on the basis of packaging, pricing and support.

Verification of the impact of e-commerce on the roles of physical distributors (for customers, producers, and for both) of four different types of products is important as product nature may have different implications for this industry. Hence, the following hypotheses were verified:

H1. The change in importance of functions for customers is higher for differentiated products, architectural products, technological products, and then complex products.

H2. The change in importance for functions for producers is higher for differentiated products, architectural products, technological products, and complex products.

H3. The change in importance for functions for both customers and producers is higher for differentiated products, architectural products, technological products, and complex products.

H4. The likelihood of functions for producers being replaced is higher for differentiated products, architectural products, technological products, and then complex products.

H5. The likelihood of functions for customers being replaced is higher for differentiated products, architectural products, technological products, and then complex products

H6. The likelihood of functions for both being replaced is higher for differentiated products, architectural products, technological products, and then complex products.

Method

The population of study includes all multinational industrial distributors in the semiconductor industry in Penang, Malaysia. It is important to mention that Penang is the seat of semiconductor business in Malaysia and East-Asia by extension. A total of 63 distributors of different countries of origin (as shown in Table I) were identified, and respondents were selected based on purposive sampling (non-probabilistic) method targeted at decision makers. Out of this, 54 usable responses were received. All the firms included in this study have a Web site where products are exhibited. They also have portals where customers as well as producers logon to access and give information regarding products, order placement and payment, etc. The distributors have ample experience with both on-line and off-line transactions. Thus, respondents are aware of the changes in importance of e-commerce having experienced the two worlds.

The questionnaire was adapted from Tidd *et al.* (1997) and Bagozzi *et al.* (1998). All questions were rated using five-point Likert-like scale. Questions relating to change in importance were measured from greatly decreased (point 1) to greatly increased (point 5), while those relating to likelihood of distributors functions being replaced or modified were measured from highly unlikely (point 1) to highly likely (point 5).

Results and discussion

The internal consistency of the measures was ascertained via reliability analysis. The Cronbach's Alpha coefficients for all dimensions show values higher than 0.60 except for likelihood of distributors (for differentiated products) function for producers being replaced, which is 0.50. As observed from Table II, the construct measures are reliable.

Table I Responding organizations by country of origin

Country	America	Asia	AME	Europe	Oceania	Total
Australia					2	2
Belgium				1		1
Finland				1		1
France				2		2
Germany				3		3
Greece				1		1
Hong Kong		6				6
Israel			1			1
Italy				2		2
Japan		5				5
Malaysia		1				1
The Netherlands				2		2
Rep. of Korea		2				2
Singapore		3				3
South Africa			2			2
Spain				2		2
Sweden				1		1
Taiwan		5				5
Turkey				1		1
UAE			1			1
UK				3		3
USA	7					7
Total	7	22	4	19	2	54

Notes: AME = Africa and Middle East; UAE = United Arab Emirate

Table II Cronbach's alpha values

	Change in Importance				Likelihood of being replaced or modified			
Role of distributors	S1	S2	S3	S4	S1	S2	S3	S4
Functions for customers	0.88	0.88	0.77	0.80	0.83	0.90	0.89	0.80
Functions for producers	0.74	0.73	0.73	0.72	0.50	0.80	0.81	0.71
Functions for both	0.62	0.73	0.75	0.74	0.65	0.81	0.80	0.83

Notes: S1 = differentiated products; S2 = architectural products; S3 = technological products; S4 = complex products

E-commerce and change in importance of distributors roles

Table III shows the mean and standard deviation for the change in importance of distributors functions for all product categories.

E-commerce has convincing impact on the importance of distributors functions with mean values ranging from 3.06 to 3.96 across product categories. The perceived impact of e-commerce on the importance of distributors" functions for customers, producers and for both respectively range from 3.60 to 3.74, 3.52 to 3.69, and 3.44 to 3.56 across product categories. The impact of e-commerce on the overall functions of distributors (a combination of functions for customers, producer, and both) is increasing for all categories. Mean and standard deviation of perceived impact on the importance of overall distributors" functions based on product categories are as follows: differentiated products (3.54; 0.62), architectural products (3.62; 0.58), technical products (3.59; 0.58), and complex products (3.50; 0.64). In all, the results show a strong impact of e-commerce on perceived importance of the roles of distributors in the semiconductor industry.

The three most important impact of e-commerce on the roles of distributors of complex products going by their mean value is in the area information gathering (3.91), promoting and highlighting new products

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Table III Change in importance of distributors" roles

	Mean				SD			
Role of distributors	**S1**	**S2**	**S3**	**S4**	**S1**	**S2**	**S3**	**S4**
Functions for customers	3.61	3.74	3.73	3.60	1.10	0.84	0.85	0.95
Right attribute	3.61	3.83	3.94	3.74	1.23	0.91	0.98	1.08
Right quantity	3.61	3.65	3.52	3.46	1.09	0.87	0.91	1.00
Functions for producers	3.69	3.66	3.60	3.52	0.81	0.70	0.73	0.73
Storing	3.59	3.30	3.24	3.06	0.92	0.79	0.75	0.81
Financing	3.64	3.76	3.75	3.59	1.09	0.83	0.85	0.96
Information gathering	3.85	3.93	3.81	3.91	0.98	0.97	1.10	0.96
Functions for both	3.44	3.56	3.53	3.45	0.58	0.55	0.58	0.64
Risk reduction	3.13	3.11	3.26	3.07	0.75	0.77	0.71	0.93
Educating customers and representing producer	3.20	3.76	3.57	3.76	1.14	1.08	1.11	1.16
Transport safely	3.35	3.31	3.30	3.19	0.85	0.58	0.69	0.73
Transport on time	3.57	3.46	3.39	3.20	0.94	0.77	0.74	0.81
Promote/highlight new products	3.74	3.85	3.91	3.89	1.07	0.94	1.00	1.02
Promo. programs for sales force	3.61	3.83	3.78	3.59	1.09	0.86	0.90	1.09
Overall function	3.54	3.62	3.59	3.50	0.62	0.58	0.58	0.64

Notes: S1 = differentiated products; S2 = architectural products; S3 = technological products; S4 = complex products

(3.89), and educating customers and representing producers (3.76). For architectural products, the three most salient functions are information gathering (3.93), promoting and highlighting new products (3.85), and right attribute (3.83), while for technological products, they include providing the right attribute (3.94), promoting and highlighting new products (3.91), and information gathering (3.81). For differentiated products, the most important functions are information gathering (3.85), promoting and highlighting new products (3.74), and financing (3.64). Clearly, e-commerce has strongly impacted the informational roles of distributors in the semiconductor industry positively as demonstrated in the above results. In all product categories in the industry, perceived impact of e-commerce on the distributors roles is very robust in the area of information gathering and disseminating. One plausible explanation for this finding is found in the very nature of the industry and its products. In the semiconductor industry, adequate product information is vital in order to overcome problems emanating from wrong orders and delivery of incorrect specifications, as it is very common for each spec to have a definite size and use, which cannot be modified or exchanged. The richness and timeliness of product information available on the Internet makes this mode very useful.

Table IV presents the ranking in the perceived change in importance for the four product categories using the Friedman two-way ANOVA. The results indicate that there is no definite ranking in the perception of change of importance for the three main functions measured in this study. Nonetheless, mean rank for differentiated products is generally highest (2.17-2.94), followed by architectural products (2.46-2.71), technological products (2.35-2.71), and complex products (2.14-2.65). This signifies that decrease of change in importance is seen more with complex products as compared to technological, architectural, and differentiated products. Further scrutiny of the data indicates that three functions have definite ranking, namely storing, educating customer and representing producer, and transport on time with Kendall test of concordance at 0.111, 0.055, and 0.049 respectively.

Likelihood of distributors roles being replaced

Table V presents the means and standard deviations for likelihood of traditional distributors being replaced. Mean and standard deviation of likelihood of using the Internet instead of traditional distributors to provide overall distributors functions based on product category are, differentiated products (3.41; 0.59), architectural products (3.24; 0.75), technological products (3.24; 0.71), and complex products (3.09; 0.78). The results show that the likelihood of the

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Table IV Friedman two-way ANOVA by rank (change in importance)

	Mean rank				Test statistics		
Role of distributors	**S1**	**S2**	**S3**	**S4**	**Chi-sq.**	**Sig.**	**W[a]**
Functions for customers	2.43	2.70	2.49	2.38	2.679	0.444	0.017
Right attribute	2.35	2.53	2.71	2.41	3.933	0.269	0.024
Right quantity	2.66	2.62	2.36	2.36	3.994	0.262	0.025
Functions for producers	2.71	2.66	2.35	2.28	5.380	0.146	0.033
Storing	2.94	2.52	2.41	2.14	17.972	0.000**	0.111
Financing	2.46	2.71	2.50	2.32	3.441	0.329	0.021
Information gathering	2.52	2.56	2.41	2.51	0.702	0.873	0.004
Functions for both	2.25	2.68	2.59	2.48	3.860	0.277	0.024
Risk reduction	2.43	2.46	2.68	2.44	3.210	0.360	0.020
Educating customers and representing producer	2.17	2.67	2.52	2.65	7.966	0.047*	0.049
Transport safely	2.61	2.56	2.50	2.33	3.743	0.291	0.023
Transport on time	2.69	2.62	2.48	2.20	8.935	0.030*	0.055
Promote/highlight new products	2.39	2.49	2.56	2.56	1.015	0.798	0.006
Promo. programs for sales force	2.43	2.59	2.56	2.42	1.455	0.693	0.009

Notes: S1=differentiated products; S2 = architectural products; S3 = technological products; S4 = complex products. * $p < 0.05$; ** $p < 0.001$. [a] Kendall's coefficient of concordance

Table V Likelihood of distributor's roles being replaced

	Mean				SD			
Role of distributors	**S1**	**S2**	**S3**	**S4**	**S1**	**S2**	**S3**	**S4**
Functions for customers	3.62	3.24	3.28	3.12	1.02	1.05	1.05	1.06
Right attribute	3.69	3.30	3.41	3.28	1.10	1.16	1.16	1.23
Right quantity	3.56	3.19	3.15	2.96	1.11	1.05	1.05	1.08
Functions for producers	3.50	3.28	3.27	3.15	0.70	0.92	0.87	0.86
Storing	3.22	2.96	3.07	2.94	1.02	1.03	0.91	0.96
Financing	3.60	3.29	3.28	3.11	1.04	1.08	1.08	1.09
Information gathering	3.69	3.59	3.46	3.41	0.95	1.17	1.08	1.16
Functions for both	3.30	3.22	3.16	3.05	0.59	0.69	0.68	0.77
Risk reduction	2.83	2.94	2.85	2.72	0.88	0.76	0.86	0.90
Educating customers and representing producer	3.31	3.26	3.15	3.19	1.04	1.15	1.09	1.27
Transport safely	3.22	3.09	3.08	2.85	0.92	0.83	0.85	0.83
Transport on time	3.30	3.13	3.09	3.04	1.02	0.91	0.83	0.80
Promote/highlight new products	3.54	3.54	3.50	3.24	0.95	1.04	1.15	1.24
Promo. programs for sales force	3.59	3.35	3.31	3.28	1.02	1.07	0.99	1.11
Overall function	3.41	3.24	3.24	3.09	0.59	0.75	0.71	0.78

Notes: S1 = differentiated products; S2 = architectural products; S3 = technological products; S4 = complex products

brick and mortar distributors roles (for customers, producers, and for both) being replaced by e-commerce is higher for differentiated products and least for complex products. This result is probably accounted for by the low level of technology novelty and market novelty of differentiated products. Since market and technology co-evolve in complex product category, the roles of distributors seemingly become more indispensable as demand for their specialized services increase. This finding corroborates that of Schmitz (2000), which reported that high degrees of standardization and low complexity of valuation are prerequisites to distributing goods via e-commerce.

In Table VI, the summary of Friedman two-way ANOVA and Kendall test of concordance's test results for likelihood of functions being replaced is provided. There is a definite ranking across all product categories for the three main functions. Generally, mean rank is highest for differentiated products (2.53-2.94), followed by architectural products (2.40-2.68), technological products (2.27-2.58), and subsequently complex

Table VI Friedman two-way ANOVA by rank (likelihood of being replaced)

	Mean rank				Test statistics		
Role of distributors	**S1**	**S2**	**S3**	**S4**	**Chi-sq.**	**Sig.**	**W[a]**
Functions for customers	2.94	2.42	2.40	2.25	11.544	0.009**	0.071
Right attribute	2.81	2.40	2.49	2.31	6.845	0.077	0.042
Right quantity	2.94	2.47	2.42	2.18	15.233	0.002	0.094
Functions for producers	2.85	2.54	2.32	2.29	7.359	0.061[b]	0.045
Storing	2.69	2.41	2.53	2.37	3.179	0.365	0.020
Financing	2.94	2.47	2.39	2.20	12.541	0.006	0.770
Information gathering	2.65	2.61	2.28	2.46	4.239	0.237	0.026
Functions for both	2.80	2.68	2.27	2.26	8.554	0.036*	0.053
Risk reduction	2.53	2.65	2.53	2.30	4.660	0.198	0.029
Educating customers and representing producer	2.56	2.52	2.42	2.51	0.534	0.911	0.003
Transport safely	2.75	2.56	2.48	2.21	9.505	0.023	0.060
Transport on time	2.69	2.51	2.41	2.40	3.456	0.327	0.021
Promote/highlight new products	2.56	2.55	2.58	2.31	2.669	0.446	0.016
Promo. programs for sales force	2.75	2.50	2.40	2.35	5.058	0.168	0.031

Notes: S1=differentiated products; S2 = architectural products; S3 = technological products; S4 = complex products. * $p < 0.05$; ** $p < 0.01$. [a] Kendall's coefficient of concordance. [b] Moderate

products (2.18-2.51) for all functions. It is therefore conclusive to state that the likelihood of functions of traditional distributors being replaced is highest for differentiated products, followed by architectural products, technological products, and complex products. Detail check shows that right attribute, right quantity, financing, and transport safely, have definite ranking for likelihood of being replaced. The mean rank for the last three is highest for differentiated products, architectural products, technological products, and complex products in order. As for the right attribute function, the order is similar except that architectural and technological products swapped positions.

The findings of the study show that there is increasing impact of e-commerce on the roles of distributors of all product categories, even though there is no definite ranking of respondents" perceptions on changes in importance across the four types of products. Thus, there is no evidence to support the validity of *H1-3*. However, their perceptions of the likelihood of distributors" functions being replaced show otherwise. As stated in *H4-6* respectively, the likelihood of distributors" functions for producers, customers, and for both, being replaced is higher for differentiated products followed by architectural products, technological products, and lastly complex products. With Chi-square (λ) of 0.009, 0.036 and 0.061 respectively, there is significant evidence supporting *H4* and *H6*, and marginal evidence supporting *H5*. This can possibly be explained from three perspectives. Firstly, the advancement in technology enables the shift in roles from distributors to customers and producers. Customers can now source for the right product and the right quantity utilizing the Internet whereby more products information is posted for customers" reference, moving the business setting to a customer centric environment. This is consistent with Frank Lynn & Associates, Inc. (1997) and Fein (1998). Moreover, as basic competition in the marketplace has enabled more comprehensive information to be posted on the Internet and competitors are relatively flexible in products offering, customers could resort to the Internet for such information, which they previously rely on distributors to provide. Next, the emergence of Internet financiers and lenders, increased lending by financial and other institutions, and decreasing need for storage occasioned by computerized stock management systems and JIT, could have impacted the likelihood of the roles of traditional distributors to producers being replaced. Lastly, availability of truck transportation and increased efficiency may have contributed to the likelihood of traditional distributors being replaced in providing safe and timely transportation. Customers and producers may not need to rely on brick and mortar distributors, but depend on forwarders or couriers for reliable shipment. This is consistent with Bagozzi *et al.*'s (1998) view.

For undifferentiated products (i.e. architectural, technological, and complex products), it is less likely (compared to differentiated products) that dis-intermediation will occur. The rationale behind this phenomenon could be that the customers and producers are not ready to take over the distributors" roles even though technology advancement is seen from day to day. On the other hand, e-shoppers are less likely to close a transaction using the Internet when the product is somewhat complicated. Thus far, most of the producers are still unprepared, either technologically or from a business process perspective, to pipe a large portion of their B2B transactions over the Internet to promote complex products that are often difficult to describe. The transaction costs involved may be too high to be absorbed by both the customers and producers. From the producers" standpoint, the extra costs incurred may include the need to provide immediacy, flexible pricing structure, advanced customer support, digital signatures or financial clearing for large-sum transactions. From the customers" perspective, sourcing information from multiple Web sites for a single non-standardized product may not be cost effective. This may be a carry over effect of single supplier source era. Also, the effectiveness of distributors in getting critical mass could be apparent to producer and cannot be underestimated. On top of that, the efficiency and value added by performing these functions could be one of their concerns. Unless the producers have resources to internalize the channel activities within its organizational boundaries, it may be deemed more cost effective to leave these functions to the hands of distributors.

Implications of study

Several implications of study are raised based on the findings. The research may provide distributors an idea of which of the functions that can be replaced and which are those that cannot be substituted based on types of products. For those functions that are more likely to be replaced, distributors should collaborate with producers and customers to integrate their operational activities in order to achieve higher efficiency level, which will eventually benefit all parties in the supply chain. For those functions that are less likely to be replaced, distributors may continue to strengthen their competitive edge and further add value to customers and producers, in particular in today's world of solution centric business model. Traditional distributors should deliver solutions instead of just commodities, which is the only way they can retain an important place in the channel. Distributors may need to ensure that massive amount of supply and demand data is well-managed and near-perfect information to buyers and sellers are easily available. The ability of distributors to provide market intelligence to producers will be considered as value added as it is difficult for producers to monitor each and every one of their customers. Furthermore, with the findings, distributors may make some strategic decision as to whether to concentrate on demand fulfillment business or demand creation activities. Apart from the above, it is not likely that Fein *et al.*'s (1999) belief that distributors can retain an important, and enhanced place in the channel will hold. The current study supports the earlier findings of Schmitz (2000) that the effects of e-commerce on intermediation depend on the characteristics of the goods under consideration, as well as the findings of King and Kang (2000) that product complexity is positively correlated to an e-shopper's propensity to use a vehicle other than the Internet to close a transaction. Therefore, since product simplicity (i.e. non-complication) is negatively associated to an e-shippers propensity to use a vehicle other than the Internet to close a transaction, brick and mortar distributors may wish to exploit this opportunity created by the inability of e-commerce to begin and complete delivery of complex products or highly technical products by extension. Besides that, the findings may trigger discussion on the possibility of consortia-like electronic marketplace being the next business model for distribution channel since it may help to achieve to a more efficient market. Distributors need to be ready and prepared for the next possible distribution channel evolution. As much as the functions of distributors of undifferentiated products may be less likely to be replaced in near term, however, the Internet will continue to deliver information and options to customers at an exponentially accelerating rate that may

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change the traditional channel practices in the long run.

Limitations of study

Some limitations and opportunities for additional research can be identified from this research. Firstly, this study is purely on understanding the respondents" perceptions and they are not tracked over time on the change in importance and likelihood of distributors" functions being replaced. Secondly, the sampling of this study is limited to semiconductor industry, hence may not be applicable to other industry sectors. Lastly, this study concentrates only on market and technology novelty as independent variables, which may underestimate the effect of other factors that could potentially influence the changes in importance and likelihood of distributors" functions being replaced.

Suggestions for future research

This study is exploratory in nature and may seem to be oversimplified focusing only on two independent variables. Several recommendations to advance research in this area is put forward. First, the future research should be longitudinal, using actual data of change in importance and likelihood of functions being replaced. This will help to ascertain if the findings based on actual data agree with findings of the current study, which is based on perceptions. Besides, the future research should also cover a wider industry sectors for a more comprehensive findings. Lastly, it is suggested that future research should include other independent factors besides market novelty and technology novelty. The factors suggested are how well verse are customers in using Internet, investment in information technology by producers and customers, readiness of the infrastructure in supporting usage of Internet, and cultural differences in different countries.

Conclusion

This study attempts to provide an understanding of the impact of e-commerce from a very specific perspective, namely the market novelty and technology novelty in the semiconductor industry by examining four product categories such as, differentiated products, architectural products, technological products, and complex products. The findings of the study reveal that e-commerce has important impact on the roles of distributors, albeit there is no definite ranking across the four product categories. Further, findings by comparing among the four different types of products show that the likelihood of distributors' functions (for producers, for customers, and for both) being replaced is higher for differentiated products followed by architectural product, technological products, and subsequently complex products. Hopefully this piece of information will be useful to the distributors in further developing their strategic and realign the business goals in order to compete in the dynamic world of technology.

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Evaluating IS usage in Malaysian small and medium-sized firms using the technology acceptance model

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Keywords

Information systems, Small to medium-sized enterprises, Malaysia

Abstract

The current research investigates the impact of persona-system characteristics, technical backing, and computing skill on information systems (IS) usage by Malaysian small and medium firms (SMF) using the TAM. The study hypothesizes that persona-system characteristics (such as perceived usefulness and perceived ease of use) and usage of systems will be greater when there is greater computing skill and strong technical backing. A total of 177 firms responded to the survey and the results show that there is a positive relationship between computing skill and technical backing on one hand and IS usage directly, and indirectly via perceived usefulness and ease of use on the other. Usage is influenced directly by usefulness and indirectly (via usefulness) by ease of use. These findings are particularly crucial to system designers and vendors targeting SMF, as well as, to information systems management in SMF. Important theoretical and practical implications are discussed.

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Introduction

There is a growing understanding of how businesses should operate using information systems (IS) to achieve optimal effectiveness, since IS has a strategic significance in an information rich economy to reduce cost, upgrade quality, improve customer service, and enhance integration with vendors to increase the economic power of the firm. A number of research (e.g. Jantan and Kannan, 1997) has asserted that information systems aid small businesses to compete with larger companies. In spite of these benefits, empirical findings (e.g. Ndubisi *et al.*, 2001) have shown that many small businesses make very limited use of their micro systems, and it has been suggested that such low usage of installed systems has been a possible key explanation for the "productivity paradox". More often mentioned reason for such low usage of systems is the dearth of computing skill, followed by inadequate connoisseur's technical backing to small and medium firms, a sector known to often face shortage of resources, capital, and expertise, which constrain exorbitant employment and experimentation with sophisticated technologies. Computing skill in the context of this research is a special ability or expertise available to small firms in using information technologies. Technical backing refers to before and after-sales support services provided by systems suppliers and other experts. Understanding the determinant structure of these key variables will help create favourable perceptions that will enhance IS usage.

Theory and model development

This section discusses the theory underlying the key constructs in the study's model. Several models have been developed to investigate and understand the factors affecting the acceptance of computer technology in organisations. The theoretical models employed to study user acceptance, adoption, and usage behaviour include the theory of reasoned action (TRA) (e.g. Fishbein and Ajzen, 1975; Ajzen and Fishbein, 1980), the technology acceptance model (TAM) (e.g. Davis, 1989; Davis *et al.*, 1989), the theory of planned behaviour (TPB) (e.g. Mathieson, 1991), the model of

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PC utilisation (Thompson *et al.*, 1991), the decomposed theory of planned behaviour (e.g. Taylor and Todd, 1995a), and innovation diffusion theory (e.g. Agarwal and Prasad, 1997). Current research has focused on the TAM because it helps to understand the relationship between users perceptions of the benefits and usability of their system(s).

In this study, the TAM (Davis, 1989; Davis *et al.*, 1989) was used to study the relationship between computing skill, technical backing, persona-system characteristics (such as perceived usefulness and perceived ease of use) and information systems usage in small and medium-sized firms. TAM was adapted from the TRA (Fishbein and Ajzen, 1975; Ajzen and Fishbein, 1980) to understand the causal chain linking external variables to technology usage intention and actual use in a workplace. TAM adopts two specific beliefs, perceived usefulness and perceived ease of use. The former refers to the user's perception of the degree to which using the system will improve his or her performance in the work place, while the latter refers to the user's perception of the amount of effort needed to use the system. Many IS studies have replicated TAM or used TAM instrument extensively to investigate a range of issues in the area of user acceptance (e.g. Moore and Benbasat, 1991; Olfman and Bostrom, 1991; Trevino and Webster, 1992; Sjazna, 1994).

TAM is acclaimed for its parsimony and predictive power that make it easy to apply in different situations. However, there have been some reservations as well. Venkatesh (2000) writes that while parsimony is TAM's strength, it is also the models important constraint. According to Venkatesh, while TAM is very powerful in helping to predict acceptance, it does not help understand and explain acceptance in ways that guide development beyond suggesting that system characteristics impact usefulness and ease of use thereby placing a limitation on the ability to meaningfully design interferences to promote acceptance. Mathieson (1991) believes that TAM is predictive but its generality does not provide sufficient understanding from the standpoint of providing system designers with the information necessary to create user acceptance of new systems. Nonetheless, Adams *et al.* (1992) called for more research on this model.

One main focus of IS implementation research has been to determine why people accept or reject new technology. IS usage is a frequently suggested measure of IS success (Igbaria *et al.*, 1997) and a key dependent variable (Delone and Mclean, 1992). Researchers have studied IS acceptance and use at the individual level (e.g. Adoum, 1998), household level (Venkatesh and Brown, 2001), and at organizational level (Akkeren and Cavaye, 1999; Julien and Raymond, 1994). Some of the organizational level studies have been directed at large firms (e.g. Delone and Mclean, 1992), small firms (Igbaria *et al.*, 1997), and the present work at medium and small firms. Usage variable has often been measured based on intention to use (e.g. Davis, 1989; Davis *et al.*, 1989), but the current research measures usage based on actual usage behaviour (in line with Ndubisi *et al.*, 2001; Sjazna, 1994), which is one of the strength of the research.

Persona-system characteristics describe the perceptions of users about the usefulness or benefits of using a technology (perceived usefulness) and the perceptions about the ease or difficulty of using the technology (perceived ease of use). Such perceptions are often partly the result of users computing self-efficacy and partly the result of the make-up or nature of the system. Perceived usefulness is a construct tied to an assessment of the benefits that accrue to an individual or firm by using the technology. Technology adoption (or usage) decisions have been typically characterised by a strong productivity orientation (Venkatesh and Brown, 2001). Perceived ease of use is tied to an individual's assessment of the effort involved in the process of using the technology. Measures of perceived usefulness of IS in this study are in terms of increase in productivity, improvement in job performance, enhancement of job effectiveness, usefulness in the job. Perceived ease of use is measured in terms of how clear and understandable is the interaction with system, ease of getting the system to do what is required, mental effort required to interact with the system, and ease of use of system (Davis, 1989; Davis *et al.*, 1989). A significant body of TAM studies (e.g. Davis, 1989; Mathieson, 1991; Adams *et al.*, 1992; Segars and Grover, 1993; Sjazna, 1994; Igbaria *et al.*, 1997) has shown that perceived usefulness and perceived ease of use are determinants of usage. Based on the above literature, this study hypothesizes the following:

H1. Perceived usefulness of a specific system will have a direct significant impact on its usage.

H2. Perceived ease of use of a specific system will have a direct significant impact on its use.

H3. Perceived ease of use of a specific system will have an indirect significant impact (via usefulness) on its use.

Computing skill refers to both hands-on experience with systems, procedural information and coaching provided by experts to users. Venkatesh and Davis (1994) found that before a direct experience with systems, system characteristics did not play a significant role in the formation of early ease of use perceptions. Moreover, ease of use of two different systems did not differ significantly before direct experience, but after direct experience, system characteristics did become significant determinant of ease of use perceptions. In addition to the theoretical and intuitive basis to believe that computing skill and perceived usefulness and ease of use might be related, there exists empirical support to suggest that computing experience, coaching, and computing support determines perceptions. Prior experience has been found to be an important determinant of behaviour (Bagozzi, 1981). Ajzen and Fishbein (1980), found that experience may make low probability events more salient, thereby ensuring that they are accounted for in the formation of attitude. Moreover, research in psychology (e.g. Fazio and Zanna, 1981), and marketing (e.g. Smith and Swinyard, 1983) have also suggested that perceptions become more specific after direct experience. Mervis and Rosch (1981) found that subjects without direct experience in a given domain base their perceptions on more abstract criteria, and after direct experience can make their judgments based on more concrete criteria. There is also evidence (Bettman and Sujan, 1987) to suggest that novice consumers base their decisions on more abstract, general criteria since they do not have sufficient knowledge to make a decision based on concrete, specific criteria. In other studies, for example Raymond and Bergeron (1992), Igbaria *et al.* (1995, 1997), it was found that personal computing training have a positive impact on perception and technology acceptance. Research reports (e.g. Bergeron *et al.*, 1990; Mirani and King, 1994) have shown that systems are more successful when there was a user computing support. Other studies that have also highlighted the importance of computing support include Cragg and King (1993), Igbaria (1992) and Igbaria *et al.* (1997). It is thus theorized that computing skill, a synergy of hands-on experience, coaching and procedural information, will positively influence perceived usefulness and perceived ease of use, which will in turn influence information systems usage. In other words, computing skill will directly and indirectly (via usefulness and ease of use) influence usage. Moreover, strong technical backing will directly and indirectly (via usefulness and ease of use) influence usage. In sum, users strongly anchor usage, usefulness and ease of use perceptions about any system to their computing skill and strong technical backing. Hence it is hypothesized that:

H4. Computing skill of a user will strongly determine his or her usage of information systems.

H5. Computing skill of a user will strongly determine his or her perception of usefulness of specific systems.

H6. Computing skill of a user will strongly determine his or her perceptions of ease of use about specific systems.

H7. Usage of information systems will be greater when strong technical backing is available.

H8. Availability of strong technical backing will lead to a more favorable perception of systems usefulness.

H9. Availability of strong technical backing will lead to a more favorable perception of system's usefulness.

Method

A total of 295 small and medium-sized firms randomly selected from the Chinese, Indian, and Malay Chamber of Commerce and Industry, Malaysia, were surveyed using structured questionnaire. A total of 60 per cent usable response was achieved, which come up to 177 respondents, on which analyses were based.

The hierarchical multiple regression model (HMRM) (Abrams, 1999; Ndubisi *et al.*, 2001) was employed to predict the relationships in the framework. In the

HMRM method, the predictor variables are entered in different stages. For example, to determine the relationship between the independent variables, the mediator variables, and the dependent variable using HMRM, the independent variables are entered into the regression in step 1 while the mediators are entered in step 2. As a result, that the increase in coefficient of determination (R^2) corresponding to the inclusion of each category of predictor variables and the unique variance in the dependent variable explained by the predictor categories could be examined. The R^2 for all sets can be analysed into increments in the proportion of Y variance due to addition of each new set of predictor variables to those higher in the hierarchy. These increments in R^2 are squared multiple semi-partial correlation coefficients.

The mediator effect of perceived usefulness and ease of use were examined based on Baron and Kenney (1986). Validated items, which were re-validated for the present study were taken from the following sources: IS usage (ISU) (International Coalition of Library Consortia (ICOLC), 1998), perceived usefulness (PU) and ease of use (PEOU) (Davis *et al.*, 1989), computing skill (i.e. hands-on experience (HOE) and coaching and procedural information (COP), and technical backing (TB) (Ndubisi *et al.*, 2001).

Results

Psychometric properties of the instruments

Factor analysis was performed on the individual items contained in the questionnaire in order to establish their suitability for performing the multivariate analyses used. The results presented here are based on parsimonious sets of variables, guided by conceptual and practical considerations: the acceptance of factor loadings of approximately 0.50 and above – this level is considered practically significant (Hair *et al.*, 1998); and cross-loadings below 0.20. The oblique factor rotation was employed for this analysis because it represents the clustering of variables more accurately (Hair *et al.*, 1998), and because the factors need not be uncorrelated and may even be conceptually linked, which requires correlation between the factors (Hair *et al.*, 1998, p. 127). This technique of rotation is more suitable for our needs than the orthogonal rotation, which keeps factors uncorrelated throughout the rotation process.

Table I shows the summary of the results of rotated factors and item loadings and cross-loadings for technical backing (factor 1) coaching cum procedural information (factor 2), and hands-on experience (factor 3). Total variance explained is 74.87. Table II shows the summary of the results of rotated factors and item loadings and cross loadings for IS usage (factor 1), perceived usefulness (factor 2), and perceived ease of use (factor 3). Total variance explained is 79.20. Factor loadings and cross loadings for almost all the items used in the study were over 0.60 and below 0.20 respectively. The factor analyses results show that items measuring the construct dimensions are valid. In other words, the items are valid measures of the dimensions under study.

Reliability analyses show the following Cronbach's alpha values: usage (0.83), perceived usefulness (0.90), perceived ease of use (0.88), technical backing (0.90), and coaching cum procedural information (0.75). All the reliability test results in this study show alpha values exceeding 0.60 recommended as the lower limit of acceptability (see Hair *et al.*, 1998), ensuring that the items grouping for the respective variables in this study are reliable.

IT usage

It is observed that 59.88 per cent of respondents are using four (one-half) out of the eight varieties of systems presented. It is also observed that 53.11 per cent of respondents use systems to do five (one-half) out of the ten job tasks listed. A total of 68.9 per cent of respondents use the systems on a daily basis, and 75.7 per cent use the system for a minimum of one hour per session. Further results are shown in Table III.

System varieties were subsequently combined into two larger groups as follows: basic systems (which include, word processing, electronic mail, spreadsheets, graphics, and database), and advanced systems (e.g. application packages, and programming languages). Specific job tasks were also grouped into those for administrative purposes (e.g. producing reports, letters and memos, data storage/ retrieval, and communication with others), planning purposes (e.g. analyzing trends, planning/forecasting, analyzing problems/

Table I Rotated factors and item loadings – oblique method

Items	Factors 1 TB	2 COP	3 HOE
Assistance with system difficulty	**−0.96**	0.04	−0.07
Specialized instruction on hard/software	**−0.90**	−0.08	0.06
Guidance on hard/software selection	**−0.86**	0.11	0.06
Coaching and information on operating systems	−0.14	**0.83**	−0.14
Coaching and information on application packages	0.13	**0.80**	0.11
Coaching and information on word processing	−0.10	**0.78**	−0.19
Coaching and information on spreadsheet	0.06	**0.59**	0.06
Hands-on experience with computing	0.03	−0.08	**0.97**

Notes: TB = technical backing; COP = coaching and procedural information; HOE = hands-on experience

Table II Rotated factors and item loadings – oblique method

Items	Factors 1 ISU	2 PU	3 PEOU
Varieties of systems	**0.94**	0.036	0.060
Job tasks where systems are used	**0.89**	−0.13	−0.04
Improvement in job performance	0.06	**−0.97**	−0.11
Increase in productivity	−0.08	**−0.83**	0.13
Enhancement of job effectiveness	0.10	**−0.87**	0.02
Usefulness in job	0.09	**−0.63**	0.21
Clear and understandable interaction with system	−0.10	−0.29	**0.67**
Ease of getting system to do what is wanted	−0.06	−0.08	**0.83**
Interaction does not require a lot of mental effort	0.12	0.13	**0.88**
Finding system easy to use	0.01	−0.08	**0.83**

Notes: ISU = information systems usage; PU = perceived usefulness; PEOU = perceived ease of use

alternatives, and making decisions), and control purposes (e.g. budgeting, controlling and guiding activities). All the respondents use at least one basic system, and (65.5 per cent) use a minimum of one advanced system. A computer system is used for at least one administrative task by all of the respondents, 59.9 per cent of respondents use system for a minimum of one planning task, and 54.8 per cent of respondents use a system for at least one control task.

Hypotheses verification

"The horizontal pyramid model" – the schema of the study relationships with their beta coefficients is presented in Figure 1.

Computing skill, technical backing on IS usage

The results in Table IV show that computing skill (synergy of hands-on experience and coaching cum procedural information) (t-value = 4.181; p-value = 0.000) and technical backing (t-value = 2.042; p-value = 0.043) are both directly associated

Table III IT usage

	Percentage of respondents
Variety of systems used	
Word processing	91.5
Electronic mail	78.0
Spreadsheets	55.9
Application packages	53.6
Graphics	44.6
Database	37.3
Programming languages	26.0
Statistical analysis	25.4
Specific job tasks where system is applied	
Letters and memos	85.9
Producing report	75.1
Communication with others	73.4
Data storage/retrieval	59.9
Planning/forecasting	46.3
Budgeting	44.1
Controlling and guiding activities	38.4
Analyzing trends	34.5
Making decisions	34.5
Analyzing problems/alternatives	23.2
Frequency of use	
Several times a day	55.9
A few times a week	18.6
About once a day	13.0
A few times a month	10.7
Less than once a month	1.1
Once a month	0.6
Amount of time spent per session	
More than 3 hours	37.3
1-2 hours	22.0
2-3 hours	16.4
$\frac{1}{2}$ hour-1 hour	11.9
Less than $\frac{1}{2}$ hour	10.2
Almost never	2.3

Figure 1 The "horizontal pyramid" model – schema of the study constructs with beta coefficients

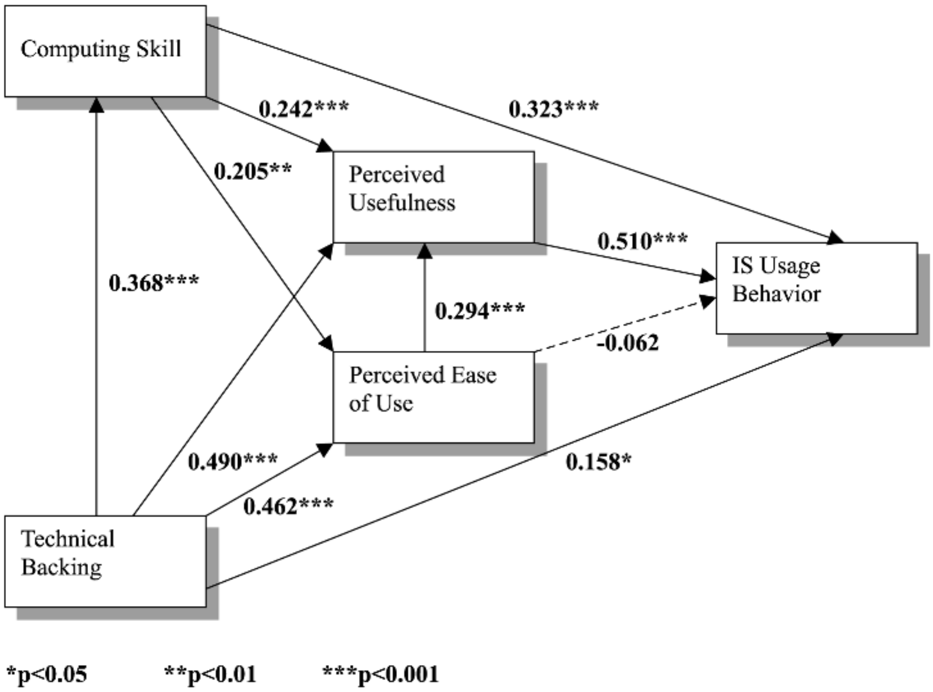

Table IV Computing skill, technical backing on IS usage

Anchors	Beta coefficients	*t-value*	*p-value*
Computing skill	0.323	4.181	**0.000**
Technical backing	0.158	2.042	**0.043**

Notes: $R^2 = 0.176$; adjusted $R^2 = 0.166$

with usage at 0.001 and 0.05 significant levels respectively. Variation in IS usage explained by computing skill and technical backing is 17.6 per cent. Moreover, technical backing is positively related to computing skill (*t*-value = 5.214; *p*-value = 0.000) and accounts for 13.5 per cent variation in computing skill, suggesting that when there is a greater measure of technical backing, users" computing dexterity also increases, resulting in greater usage. Summary of the results is shown in Table IV.

The study further isolated two types of technical backing (based on the time it is provided), such as before-adoption and after-adoption support, to see their impact on system usage. The mean and standard deviation for before-adoption and after-adoption technical support are respectively 5.42; 1.59 and 3.69; 1.04. Each has significant impact on system usage. Total variance in usage explained by before-adoption support is 6.7 per cent while variance explained by after-adoption support is 4.4 per cent. While the direction of the beta coefficients for before and after-adoption support is the same (i.e. positive), the strength of the coefficients differ (before-use $\beta = 0.259$; after-use $\beta = 0.209$). Moreover, before-use support is significantly associated with system usage at 0.1 per cent significance level (*t*-value = 3.552; *p*-value = 0.000), while after-use support has significant association with usage at 1 per cent level (*t*-value = 2.829; *p*-value = 0.005). The above findings imply that while system usage is determined by technical backing from experts provided before and after the system use, users will prefer technical backing provided before trial to that provided after failed trial.

Mediation effect of usefulness and ease of use

The relationship between computing skill and technical backing on the one hand and usage on the other were mediated by perceived usefulness and ease of use (refer to Table V). According to Baron and Kenney (1986, p. 1176), a variable functions as a mediator when it meets the following conditions:

(1) variations in levels of the independent variable significantly account for variations in the presumed mediator;
(2) variations in the mediator significantly account for variations in the dependent variable; and

Table V Mediation effect of usefulness and ease of use

	Model 1 (beta coefficients without usefulness)	*Model 1 (beta coefficients with usefulness)*
Computing skill	0.323***	0.226**
Technical backing	0.158*	−0.002
	$R^2 = 0.176$	$R^2 = 0.257$
	Adjusted $R^2 = 0.166$	Adjusted $R^2 = 0.244$
	Model 1 (beta coefficients without ease of use)	*Model 1 (beta coefficients with ease of use)*
Computing skill	0.323***	0.299***
Technical backing	0.158*	0.108
	$R^2 = 0.176$	$R^2 = 0.185$
	Adjusted $R^2 = 0.166$	Adjusted $R^2 = 0.171$

Notes: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

(3) when (1) and (2) above are controlled, a previously significant relation between the independent and dependent variables is no longer significant or it is significantly decreased.

The mediation effect of perceived usefulness is confirmed by the increase in R^2 of 0.081 between model 1(regression with only computing skill and technical backing) and model 2 (regression with computing skill, technical backing, and perceived usefulness). This, added to the decrease in beta coefficients of 0.096 for computing skill and 0.160 for technical backing between model 1and model 2 explain the mediator effect of perceived usefulness in the relationship between computing skill, technical backing and IS usage. In the same manner, the mediation effect of perceived ease of use is ascertained by the increase in R^2 of 0.009 between model 1 (regression with only computing skill and technical backing) and model 2 (regression with computing skill, technical backing and ease of use). This increase in addition to the decrease in beta coefficients of 0.024 for computing skill and 0.050 for technical backing between model 1 and model 2 explain the mediator effect of perceived ease of use in the relationship between computing skill, technical backing, and IS usage. Hence, perceived usefulness and ease of use mediate the relationship between computing skill and technical backing on one hand and information systems usage on the other. Table V summarizes the regression results.

Computing skill, technical backing on perceived usefulness and ease of use

Computing skill and technical backing accounts for 41.1 per cent variation in perceived usefulness and 34.3 per cent variation in perceived ease of use. There is a positive relationship between computing skill (t-value = 3.636; p-value = 0.000), technical backing (t-value = 7.358; p-value = 0.000) and perceived usefulness. Also there is a positive association between computing skill (t-value = 2.933; p-value = 0.004), technical backing (t-value = 6.613; p-value = 0.000), and perceived ease of use. Tables VI and VII show the summarized results.

Perceived usefulness, ease of use, and IS usage

Perceived usefulness of a system has significant direct impact on its usage, but perceived ease of use does not have any significant direct impact on usage. The results of the tests for these relationships show that usefulness is directly related to usage (t-value = 5.442; p-value = 0.000), while no direct relationship was found between ease of use and usage (t-value = −0.666; p-value = 0.506) at 5 per cent significance level. However, ease of use exhibits an indirect relationship via usefulness on usage. Based on

Table VI Computing skill, technical backing on perceived usefulness

Anchors	Beta coefficients	*t*-value	*p*-value
Computing skill	0.242	3.636	**0.000**
Technical backing	0.490	7.358	**0.000**

Notes: $R^2 = 0.411$; adjusted $R^2 = 0.404$

Table VII Computing skill, technical backing on ease of use

Anchors	Beta coefficients	*t*-value	*p*-value
Computing skill	0.205	2.933	**0.004**
Technical backing	0.462	6.613	**0.000**

Notes: $R^2 = 0.343$; adjusted $R^2 = 0.335$

Baron and Kenney (1986), the mediation effect of perceived usefulness in the relationship between ease of use and IS usage is confirmed by the increase in R^2 of 0.133 between model 1(regression with only ease of use) and model 2 (regression with ease of use and usefulness). The increase in the coefficient of determination, plus the decrease in beta coefficients of 0.356 between model 1(regression with only ease of use) and model 2 (regression with ease of use and usefulness) explain the mediator effect of perceived usefulness in the relationship between ease of use and usage. Thus, perceived ease of use of a specific system will have an indirect significant impact (via usefulness) on its use. Summaries of these results are shown in Tables VIII and IX.

Discussion and implications

Several key findings emerged from the current work. The results strongly support the TAM model, which further affirms the TAM as a good model on which to base research. The findings show that usage of information systems by Malaysian small and medium firms is driven directly by their perception of the system's usefulness, acquired computing skills, and technical backing provided by systems designers or vendors and indirectly (via usefulness) by ease of use. Apart from their direct influence on usage, computing skill and technical backing/support indirectly (via usefulness and ease of use) determine usage of information systems in small and medium firms. In addition, technical backing is positively associated with computing skill. It is further revealed that the more users perceive the system to be easy to use, the more they will see it as useful. Clearly, perceived usefulness, computing skill, and technical backing are strong determinants of IS usage in small firms. The salience of perceived usefulness on the usage of information systems has been recorded in many previous studies (e.g. Davis *et al.*, 1989; Ndubisi *et al.*, 2001). Firms, which have strong and favorable perception of the usefulness of the systems, use more of them than those with weak or unfavorable usefulness perception of the systems. Furthermore, technologies perceived to be easy to use all things being equal are deemed as useful, as suggested by the direct relationship existing between ease of use and usefulness. The indirect relationship via perceived usefulness between ease of use and usage, suggests that ease of use in itself will not lead to system usage, however if easy to use systems are judged useful systems, usage will be enhanced. Hence, perceived usefulness is more salient then ease of use in determining usage.

The importance of computing skill and technical backing in determining IS usage in SMF is striking. Both directly and indirectly (via usefulness and ease of use) computing skill and technical backing has strong influence on usage of information technologies. Implicitly, as long as the organizations continue to improve general computing skills, and as long as technical backing by experts is available to users, usage of information systems will be sustained or enhanced. Moreover, persona-system characteristics such as, perceived usefulness and ease of use are anchored to computing skill and technical backing. The positive relationships between the anchors and perceptions make sense for two twin plausible reasons. First, as one gets more skilled in a task, the easier the process becomes, and the better one's appreciation of the benefits of carrying out the task. Second, when backed by the assistance of an expert, even difficult tasks tend to be easier, and a better understanding of the full significance of the task becomes more likely.

From the foregoing, systems designers and vendors have important lessons to learn and some caveats to avoid in their future designs. The first caveat of note is the possible deception that once systems are useful, usage

Table VIII Perceived usefulness, ease of use, and IS usage

Perceptions	Beta coefficients	*t*-value	*p*-value
Usefulness	0.510	5.442	**0.000**
Ease of use	−0.062	−0.666	**0.506**

Notes: $R^2 = 0.219$; adjusted $R^2 = 0.210$

Table IX Perceived usefulness mediating ease of use and usage relationship

	Model 1 (beta coefficient without usefulness)	Model 2 (with usefulness)
Ease of use	0.294*	−0.062
R^2	0.087	0.219
Adjusted R^2	0.081	0.210

Note: * $p < 0.001$

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will rise irrespective of whether or not they are easy to use. This assumption is fallacious in that users (as the study shows) deem easy to use systems as useful systems, thereby contributing to increase in usage through its influence on usefulness. Very often designers of complex systems justify this design lag with the notion that "users will learn with time" but more often, small firms either lack the time, money, and expertise or they are not willing to commit their scarce resources to figuring out complex systems. Such a situation could culminate to rejecting or resenting the system, or at best grossly under-utilizing them if they ever get adopted. Landauer (1995) and Sichel (1997) have linked the gross under-utilization of systems to the productivity paradox. Another caveat is the deception that computing skill and technical support can substitute for ease of use. The danger in this is that not all firms can afford the cost of training and the trouble of seeking for expert's assistance. To these firms, user friendliness of systems is more vital than any assistance or training that might come along with complicated systems.

The present research presents further implications for practice and IS management in small firms. As users strongly anchor usefulness and ease of use perceptions about any system to their computing skill and strong technical backing, systems designers and vendors could beef up usage by promoting the perceptions of usefulness and ease of use of their systems through emphasis on these anchors. By providing before and after-sales support and helping to impart computing skill in users, designers and vendors will not only create a stronger and more favourable perceptions of the systems usefulness and ease of use, but also will be encouraging greater usage.

On the point of IS management in the firms, there is an urgent need for a shift from mere usage of systems for mundane administrative purposes to more strategic use of information systems. Ndubisi *et al.* (2001) defined strategic use of IT as the application of IT in critical areas of the business functions of the organisation in order to enhance job effectiveness, improve job performance and/or increase productivity beyond competition. Zain (1998) defined strategic use of IT as the usage of information technologies to support planning and management control. From the study it was observed that only 59 per cent and 54 per cent respectively of the entrepreneurs were using a system for at least one planning or one control task compared to 100 per cent of respondents who uses a system for a minimum of one administrative task. Such low strategic use of information systems is a plausible explanation why the gains from information systems deployment fall below expectation.

This research presents interesting direction for future research. Since users seem to anchor their perceptions of usefulness and ease of use to computing skill and technical backing, when users come in contact with systems that are too difficult to handle with available computing skill and technical support, the user is more likely to reject such a system. This gap between computing skill and technical backing on one hand, and difficulty of use on the other could be critical in determining the success of implemented systems and adoption of new ones. While systems that fall within the acceptable range will have a better chance of acceptance, those that fall outside of the threshold of a user's computing skill and available technical support are more likely to be rejected. Future research could focus on understanding this issue thoroughly.

Another future research direction could be in the line of understanding in more depth, the extent of strategic use of information systems by SMF. There are as many views on what is strategic use of IS as there are scholars, an assessment of the SMF strategic use of IS based on one view has a big chance of painting an inaccurate picture of the extent of strategic use of IS by these firms. Future research should examine a number of (if not all) these views, with particular interest in unveiling strategies to greater strategic use of information systems.

Strengths of the current research

It is germane to highlight some of the strengths of this research. Firstly, the model is based on theory grounded on existing management information system studies. Secondly, actual usage behaviour rather than usage intention was used as the dependent variable. Lastly, albeit validated items were used to measure the dimensions in the construct, they were re-validated and tested for reliability via factor and reliability analyses to ensure parsimony and consistency.

Conclusion

This research has examined the role of computing skill, and technical backing as anchors to perceptions of usefulness and ease of use in determining information systems use in small and medium firms in Malaysia. It was found that not only do computing skill and technical backing serve as strong anchors to users perceptions of the usefulness and ease of use of information systems, they also wield direct influence on systems usage. Technical backing has a direct influence on computing skill as well. Before and after-adoption technical backing are both influential factors, but surprisingly, the former has a stronger influence. Only one element of persona-system characteristics (i.e. perceived usefulness) has a direct relationship with system usage. Perceived usefulness is robust in determining usage, having direct influence on usage and also mediating in the relationship between the second element of persona-system characteristics (perceived ease of use) and usage. Ease of use has no direct influence on usage of systems instead its role in determining usage is only through perceived usefulness.

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A case study of supplier selection for lean supply by using a mathematical model

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Keywords

Cellular manufacturing, Just in time, Lean production, Supplier evaluation

Abstract

The role of purchasing departments has changed significantly in today's competitive environment. In order to keep the promises to customers; an effective material procurement system becomes necessary beside the improved manufacturing methods and technology. It becomes a necessity to work with the suppliers to provide quality and just in time delivery by supplying raw materials, parts and products. A purchasing department can take on both the active and effective role by applying the lean supply principles as much as possible. Single sourcing provides to easy control of procurement for achieving the lean supply objectives. In this paper, the supplier selection and evaluation for a manufacturing company is studied under lean philosophy. In order to reduce the supplier base, the supplier selection and evaluation study is conducted by multi-attribute selection model (MSM) in five basic steps. Consequently, the selected two suppliers are proposed to top management.

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Introduction

Quality, flexibility, and quick response have become important for the manufacturers in regard to customer satisfaction in today's competitive environment. In order to keep the promises to customers; it is required to realize lean production, with necessary qualification and without any cease. Therefore, an effective material procurement system becomes necessary beside the improved manufacturing methods and technology. It becomes a necessity to work with the suppliers to provide quality and just in time delivery by supplying raw materials, parts and products. Purchasing is repositioned as a key strategic and operational process rather than an internal stand-alone function by Hines (1996). Hence, the role of the purchasing departments has changed significantly in today's competitive environment. A purchasing department can take on both the active and effective role by applying the lean supply principles as much as possible.

Lubben (1988) expresses the objectives of lean supply as the following; to improve purchasing efficiency, to improve quality and delivery performance of suppliers, to isolate factors that influence the cost of materials, and to remove unnecessary cost factors in the materials supply system. In order to achieve these objectives, it is necessary to apply the following tactics:

- regarding suppliers as an extension of the internal manufacturing process and cultivating them as long-term business partners;
- establishing long-term purchasing and supply commitments;
- improving communications with suppliers;
- involving suppliers in early stages of new product planning; and
- using supplier expertise to improve design manufacturability and reducing product cost.

It is expressed that lean production is not a prerequisite to apply lean supply in a firm. Contrarily, in order to achieve lean production, it is necessary to implement and activate the lean supply system. Zero defect, small purchase lot sizes and frequent deliveries, small number of suppliers, long-term relationships, the closest supply sources, and a fair price are important elements of lean supply (Handfield, 1993). Cooper and

Slagmulder (1999) addressed the four major characteristics of lean buyer-supplier relations such as the reduced supplier base, the level of the relationship, the nature of the lean buyer-supplier relationship, and the organizational boundaries. A small number of sources of supply has resulted in some important advantages such as long-term relationships, consistent quality, savings of resources, lower costs, special attention, and savings on tooling to the firms (Ansari and Modarress, 1988).

Purchasing efficiency is improved by working with fewer suppliers of a higher caliber who provide better service and product cost over a longer period of time (Lubben, 1988). In general, the managers can reduce the supplier base in the following three ways: reducing the number of suppliers for each part, reducing the number of suppliers for each family of parts, and outsourcing fewer parts. Most lean producers rely on a single lean supplier for each part, trusting that particular supplier to deliver near-perfect products on time (Cooper and Slagmulder, 1999).

There are many studies focused on the buyer-supplier relationships under lean concepts. Macbeth et al. (1988) designed a project to identify or develop a "best-practice model" for buyer-vendor relationships under lean supply. Ramasesh (1990) provided a model for the implementation of lean concepts in purchasing systems that have not yet advanced the ultimate level of JIT purchasing. Hong and Hayya (1992) focused on single and multiple sourcing. They formulated and solved a mathematical programming problem to obtain the optimal selection of suppliers and the size of split orders for multiple sourcing; and provided a procedure that yields the optimal number of deliveries for single sourcing.

Bartholomew (1984), Newman (1988), Forbes et al. (1989), Fandel and Reese (1991), Choi (1994), Aderohunmu et al. (1995), Gilgeous and Yamada (1996), Kelle and Miller (1998), Miller and Kelle (1998), Roy and Guin (1999), Dong et al. (2001) are some authors who interested in the supplier-buyer relationships. Supplier evaluation and selection is also subjected on the studies of lean supply. Ansari (1986) determined a set of critical – human and operational – factors for successful implementation of just in time purchasing by a survey. Hirakubo and Kublin (1998) studied on the purchasing behavior in the Japanese electronic and office equipment industries. They researched to asses and compare the relative importance of several vendor selection criteria such as quality, price, delivery, cost reduction capability, design, proximity, etc. for the two product types by a mail survey. Freeland (1991) made a survey of just-in-time purchasing practices in the USA by questionnaire with 60 people in a variety of industries. As a finding of the survey, he ranked the supplier selection criteria and determined the quality is the most important criterion for supplier selection.

This paper studied the application of a mathematical model for supplier evaluation and selection under lean concepts in a company. The methodology is introduced in general firstly, and then the application of this model is explained step by step in a case company.

Methodology

In this paper, a study of supplier selection and evaluation is conducted by using the multi-attribute selection model (MSM). MSM is described by Lubben (1988) as a model, which provides a method of analytically matching a supplier's capability to the company needs, permits comparison of the abilities of several suppliers, and serves to evaluate the possibility of improving a supplier's performance. A list of supplier requirements or attributes, a questionnaire, and the MSM form are the input requirements of MSM. The MSM is applied in following five steps as mentioned above:

(1) *Generate criteria for prescreening suppliers*. Some criteria and constraints, such as applying lean production, having quality assurance systems, or ownership position in competitive companies, etc. are identified in this step. This information is used to establish the criteria for prescreening suppliers.
(2) *Selecting the attributes for the MSM*. Relevant attributes required by suppliers, that will be used to measure supplier capability, are identified. Ten or 15 attributes are proposed as a practical limit for MSMs. Each attribute is evaluated by a detailed questionnaire. Financial conditions, production capability, lead time requirements, facility, process control capacity, special equipment, etc.

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are the typical examples of the attributes for the supplier selection process.

(3) *Developing the MSM criteria.* Each attribute is measured by a series of criteria, each of which has the range of 0 to 100 percent. These are the examples of the criteria related to the attributes cited above, such as financial stability and investors; number of designs produced per year and current available capacity; prototype and production; geographic location, condition of facility, and condition of equipment and tooling; statistical process control, inspection, reliability and total quality control; CAD and CAM, respectively.

(4) *Determining the proportional value of the attributes.* In this step, the attributes are listed and the relative importance of each are determined by assigning a number between 0 and 100. These numbers then are added together and the proportional value of each attribute is obtained by dividing the number assigned to each attribute by the sum of all the attribute values. The sum of the proportional values must equal 1.0. Each attribute receives a normalized value that is the sum of the values given to the criteria, divided by the number of criteria used. Finally, the expected utility of each attribute is calculated by multiplying the proportional value and the normalized value. The total expected value must be calculated for each supplier in this step.

(5) *Constructing the MSM evaluation form.* The form is designed to present the normalized values, proportional values, expected utilities of each attribute, and the ranking of suppliers according to the total expected utilities. Thus, the values of various attributes for the suppliers may be monitored at the same time.

As a result of these five steps, the appropriate supplier is selected for the buyer company. However, this supplier may not always be the one that provides the highest expected utility. For example, even the supplier company has the highest technical capability, it may not use the quality control technique, but the buyer can decide on this supplier by aiming to help the supplier training on quality. In order to make right decision; the managers should evaluate the supplier ranking on the MSM form in more detail.

An application of MSM for supplier selection in a case company

In this section, it is aimed to reduce the supplier base of a company under lean philosophy. The considered company is active in the glass industry. Four basic products are produced in the company, such as glass molding machines, their spare parts, glass molds and their accessories, parts and machines for the defense industry. The procurement activities are carried out traditionally and purchases are done by methods, such as offering, bargaining or covering in the company. The receiving control is applied on the purchased parts and materials through 100 percent inspection or sampling methods. Scrap, return, correction, and standard repair decisions are made for inappropriate parts or materials by the receiving team. There is a study of conversion to the cellular manufacturing in the company, which is the reason why this company is chosen for applying MSM. It is necessary to reduce the number of the suppliers as much as possible for successful implementation of a cellular system. Thus, it is possible to work with proper suppliers and realize the supply activities according to their schedules for supplying the parts and materials at the required quality, in the required number, in the required specifications, and just in time. Reducing the number of suppliers in a company under cellular manufacturing is more rational than a company with functional layout. If there is a defect or a delay in a cell, it has a negative effect on only its cell, but the whole system is not affected, whereas, any problem in material supply in a functional layout affects the output of the whole system negatively. Because of this, it is useful to say that the manufacturers with functional layout must operate with multiple suppliers to reduce the problems of material supply (Durmuşoğlu and Altuğ, 1997).

The application steps of the MSM at the company follow.

Generating criteria for prescribing suppliers

Since the glass mold and spare parts production are the main activities of the company, the suppliers concerned with these activities are considered for evaluation. In the company, some products are sent to the subcontractors for processing or complete manufacturing. The processes are done by the products in these subcontractors such as metal cutting, casting, modeling, pantograph, welding, special operation, threading, steel construction, grinding, polishing, cutting and bending, spring, etc. These processes are listed separately for two basic production types, which are mold and spare parts production. The bases of product, producer (supplier) or process are taken into account, as the selection criteria for considering which suppliers will be evaluated. It is decided that the selection and evaluation of suppliers on the process basis is more effective as a consequence of discussions with managers. Table I shows the number of subcontractors by the types of processes and the basic types of productions.

The number of suppliers is examined for mold and spare parts production according to the processes cited above, and the metal cutting process with the most assortments is selected for the application of MSM. As seen in Table I, the company works with 58 suppliers for metal cutting process which of 43 for spare parts and 15 for mold production. Ten subcontractors are decided for the selection process, which can be alternatives for each other, and the company prefers them at most.

Selecting the attributes for MSM

In this step, the important attributes for the company are determined under lean supply principles, which are A_1 (reliability), A_2 (capability), A_3 (quality organization), A_4 (geographic location), A_5 (financial condition), A_6 (service level) and A_7 (price).

Table I Number of subcontractors by the products

Process type	Spare parts mnfg	Glass molds mnfg
Metal cutting	43	15
Casting	17	7
Modeling	3	1
Threading	3	–
Special process	3	–
Grinding	2	1
Pantograph	3	1
Cutting and bending	3	–
Welding	1	1
Spring	1	–
Steel construction	2	–
Polishing	–	3
Special operation	–	2

The related criteria determined for the attributes are demonstrated as C_i in Table II.

Determining the proportional value of the attributes

In this step, the relational value is assigned to the attributes considering the lean requirements. The relational and proportional values (PVs) of the attributes are presented in Table III. It is seen from the table that the most important attribute is A_3 (quality organization), the second most important A_6 (service level), and the price the least.

Developing the MSM criteria

A_1: reliability of subcontractor

This is measured by C_1 (from the highest business experience to the lowest), C_2 (from the highest number of companies referenced to the lowest), and C_3 (from the highest number of years worked with the company to the lowest). Table IV gives the reliability of each subcontractor.

A_2: capability of subcontractor

This is measured by C_1 (technology level) and C_2 (total monthly capacity). C_1 is examined by the high (CNC, digital coordinate machines and the machines with 0.1 percent accuracy), medium (NC and the machines with 1 percent accuracy), and low (the machines with 2 percent and more accuracy) technology levels, and is assigned 100, 70, and 40 points respectively. In calculating the total monthly capacity of the company, C_2 is examined and a subcontractor with the highest capacity (as machine hours) is evaluated with 100 points, considering that the subcontractor works eight hours in a day and 22 days in a month. the capability of each subcontractor is given in Table V.

A_3: quality organization

This is measured by three criteria as seen in Table VI. C_1 (quality performance) is evaluated by two measures in the company, and the first one is used by quality, and the purchasing department is responsible to build the preferred subcontractors list by considering the quality performance measure number 2 prepared by the quality department. The subcontractors with points between 85 and 100 are preferred for the preference list among these performance values in 0-100. The performance values in the preference list prepared by purchasing

Table II Attributes and related criteria

Attribute/criteria	C_1	C_2	C_3
A_1: reliability	Years in business	Customers referred	Years in work together with
A_2: capability	Technology level	Total monthly capacity	
A_3: quality organization	Quality performance	Certification	Quality control applications
A_4: geographical condition	Geographic proximity		
A_5: financial condition	Financial stability		
A_6: service	Keeping a promise of due dates	Keeping the right amounts of orders	
A_7: price	Sales price		

Table III Assigning the proportional values to the attributes

Attributes	Relational value	Proportional value PV
A_1	75	0.13
A_2	90	0.15
A_3	100	0.17
A_4	85	0.14
A_5	85	0.14
A_6	95	0.16
A_7	70	0.11
Total	600	1.00

department are based for C_1. C_2 is evaluated as 0 points since none of subcontractors are certified. C_3 is evaluated by quality control efficiency (received/total*100). As examining these values, it is determined that the subcontractors cannot provide the quality perfectly. Due to this reason, eliminating the receiving inspection is not quite possible. However, the company provides the technical aid for the calibration of measurement tools and the control of machine accuracy to the subcontractors for improving their conditions.

A_4: geographical condition
This is measured only by the geographic proximity. All of the subcontractors are assigned 100 points because they are close to the company.

A_5: financial condition
The financial condition of the subcontractors is evaluated by financial stability C_1. Considering the information from the purchasing department, it is assigned 60 points for good, 80 points for better, and 100 points for the best.

A_6: service
Statistics is used in the purchasing department for A_6. C_1 (keeping a promise of due dates) and C_2 (keeping the right amounts of orders) are examined. It is determined that all the purchased materials are delivered early by due dates from the subcontractors, and purchase order quantities are not provided. In spite of this situation, the company does not apply any procedure. Delivery of purchased materials early or late by due dates is the problem for just in time or effective purchasing. As the basis of one week early, C_1 is evaluated for each subcontractor as follows.

Table IV A_1: reliability of subcontractor

Subcontractor no.	C_1: years in business	Point	C_2: customers referred (units)	Point	C_3: years in work together	Point
1	16	53	1	50	16	80
2	30	100	1	50	20	100
3	21	70	3	80	10	50
4	10	33	1	50	7	35
5	9	30	6	100	9	45
6	1	3	1	50	1	5
7	14	47	1	50	2	10
8	25	83	1	50	5	25
9	15	50	1	50	2	10
10	16	53	1	50	5	25

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Table V A_2: capability of subcontractor

Subcontractor no.	C_1: technology level	Point	Number of machines	C_2: total monthly capacity (machine-hours)	Point
1	Medium	70	6	1,056	40
2	Low	40	15	2,640	100
3	Medium	70	6	1,056	40
4	Medium	70	3	528	20
5	High	100	9	1,584	60
6	High	100	6	1,056	40
7	Medium	70	5	880	33
8	Medium	70	5	880	33
9	High	100	10	1,760	66
10	Low	40	7	1,232	47

Table VI A_3: quality organisation

Subcontractor no.	C_1: quality performance	Point	C_2: certification	Point	C_3: quality control applications	Point
1	91.62	92	–	0	0.87	87
2	92.10	92	–	0	0.89	89
3	81.13	81	–	0	0.73	73
4	89.79	90	–	0	0.83	83
5	97.67	98	–	0	0.81	81
6	97.29	97	–	0	0.52	52
7	89.31	89	–	0	0.86	86
8	87.58	88	–	0	0.82	82
9	92.26	92	–	0	0.85	85
10	96.97	97	–	0	0.87	87

The E_i/N_i ratio is calculated where E_i is the number of early delivery for each subcontractor and N_i is the total number of order for each subcontractor. For the highest ratio of C_1 is evaluated as 70 points. The amount of incoming material and ordered number are compared, and C_2 is evaluated by the ratio of OS_i/N_i*100.

A_7: price

Price is measured by sales price C_1. It is determined that the subcontractors do not have any price policy, and due to these inconsistent prices C_1 is assigned 40 points for all subcontractors. Geographical and financial condition, service and price are given in the Tables VII-X, respectively.

Evaluation of the MSM form

The next step is concerned with the calculation of the expected utilities for each subcontractor. In order to obtain the expected utilities, first the normalized values are calculated for each attribute (Table XI). Normalized value (NV) is calculated as the sum of the values given by the criteria, divided by the number of criteria used. Then, the expected utilities related the attributes (EU_k) for each subcontractor and the total expected utilities of each subcontractor (TEU) are obtained. The formula for these calculations is given below and the results are presented in Table XII as a MSM form:

$$EU_k = PV_k * NV_k TEU_k$$

$$= \sum_{k=1}^{7} (PV_k * NV_k). \quad (1)$$

As it seen in Table XII, subcontractor 1 provides the highest expected utility. It is offered that the subcontractor 5 is an alternative. Even if these two suppliers have equal values to the attribute A_3 (quality organisation), which is the most important for just in time purchasing, subcontractor 1 that has obtained the higher value according to the attribute

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Table VII A_4: geographical condition

	Subcontractor no.									
	1	2	3	4	5	6	7	8	9	10
C_1: geographic proximity	100	100	100	100	100	100	100	100	100	100

Table VIII A_5: financial condition

	Subcontractor no.									
	1	2	3	4	5	6	7	8	9	10
C_1: financial stability	80	100	80	60	100	80	60	60	60	80

Table IX A_6: service

Subcontractor no.	C_1: keeping a promise of due dates (E_i/N_i)	Point	C_2: keeping the right Amounts of orders (OS_i/N_i)	Point
1	0.9	63	31/48	65
2	0	0	1/5	20
3	0.4	28	3/5	60
4	0.1	7	8/8	100
5	0.3	21	11/45	24
6	0.5	35	7/15	47
7	1	70	6/29	21
8	0.6	42	13/13	100
9	0.6	42	5/5	100
10	1	70	8/18	44

Table X A_7: price

	Subcontractor no.									
	1	2	3	4	5	6	7	8	9	10
C_1: sales price	40	40	40	40	40	40	40	40	40	40

Table XI Normalised values for subcontractors

Attribute	A_1	A_2	A_3	A_4	A_5	A_6	A_7
Proportional value (PV)	0.13	0.15	0.17	0.14	0.14	0.16	0.11
Normalised values							
Subcontractor 1	61	55	59.6	100	80	64	40
Subcontractor 2	83.3	70	60.3	100	100	10	40
Subcontractor 3	66.6	55	51.3	100	80	44	40
Subcontractor 4	39.3	45	57.6	100	60	53.5	40
Subcontractor 5	58.3	80	59.6	100	100	22.5	40
Subcontractor 6	19.3	70	49.6	100	80	41	40
Subcontractor 7	35.6	51.5	58.3	100	60	45.5	40
Subcontractor 8	52.6	51.5	56.6	100	60	71	40
Subcontractor 9	36.6	83	59	100	60	71	40
Subcontractor 10	42.6	43.5	61.3	100	80	57	40

A_6 (service level) has the second importance. However, capability of subcontractor 5 is better. Some suppliers are ranked below whereas their A_3 values are high. Consequently, it is possible to say that subcontractor 1 is the most appropriate supplier for the company.

Conclusions

The evaluation of suppliers is the most important continuing process of purchasing. Single sourcing provides easy control of procurement for achieving the lean supply objectives beside some important advantages

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Table XII Ranking of the suppliers by MSM

Subcontractor no.	A_1	A_2	A_3	A_4	A_5	A_6	A_7	*TEU*	Rank
1	7.93	8.25	10.132	14	11.2	10.24	4.4	66.152	1
2	10.829	10.5	10.251	14	14	1.6	4.4	65.580	3
3	8.658	8.25	8.721	14	11.2	7.04	4.4	62.269	6
4	5.109	6.75	9.792	14	8.4	8.56	4.4	57.011	9
5	7.579	12	10.132	14	14	3.6	4.4	65.711	2
6	2.509	10.5	8.432	14	11.2	6.56	4.4	57.601	8
7	4.628	7.725	9.911	14	8.4	7.28	4.4	56.344	10
8	6.838	7.725	9.622	14	8.4	11.36	4.4	62.345	5
9	4.758	12.45	10.03	14	8.4	11.36	4.4	65.398	4
10	5.538	6.525	10.421	14	11.2	9.12	4.4	61.204	7

such as long-term relationships, consistent quality, lower costs, special attention, savings on tooling, etc. In this paper, a case study of a company of supplier evaluation and selection for lean supply is presented.

The considered company is active in the glass industry. The purchasing and procurement activities are carried out traditionally, and the purchasing department of this company works with a large number of and different kinds of suppliers, such as vendors, subcontractors, etc. On the other hand, a study of conversion to the cellular system has been conducted in the company. For successful cellular system implementation, it is necessary to reduce the number of suppliers to a minimum. In order to reduce the supplier base for obtaining the cellular system benefits under lean supply, the supplier selection and evaluation study is conducted by MSM in five basic steps.

In the first two steps, the criteria are generated for prescreening suppliers, and the attributes for MSM are selected by consulting the managers. Discussions held with managers have led to the decision that the selection and evaluation of suppliers on the basis of process is more effective and ten subcontractors are decided for the selection process. The MSM criteria are developed in the third step under lean principles. Quality organization of the supplier and service are identified as the most important factors of evaluation. The proportional value of the attributes is determined in the fourth step. Finally, the MSM evaluation is realised and the selected supplier (subcontractor 1) is proposed to top management.

Subcontractor 1 provides the highest expected utility, however it has not the highest values for all attributes. It means that subcontractor 1 needs some improvements, especially for the attributes A_3, A_6, and A_2. The following recommendations are made based on the MSM evaluation under lean supply:

- To improve product quality, incoming control must be eliminated at the company. Subcontractor 1 is motivated to achieve higher quality by moving the responsibility for incoming control to itself after regular auditing of its plant by the company engineers. Therefore, improving technology and sustaining long-term relations will affect the quality performance in a positive way.
- Subcontractor 1 must improve the service performance by increasing the percentage of time and amount that delivery promises are met. On the other hand, since there is no effort for just in time purchasing in the company, beyond reducing the number of suppliers, it is especially necessary to eliminate the inventory waste due to the wrong lead times and due dates in order to conduct effective purchasing. The company and subcontractor 1 should collaborate on timely notification regarding parts, lead time, material shortages, production shutdown, etc.
- Subcontractor 1 can improve capacity performance by adopting the modern technology and increasing total monthly capacity.
- Sales price is at the same level with respect to other suppliers. Employment of cost reduction techniques may cause decreases in price.

Supplier selection is only considered for the metal cutting process in this study.

Conducting the supplier base reduction for casting process, and the supplier development project are proposed to future study.

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