SUPPLIER EVALUATION IN ELECTRONIC PROCUREMENT

(ELEKTRONİK SATIN ALMADA TEDARİKÇİ DEĞERLENDİRMESİ)

by

Berke Baran ÇALIŞKUR, B.S.

Thesis

Submitted in Partial Fulfillment
of the Requirements
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Berke Baran ÇALIŞKUR
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LIST OF SYMBOLS

AHP: Analytic Hierarchy Process

AI: Artificial intelligence

ANP: Analytic Network Process

ASP: Application service provider

B2B**:** Business-to-business

CA: Cluster Analysis

cXML: Commerce XML

CMM: Computerized Maintenance Management

DEA: Data Envelopment Analysis

DISA: Data Interchange Standards Association

DTD: Document Type Definition

EDI: Electronic Data Interchange

ERP: Enterprise Resource Planning

FST: Fuzzy Set Theory

JIT: Just-in-Time

MCDA: Multicriteria Decision Analysis

MP: Mathematical programming

MRO: Maintenance, Repair and Operating

OAGI: Open Applications Group, Inc.

ORM: Operating Resource Management

RFP: Request for Proposal

SCM: Supply Chain Management

SGML: Standard Generalized Markup Language

SRM: Supplier Relationship Management

SWIFT: Society for Worldwide Interbank Financial Telecommunications

TCO: Total cost of ownership

xCBL: XML Common Business Library

XML: Extensible Markup Language

VAHP: Voting Analytical Hierarchy Process

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ABSTRACT

E(lectronic)-procurement is the business-to-business purchase and sales of supplies and services over the Internet. Depending on the approach, buyers or sellers may specify prices or invite bids, and transactions can be initiated and completed. Participating companies expect to be able to control parts inventories more effectively, reduce purchasing agent overhead, and improve manufacturing cycles.

As a part of e-procurement, multiple sellers of products vie for the business of a single buyer in reverse auctions. Bidding continues until a pre-established bidding period ends or until no seller is willing to bid any lower price. Reverse auctions have been identified by many large organizations as an effective tool to achieve procurement savings and with the advent of Internet, more and more companies are adopting its online version.

An important problem with reverse auctions is that they are narrowly focused on price reduction. Most of the time, bidding companies are forced to sacrifice form their product quality to remain in the competition. To overcome this complication, we propose an evaluation framework where sellers can compete in several dimensions concurrently and buyers have the opportunity to procure the best compromise. The approach is based on a multi-criteria decision making technique, namely 2-additive Choquet Integral aggregation, where interactions among decision criteria pairs can be taken into account. An automatic recommendation system is developed for the sellers to adjust their offers based on the winner of the actual auction stage. The proposed framework is applied for the procurement of an IT system in a Turkish company.

Keywords: E-procurement, Supplier selection, Bid evaluation, Multi-criteria decision making, Choquet integral

RESUME

L'approvisionnement électronique concerne l'achat et vente interentreprises des biens et des services sur Internet. Selon l'approche choisie, les acheteurs ou les vendeurs peuvent fixer les prix ou faire des appels d'offres, initialiser ou conclure des transactions. Les entreprises participantes à ce système prévoient de contrôler leurs inventaires plus efficacement, réduire les frais de commission versés aux intermédiaires, et améliorer leurs cycles de production.

Les enchères inversées en ligne font parti de l'approvisionnement électronique où plusieurs vendeurs sont en concurrence pour faire des affaires avec un seul acheteur. L'enchère continue soit pendant une durée déterminée à l'avance ou aucun des vendeurs n'offre un prix plus bas par rapport a l'actuel. Les enchères inversées ont été identifiés par beaucoup de grandes organisations comme un outil efficace pour réaliser des économies, et âpres l'invention de l'Internet, de plus en plus d'entreprises l'adaptent en ligne.

Un problème important lié aux enchères inversées est qu'elles sont canalisées à la réduction des prix. Fréquemment, les vendeurs sont obligés de sacrifier la qualité de leurs produits pour ne pas être hors de la compétition. Pour surmonter cette difficulté, nous proposons un système d'évaluation où les vendeurs peuvent concurrencer simultanément sur plusieurs dimensions et les acheteurs ont la possibilité d'acheter le meilleur compromis. L'approche s'est basée sur une méthode de prise de décision multicritères, l'intégrale de Choquet 2-additive, qui rende compte les interactions entre les paires de critères. Un système de recommandation automatique est développé pour les vendeurs voulant changer leurs offres selon le gagnant l'étape actuelle de l'enchère. Le système proposé est appliqué pour l'achat d'un équipement informatique pour une entreprise Turque.

Mots clés: Approvisionnement électronique, Sélection des fournisseurs, Evaluation des offres, Prise de décision à multicritère, Intégrale de Choquet.

ÖZET:

E(lektronik)-satınalma, malzeme ve hizmetlerin internet üzerinden işletmeler arasında alımı ve satımıdır. Kullanılan yaklaşıma göre, alıcılar veya satıcılar fiyat belirleyebilir veya teklif cağrısında bulunabilirler, alışveriş işlemini başlatıp sonlandırabilirler. Böyle bir sisteme katılan firmalar, stoklarını daha etkin kontrol etmeyi, aracılara yapılan masrafları azaltmayı ve imalat süreçlerini iyileştirmeyi beklerler.

E-satınalmanın bir parçası olan açık eksiltmeli ihalelerde, birden fazla satıcı tek bir alıcıyla iş yapabilmek için rekabet eder. Burada firmalar daha önceden karar verilmiş bir süre sonuna kadar veya daha düşük fiyat veren kalmayana kadar teklif verebilirler. Açık eksiltmeli ihaleler, büyük kurumlar tarafından önemli bir tassarruf aracı olarak görülmekte ve Internet'in ortaya çıkması ile daha çok sayıda şirketin benimsediği çevirimiçi bir faaliyet haline gelmektedir.

Açık eksiltmeli ihalelerin doğaları gereği içerdikleri bir kusur sadece fiyat odaklı olmalarıdır. Teklif veren firmalar yarışa devam edebilmek için çoğu zaman ürün kalitesinden fedakarlıkta bulunmak zorunda kalmaktadır. Bu sorunu aşmak üzere, satıcıların aynı anda birden fazla boyutta rekabet edebildiği ve alıcıların da eniyi ortalama çözümü edinme olanağına kavuştuğu bir değerlendirme sistemi önermekteyiz. Yaklaşım, karar ölçüt çiftleri arasındaki etkileşimi dikkate alan ve bir çok ölçütlü verme yöntemi olan 2-toplanır Choquet tümlevine dayanmaktadır. Ayrıca, satıcıların ihalenin tamamlanan bir aşamasındaki galibe göre tekliflerini yeniden düzenlemede faydalanabilecekleri bir otomatik öneri sistemi geliştirilmiştir. Önerilen düzen bir BT sisteminin satınalmasında kullanılmıştır.

Anahtar sözcükler: Elektronik satınalma, Tedarikçi seçimi, Teklif değerlendirmesi, Çok ölçütlü karar verme, Choquet tümlevi.

1. INTRODUCTION

The 'e' in eprocurement stands for *electronic.* E-Procurement is the term used to describe the use of electronic methods in every stage of the purchasing process from identification of requirement through to payment, and potentially to contract management, and is at the same time, the use of electronic tools and systems to increase efficiency and reduce costs during each stage of the purchasing process.

E-procurement (electronic procurement, sometimes also known as supplier exchange) is the business-to-business or business-to-consumer purchase and sale of supplies and services through the Internet as well as other information and networking systems, such as Electronic Data Interchange and Enterprise Resource Planning. Typically, e-procurement Web sites allow qualified and registered users to look for buyers or sellers of goods and services. Depending on the approach, buyers or sellers may specify costs or invite bids. Transactions can be initiated and completed. Ongoing purchases may qualify customers for volume discounts or special offers. E-procurement software may make it possible to automate some buying and selling. Companies participating expect to be able to control parts inventories more effectively, reduce purchasing agent overhead, and improve manufacturing cycles. E-procurement is expected to be integrated with the trend toward computerized supply chain management.

With the advent of the Internet, many businesses now sell only via computer technology. It is an excellent way for businesses to cut overhead costs and reach a larger customer base. E-procurement is not only beneficial for businesses; customers can also find this method of purchasing advantageous. They have a wider choice of merchandise and can shop without leaving their home. With a little web research, they can easily find the lowest price when purchasing goods. E-procurement is done with a software application that includes features for supplier management and complex auctions. eBay's tools for its sellers have similar features.

The Internet and Internet-based technologies are impacting businesses in many ways. With the increasing pressure that companies are experiencing as markets become more global, the Internet continues to play a critical role to speed up operations and to cut costs. By enabling new business processes, Internet also helps organizations to react quickly and efficiently in order to keep up with changing market requirements [1].

One such business process that has gained much attention in recent times is Business-to-Business e-procurement. E-Procurement is an Internet-based business process for obtaining materials and services and managing their inflow into the organization. Procurement is an important part of the more general supplier selection or vendor selection problem [2, 3], which is concerned with the selection of candidate suppliers, determining the nature of contracts with them, and then selecting the best set of suppliers among the alternatives.

The changing nature of the marketplace along with the increasing power of internet technologies has lead to an increased demand for innovation, quality and cost control. In today's competitive marketplace, companies have to consider re-engineering their process and getting rid of traditional understanding of management in order minimize their cost, build a strong foundation, and survive. Instead of traditional relationships, companies have to built " true business partnerships " that can lead to agreement that provide equal risk sharing [4].

E-procurement is the outcome of the all these efforts particularly aiming to improve supply process to gain efficiency and save money. E-procurement technology is defined as any technology designed to facilitate the acquisition of goods by a governmental or a commercial organization over the internet. Upgrading to e-procurement from traditional procurement helps organizations to reduce operational costs, to shorten the order fulfillment cycle time, to lower inventory levels, and to create collaborative partnerships [5].

The structure that is developed in this thesis is a supplier evaluation in e-procurement that can be used to evaluate the alternatives. The technique for analyzing the decision is based on Choquet Integral method. The dynamic characteristics and complexity of our decision criteria, which is true for most strategic decisions and evaluations, makes the Choquet Integral method a suitable tool.

The organization of this thesis is then as follows: The thesis begins with the presentation of E-procurement. In this part e-procurement vision of the future, support for and the benefits and disadvantages of e-procurement are set forth. Then, the author structures main components of e-procurement into a supplier evaluation framework. The criteria are explained in detail and the effects of them are analyzed. With the help of Choquet Integral method , a conceptual evaluation is represented. In the next phase the thesis focuses on the illustration of the methodology through the case of bids. As a conclusion, the author gives some concluding remarks.

2. E-PROCUREMENT

2.1. E-PROCUREMENT VISION OF THE FUTURE

Any employee can be provided on his or her desktop PC with access to a user-friendly point and-click system on which he or she can browse through on line catalogs of the company's approved vendors. Products can be identified by features or by model numbers or names, and the search will prioritize the results according to how well items match the buyer's requirements. Prices can be compared between suppliers, and discounts calculated easily. Information concerning availability, delivery, and payment of supplies is readily available, and payments can be made electronically.

Approvals for standard supplies are automatic. There is a complete audit trail of the request, price, approval, and payment information, and transaction information is captured and recorded for vendor performance analysis. All purchase order and delivery details are available online for both the supplier and the buyer to see.

Advanced companies are already able to tap the Internet to source parts globally, manage inventory collaboratively, forecast and plan production and manufacturing starts with key suppliers, and provide transparency between enterprise resource planning (ERP) systems so that suppliers can "see" and participate in the planning and execution of manufacturing forecasts. All of this can be done in real time, greatly reducing the need to carry excess safety stock or to maintain complex contractual relationships with preferred vendors.

In its most perfect state, the simultaneous availability of data to all the parties in the extended supply chain means that—with the elimination of uncertainty, people, and paper—transaction time will be reduced to very little more than the actual time it takes to physically transport the materials. At best, this can dramatically increase service levels, smooth out the supply chain, and reduce costs.

E-procurement becomes the catalyst that will allow companies to finally integrate their supply chains from end to end, from sales to supplier, with shared pricing, availability, and performance data that will allow buyers and suppliers to work to optimum and mutually beneficial prices and schedules. Fortunately, the question is not whether or not this level of functionality can be achieved; it is more a question for individual companies of how to achieve it, and at what price.

2.2. MAKING THE BUSINESS CASE FOR E-PROCUREMENT

As with any major investment of time and resources, an eprocurement initiative should be based upon a strong and well-documented business case. The e-procurement business case comes from three areas: *process efficiencies, compliance,* and *leverage*

2.2.1. Process Efficiencies

Three areas of focused improvement: process efficiencies, compliance, and leverage are important then to look at when developing an e-procurement business case. There are several ways that an e-procurement system creates cost savings. The first and most obvious are the savings that come from automating the process, eliminating paperwork and human intervention, and reducing transaction costs and cycle time.

The second focus area for efficiency savings is more structural than procedural, and comes from shifting the selection and ordering process back to the employees' desktop, eliminating the multiple purchasing middlemen now involved in everyday indirect goods procurement, and giving the individual employee the choice—and responsibility—for purchasing goods.

2.2.2. Process Automation Savings

Any good e-procurement software system today is designed to greatly reduce the time and effort required to complete purchasing transactions by eliminating our traditional paper chain of requisitions, approvals, receiving, and payment reconciliation. The key features of most of these e-procurement approaches enable users to find an item in an electronic catalog, create a requisition, have the order requisition routed for approval (if necessary), create and transmit the order to vendors, and (in varying degrees) help to automate the payment and invoicing process.

There are two key elements to this approach. First, the entire procurement process—budgeting, requisitioning, ordering, approval, purchase order development, payment, and delivery—should be completed electronically and, as much as possible, simultaneously, so that there is a minimum of manual intervention or delay. Second, the entire process becomes "rebalanced" so that the hundreds of thousands of ordinary and uncontroversial purchases take place with the minimum of supervision or human intervention, and only "exceptions" are flagged through exception reports for the attention of procurement specialists or management.

At the heart of this system is the online catalog, usually assembled and maintained by the supplier. These catalogs provide information such as product descriptions with clear specifications and sizes, availability and lead times, delivery policies, schedules, and the negotiated terms, conditions, and discounted prices of items. The requisition and approval process is activated automatically, and the system then converts the requisition into electronic purchase orders that are automatically integrated into the buyer's ERP and back-end systems. Aside from the catalogs, most good e-procurement systems also then include:

• **Requisitioning**

The system should provide customized supplier lists and electronic catalogs, which can be searched using powerful search engines that help employees to quickly locate what they want to purchase by broad category, part description, or supplier. These databases can be customized by group or department, and include security systems based on passwords and authorization. The system should also provide comparative product and pricing information, online standard forms, contracts, hyperlinks to supplier Web sites and RFPs (Request for Proposal), and user-friendly purchasing negotiation tools for nonspecialists.

• **Approval routing**

All good e-procurement systems provide an automated, e-mail-based approval workflow tool that can be customized around approval parameters and can be set to automatically prioritize according to required date. They also ensure timely approval by electronically appearing on the approving manager's screen, and if no response is received, moving on automatically through a series of deputies.

• **Order management**

This includes consolidated and automated ordering, shipping and reordering, and receiving and invoice approval functions. The requisition numbers and purchase order numbers are automatically reconciled, removing the tedious and inaccurate "rationalization" process that takes up so much employee time today. Paper requisitions totally disappear. Good systems also provide for real-time order tracking and requisition status.

• **Summary billing and consolidated reporting**

The system automatically notifies accounts payable, without having to produce a paper-based invoice or to match against the original requisition form. There is an accurate and auditable posting of all purchases and costs, providing the company with information on committed costs at the instant that they are recorded.

• **ERP and CMM (Computerized Maintenance Management) systems integration**

Most e-procurement systems provide a number of direct links to your company's ERP procurement modules and, if procuring blue collar maintenance (MRO) inventory, can provide much higher accuracy and lower inventory handling costs by exchanging information on forecasts, purchases, inventory levels, and delivery status directly to and from your CMM system.

• Decision support

These systems also provide flexible reporting options that help procurement specialists capture company spending history by item, person, department, and vendor, providing the information necessary to predict future purchasing trends, estimate workloads, and negotiate better contracts with suppliers.

• Asset management

Purchasing is just the first step in the asset management process, and costs related to delayed orders, long approval times, lost orders, or purchasing IT products with incompatible technologies are increasingly significant—particularly as organizations continue to see hardware and software products proliferate throughout the firm.

The system should be as simple and straightforward as possible, using click-and-order technology with frequently purchased goods bookmarked and each item presented with a color identification photo and a detailed product description. It should be events-based so that it can support recurring events, such as training workshops for which there will be a need for manuals, flip charts, overhead markers, and catering. It should seamlessly transcend multiple supplier and catalog boundaries, and support changes to pricing and promotion materials on a real-time basis. And, finally, it should provide strong workflow direction, including automatic approval deputization, a full audit trail, and instant update of in-house financials and other back-office systems.

2.2.3. Compliance

The system reduces maverick buying and ensures compliance to the organization's purchasing guidelines, which in turn means both lower transaction costs and more certain receipt of discounts. The system also provides accurate and comprehensive data on buying, and on the flip side, accurate and timely data on supplier costs and performance. This clarity on purchasing activity—possibly most important of all—provides organizations with the ability to understand the trade-offs between service and price.

"Self-service" model requires a good deal of change management, rethinking rules, and changing behavior; but is ultimately the key to eliminating redundant processes and maverick buying. Although electronic controls are effective, they are much less obvious than the paper-based requisitions or signed approval slips, and at the outset, may be a little below the comfort level of some managers.

The very fact that indirect, and particularly MRO goods, is so easy to select and buy, of course, makes this area the first to be targeted for streamlining and automation. There is a logical progression in terms of software and support offerings that for the last years has focused on straightforward indirect purchasing, but is quickly shifting toward the more complex purchasing decisions of MRO and direct materials.

2.2.4. Leverage

One of the most important advantages that come from an e-procurement infrastructure is that robust new reporting and decision support tools now help procurement specialists to scrutinize their buying patterns, providing more dependable information on performance, compliance, and the effectiveness of comparative buying practices or supplier selection. A key area, for example, in the global supply chain, is often-overlooked extra costs or cost savings associated with customs duties or export taxes. Purchasing an item from China less expensively may result in a customs tax that negates the savings, while paying more for the same item from a second country, even at a higher price, might mean an overall savings.

Accordingly, reporting capabilities should

- Provide a better understanding of users' behavior.
- Strengthen relationships with vendors.
- Accurately record vendor performance.
- Reduce off-contract or maverick buying.
- Provide exact figures on process cost.
- Calculate any legal or tax consequences of the purchase.

Not only does this allow for better strategic and tactical buying, but all of this frees up staff to work on other things, including analyzing best performance, working with suppliers to improve cost effective relationships, and renegotiating performance rewards.

2.3. E-PROCUREMENT STRUCTURE AND APPLICATION TYPES

Particular solutions for specific businesses and different understandings of e-procurement have resulted in four main types of e-procurement applications: Internet purchasing consortia; Internet B2B auctions, Internet market exchanges and E-procurement software solutions as mentioned by Davila et al. [6]. All these applications need a common technological support. Companies decide what kind of application they should implement and consider their place in the market.

For companies the application selection process depends on companies' policies defining what degree of relationship they would like to have with their buyers or suppliers.

2.3.1. Internet Purchasing Consortia

Internet purchasing consortia is the internet service that gathers the purchasing power of many buyers to negotiate more aggressive discounts. Some organizations aggregate buying power for manufacturing inputs, while others perform similar functions for indirect goods. Buyers and suppliers know each other very well and do not communicate through a third party in Internet purchasing consortia. An Internet purchasing consortium can be seen as a much organized but small type of Internet market exchange. Entering into consortia is supported by regulations which are created by both parties and is more restricted than Internet market exchanges. Some examples can be seen in local businesses and municipalities. There are no information exchange mechanisms which prevent suppliers and buyers from going into the collaborative partnerships although there are strong relationships among buyers and suppliers.

2.3.2. Internet Business-to-Business (B2B) Auctions

Internet B2B auctions are events in which multiple buyers place bids to acquire goods or services at an Internet site. There are a variety of e-auction formats. The two most popular auction formats are the Dutch auction where the sellers control the minimum bid and prices move upward from the minimum bid and the reverse auction that is designed in a way that the buyer invites suppliers for bidding and the supplier who submits the lowest bid wins. A major benefit of auctions is that they enable organizational buyers to identify the best offer from an expanded base of potential suppliers from around the world. Sellers benefit by obtaining access to bid for business on a level playing field rather than attempting to obtain business based on networks of personal relationships. Auctions also provide sellers with a ready market for the anonymous sale of excess inventory. In this case the auction keeps away buyer from having strong relationships with its suppliers. Internet B2B auctions mostly end up with "win-lose" rather than "win-win" situations because auctions are competition tools. That will lead to "competitive relationships" between buyers and suppliers instead of "collaborative relationships". Since procuring these goods does not necessarily need collaborative partnerships, these tools can be used for procuring (MRO) goods.

2.3.3. Internet Market Exchanges

Internet market exchanges are the web sites that bring multiple buyers and sellers together in one central virtual market space and enable them to buy and sell from each other at a dynamic price that is determined in accordance with the rules of the exchanges. The evolution of e-procurement sites has been so rapid that it prompted some analysts to say that "Charles Darwin never saw anything like this" [7]. Still, there have been several identifiable stages in the fast forward evolution of B2B marketplaces [8, 9, 10]:

1. Big corporations such created buying and selling hubs in the Internet designated to cut costs and speed supply procurement.

2. Third-party exchanges appeared, facilitated by independent firms. They brought together many buyers and sellers and created a genuine market in a number of areas (primarily non-production-related goods).

3. Major players of some vertical industries are joining in eprocurement consortiums.

These different marketplace forms coexist although they represent different stages of e-procurement evolution. Whether all of them survive depends on the way the industries whose needs they serve will be structured in the future. Currently, two extreme structures determine the organization of the industries. Some are organized in an asymmetric, "pyramid shaped" manner, with a limited number of either buyers or sellers; others are "butterfly-shaped," that is, highly fragmented on both sides [10].

The first type of structure tends to generate "biased markets" [10] that "naturally favor one side of the deal flow" [10]. These marketplaces approximately correspond to the first and third model of a B2B marketplace mentioned above. They have the advantage of low cost, associated with persuading the critical mass of users to join the marketplace. And they can be financed and/or owned by market participants without compromising themselves, since small firms are used to the idea of working alongside big ones [10].

The butterfly-shaped markets are "neutral" [10]. They lend themselves to independent, third-party exchanges that are closer to the second model. They have the advantage of being more like true markets such as stock exchanges and, thus, are better able to lower prices and improve liquidity by matching buyers and sellers [10]. The potential for these exchanges is great, but gaining critical mass of users is difficult, which undermines the future of many of the exchanges.

Some authors claim that e-procurement consortiums based on specific vertical industries (but not dominated by a single organization) represent clear progress in the evolution of a B2B marketplace [7, 10]. Such a marketplace brings all participants of a supply chain together in a single location. This may result in cross-pollination of cost-saving and market access effects across the whole supply chain.

Some other classifications of e-procurement sites stress the technical side of their operation. For example, Deloitte Consulting identifies three types of B2B services based on the content and features they offer [11]:

1. Online versions of companies' catalogs with listed products, prices, specifications, and sale and delivery terms.

2. Online auctions, which can be useful for dumping excess inventory and picking up bargains.

3. Online exchanges, which match buyers and sellers through bids.

It is quite possible and, even likely, that the pool of potential B2B marketplace models is not exhausted, and that in future we shall see new forms of e-procurement services. These new forms will bring new advantages to participants of such marketplaces. However, even today the benefits offered by B2B e-commerce are enormous, and most businesses cannot afford to neglect them.

2.3.4. E-Procurement Software

E-procurement software is another type of e-procurement applications that enables employees to purchase goods from approved electronic catalogues in accordance with company buying rules, while capturing necessary purchasing data in the process. The employee's selection of a good for purchase from a supplier catalogue is automatically routed through the necessary approval processes and protocols. E-Procurement software investment may take several forms, including purchase of a software package from a third party technology provider, use of an e-procurement system embedded in an Internet market exchange, subscription to e-procurement software hosted and supported by an application service provider (ASP), or development of a proprietary in-house system. E-Procurement software solutions are known as electronic Supplier Relationship Management (e- SRM) solutions and are basically designed to satisfy most of the needs of buyers who would like to deal with their suppliers by using electronic means. These software solutions are mostly created by giant enterprise software solutions providers. Some of these providers are given below.

1. Insight
2. Peoplesoft
3. Epicor Software
4. Ingram Micro
5. American Management Systems
6. Baseware Corporation
7. PurchasePro
8. Supply Works

Buyers who invest on e-SRM solutions don't deal with large number of suppliers and want to have strong relationships with their suppliers. They create a closed circuit by modifying the software for their needs and establishing secure connections through the use of e-SRM, in which suppliers and buyers can exchange critical information that may lead them to build collaborative partnerships.

Buyer companies have to classify their needs and make plans for moving their procurement process to the electronic environment. To have collaborative partnerships with suppliers is important but it doesn't have to be default case for all situations. The best way for companies to proceed is by following a flexible approach in which they can categorize their procurement process and adopt a different type of e-procurement application for each process.

2.4. TECHNOLOGY SUPPORT FOR E-PROCUREMENT: STANDARDS, XML AND EDI

In buyer and supplier relationships, the evolution of information technologies (IT) goes through four stages claims [12]. Hard copy forms take place everywhere but IT and telecommunications play minor roles in the first stage. In the second stage, Electronic Data Interchange (EDI) manages the electronic exchange of most of the business transactions. Inter-enterprise systems coordinate and integrate the operations using a centralized database. In the third stage, extensive information flows, strategic alliances and decision support systems characterize the final stage.

The development of new communications standards that allow buyers and sellers to transmit important purchasing transaction data easily and securely has been a critical element in the successful development of e-procurement systems. Because the effectiveness of any e-procurement or integrated order fulfillment system is dependent upon passing purchasing data from system to system, agreement on industry standards for communications has become of paramount importance.

Most companies have, or will soon implement, some form of ERP system, and it is the need to integrate procurement data—item numbers, descriptions, contracts, prices, invoice details—with those back-end systems that makes broad agreement on industry standards essential.

For the past years, Electronic Data Interchange has been the only real method for electronic transmission of business data between buyers and sellers. Although many large companies moved to develop EDI connections at least between their major trading partners, the combination of high maintenance overhead, expensive leased lines, and cumbersome protocol translations meant that EDI was too complicated and too expensive for all but the largest buyers and their key suppliers.

In 1996, however, a potentially revolutionary business data interchange standard came to the market with a new Extensible Markup Language (XML), which promised for the first time to provide a simple and affordable solution for secure exchange of transactional business data between firms.

XML promises to provide a simple and affordable solution for secure exchange of transactional business data between firms. XML standards are being set by various bodies and tend to be different in their development, based upon major industry sectors.

XML was everything that EDI was not. Because EDI assumed (correctly) that bandwidth would be extortionately expensive, EDI messages use a compressed and confusing set of codes, and much of the explanatory metadata that help programmers to decipher and debug messages has been left out. These compressed message formats not only make EDI transactions expensive and difficult to code, but they are inherent to the code itself, which essentially means it can't be fixed. All of this makes EDI programming difficult and expensive and EDI programmers often difficult to train and to keep.

XML is not a language itself, but a meta-language standard that provides a flexible and inexpensive way to create common data formats. A subset of the Standard Generalized Markup Language (SGML), XML uses plain text to provide *tags* that describe both the format for the data and the data content itself. These tags can be used to easily identify key pieces of everyday business data—an address, a price, or a customer name—and to code for a transfer of that data to respective symbols in other applications. This means that once XML tags are programmed to recognize and match against another application's symbols, that application can continuously receive transfers of data without having to redefine these links. Therefore, if all suppliers use an agreed-upon XML standard, once the interactive format is defined, the in-house system can read electronic data messages from any supplier using that set of XML data tags.

To make things even more sensible, each XML document is self defining and carries with it a Document Type Definition (DTD) that provides an explanation of the data language used in the document. In this way, although XML does not affect the way that companies label or organize their current data, it means that any system that supports XML can read and understand the data inside the document.

Creating DTDs is not difficult, and unlike Java and other codes, XML is easily learned and manipulated. But although each company could reformat their current systems to understand various DTDs, a proliferation of various and overlapping DTDs helps no one. For that reason, many hundreds of interested companies, including key IT industry leaders such as Sun Microsystems, IBM, and Microsoft are moving quickly to set industry standards for DTDs that are universally accepted by suppliers and vendors in their industry verticals. For those companies that have significant investments in EDI, there are a number of translators that will, with varying degrees of effectiveness, attempt to transform EDI into an XML format, or to break out the EDI codes into readable XML symbols, using an EDI parser.

In 1998, the Data Interchange Standards Association (DISA) conceded that XML as a Web-based technology would very likely replace the traditional ANSI X12 EDI as the business-to-business standard for business data exchange. For buyers, this means that they suddenly have potential direct electronic access to secure business file data transfer from small or specialist suppliers who would never have been able to participate in a program of EDI. For suppliers, they now have a relatively simple and inexpensive way to communicate directly with buyers.

There is still no true agreement on cross-industry standards for protocols at the product labeling or business transaction levels, and many groups within each industry are still struggling to come to terms with different variations. For example, if a company is in the financial services arena, it is likely that it agreed XML standards will be based on those agreed to by the 6,800 member banks of the SWIFT cooperative (Society for Worldwide Interbank Financial Telecommunications).

Electronic component suppliers will use XML data formats agreed to by RosettaNet. Insurance firms will use ACORD standard protocols. If as a supplier, you sell horizontal product lines—office supplies or travel services—to companies in a variety of industries, you may need to adhere to standards set by members of the OAGI (Open Applications Group, Inc.). Exchanges built on Ariba's software use the cXML (Commerce XML) protocol, while those using Commerce One are based on xCBL (XML Common Business Library).

2.5. THE BENEFITS OF E-PROCUREMENT

B2B marketplaces in the Internet could prove to be the most radical innovation in modern business since the assembly line was invented. Like assembly lines in the beginning of the 20th century, e-procurement sites promise significant increases in productivity across many industries of the economy. Their most often quoted advantage is their potential to cut costs of purchased goods and services [9, 13, 14]. The phenomenon of cost saving allowed by e-procurement is based on the new processes that cut all costs associated with purchasing, that is, the cost of goods and services purchased, ordering costs, and holding costs [7, 14, 15].

The availability and generally low cost of information and technology provided by Internet-based purchasing create absolutely different economics characterized by the following:

- low barriers for market entrance [14, 16],
- price transparency [7, 14],
- better opportunities to avoid "maverick buying" and to use preferred supplier networks [14],
- better balance of power between sellers and buyers [7].

These new economics of purchasing lead to competition that is closer to perfect and, as a result, to goods and services of better quality purchased for lower cost. A survey conducted by Aberdeen Group in November 1998 found that early adopters achieved a 5%–20% reduction in prices paid for operating resources [15]. Reduction in ordering cost, the second area of large cost savings, is associated primarily with the technological advantages of e-procurement.

The ordering process contains four key stages. These are request, buy, supply and remit. Costs associated with each of those purchasing process stages are effectively reduced when e-procurement systems are implemented [7]. Estimates made by Goldman Sachs, an investment bank, reveal that the ordering cost savings in manufacturing associated with e-procurement vary between 2% and 39% of the costs of goods and services purchased. The study by Aberdeen Group mentioned aproves the validity of those estimates [15]. The early adopters of e-procurement reached a 70% reduction in administration costs associated with processing a purchase request [15]. Cisco claims that it has already reduced those costs from \$130 to \$25 per order, and Microsoft, from \$60 to \$5 per order [17].

Further, e-procurement, as well as other Internet technologies, provides recently unthinkable opportunities for efficient integration of supply chains [15, 18]. Thanks to their low acquisition and implementation costs, eprocurement technologies outperform similar functions of ERP applications in the cost of acquisition and speed of implementation, allowing even small businesses and highly fragmented industries to benefit from integrating into supply chains. Supply chains create conditions that stimulate the implementation of modern Just-in-Time (JIT), lean manufacturing technologies.

Thus, the far-reaching result of economy wide adoption of e-procurement may be lower inventories and, consequently, lower inventory costs. Early adopters of e-procurement already demonstrate 25%–50% cuts in inventory costs [15]. Another important and frequently mentioned result of e-procurement implementation is shorter product development cycles [18]. These are rooted in the following improvements allowed by e-procurement systems [7, 15, 18]:

• Shorter order cycles.
• Significant improvement in project management and team collaboration across supply chains.
• Integrated information sharing across supply chains.

The shortening of product development cycles due to e-procurement practices is already evident in the U.S. automotive industry [7]. But apart from these astonishing opportunities, e-procurement poses a number of disadvantages that may make some of its potential users employ a “wait and see” strategy.

2.6. DISADVANTAGES OF E-PROCUREMENT

E-procurement, as any other improvement initiative, does not come without challenges. This section outlines some of the main impediments that have been discussed in the literature.

• **Technology uncertainty:**
A commonly quoted impediment is the immaturity of the technology. This is reflected in a number of concerns such security, reliability, interoperability and integration with other systems [19, 20, 21].

• **Process change**:

Rather than automating traditional procurement processes, organizations should focus on simplifying and improving these, however this requires time and resources [19, 21].

• **Cultural change:**

Moving from telephone, fax and paper processes and interpersonal communications involves an important change in attitudes and practices of people in organizations. Therefore the deployment of e-procurement can encounter various degrees of resistance [19, 21, 22].

Added to this, organizations might find their business partners do not have the technology to use electronic tools, or they are unwilling to accommodate the technical requirements supporting the systems [20, 23].

• **Logistical infrastructure not in place:**

E-procurement demands flexibility and responsiveness from the logistical support system. Traditional systems might not be ready for the increasing velocity of inventory and reduced shipment size and might require substantial reengineering to support the e-procurement operation [19, 22].

• **International trade via the Internet is still immature:**

Many buyers and sellers are not equipped to transact internationally. Issues such as language, culture and regulations barriers might prevent some companies from obtaining all the benefits of e-procurement [22].

• **Value:**

Van-Wassenhove and Yucesan argue that web technologies provide extended ‘‘reach’’ into a wider pool of potential suppliers. However, the ‘‘richness’’ of suppliers' capabilities provided by current web Technologies may not be adequate. This can represent a major obstacle for the development of e-procurement [24].

2.7. THE FUTURE OF E-MARKETS

Many industry watchers and software vendors would counter that it is only a matter of time before that higher level of integration is provided by the e-market portal owners. In fact, this need has already been partly addressed by a whole new platform of third-party integration software known as connectors.

Many of the early exchanges and auctions that focused on spot markets found that they were soon overtaken by larger, better-funded trading communities sponsored by alliances between market creators and the large software companies. Moreover, many of the smaller auction sites have found that contractual details and performance guarantees, necessary to ensure that buyers won't get burned badly by participating, require software and processes that incorporate a sophisticated and detailed approach to automated bidding—levels of expertise that they do not have and software that very few of them can either build themselves or afford to buy.

The idea behind strategic sourcing is that a few, preselected, tested, and trusted vendor partnerships are far more cost-effective—because of familiarity with processes and expectations, negotiated discounts, and ability to be trusted with secure information—than many partnerships with unknown or untested vendors, even if they are offering one-off low prices for their goods.

In contrast, many procurement specialists—both buyers and sellers—assert that spot markets, auctions, and many-to-many exchanges completely undermine the trusted one-to-one relationship that is at the heart of the strategic sourcing movement. On the contrary, at least until these e-market portals can be closely and securely integrated with a buying company's ERP and back-end systems, item price becomes the single most important criteria for trading with a particular vendor, which may be one of thousands of suppliers, each one selling on multiple horizontal and vertical industry e-markets. It is an unexpected strategic paradox that promises to divide the procurement community.

Eventually, it is the very concerned that a single e-marketplace will become dominant (winner take all) that are part of the motivation for venture capitalists to risk money backing a myriad of these e-marketplace startups. So volatile is this portion of the economy that there is some merit in spreading your risk. Customers will increasingly demand higher levels of service and integrated functionality from trading hubs, forcing a form of natural selection to take place in each industry vertical.

Much in the same way, there is also little doubt that customer demand, legal barriers permitting, will soon force these multiple and competing groups—e-procurement software vendors, ERP firms, market creators, auctions, exchanges, ASPs—toward consolidation. Customers are already demonstrating that they don't want to have to deal with a myriad of different vertical and horizontal suppliers. They want one or two organizations that can provide centralized sourcing for them. Many research groups contend that the need for a single, integrated solution for the full e-procurement process—for both indirect and direct materials and with an acceptable balance of systems integration capability and security—will quickly force a consolidation of the now fragmented e-procurement marketplace.

It may well be that if only as a matter of survival, as some argue, e-markets will move quickly to build in the third-party delivery and quality assurance services necessary to reassure buyers. The larger and more progressive trading communities—and this is where things become potentially revolutionary—are already providing a marketplace for direct materials, creating a much closer integration of supply chain systems than could have been contemplated only two years ago. There are many reasons for this, not least that the potential earnings are so good that the e-procurement and ERP software groups are scrambling to reshape themselves as partners in these hubs and exchanges, and are bringing valuable procurement expertise to add on to the features of the industry focus.

The reason that these types of Internet-based markets are so important, then, is that they may well be the catalyst that will push e-procurement away from the limited one-to-many extranet model, focused on a single buyer and several preferred vendors, toward a many-to-many arrangement where, even for many direct materials, buyers will go to a single online portal in order to bid on materials being sold on a real-time market.

3. LITERATURE REVIEW

3.1. UNDERSTANDING BUYER-SUPPLIER RELATIONSHIPS

Walter et al. [25] argue that buyers and suppliers engage in relationships towards gaining a "value" which they expect to have as an outcome of the relationships. The paper describes the concept of value as a variety of benefits that not only buyers but also suppliers acquire. The authors looked at the issue of value creation from the suppliers' perspective and conducted an empirical study for the sake of defining key elements of value creation.

Buyer and supplier relationships can be modeled through functions which can be divided into two parts: direct and indirect functions. Direct functions create value for the supplier and their results do not effect the supplier's other relationships. Three important direct functions are: profit, volume, and safeguard. In contrast, indirect functions effect the supplier's other relationships. Market function is one of them and it is created through getting referrals from existing buyers. These referrals help the supplier acquire new buyers. In this case, getting a small financial benefit is less important than having a good referral. The scout function is the second indirect function. Having a buyer with a wide variety of market contacts acting as a scout for the supplier helps the supplier stay informed about market developments and changes. Finally, the access function lets suppliers use the experience of buyers in terms of how to deal with official authorities, banks and other associations.

Walter et al. [25] discussed the benefits of relationships from the suppliers' perspective. In contrast, Gadde and Snehota [26] looked at the benefits perceived buy buyers from cooperation with suppliers. The authors argue that collaboration with suppliers is reasonable as long as the benefits derived from the relationship are greater than the collaboration costs. In the long term buyers and suppliers relationships bring cost benefits and revenue benefits for both of them.

Questionnaires, surveys and interviews are the main elements in research on supplier relationships but results from a small amount of filled out questionnaires might not truly reflect the situation in the market either. Finally, researchers have realized the importance and difficulty of establishing supplier relationships. They have focused on how the relationship between buyers and suppliers should be organized and managed and to that end a number of them tried to develop a framework for supply strategy.

3.2. STRATEGIC SOURCING

Over the past decade, particularly, one of the ways that companies were encouraged to overcome a myopic focus on price and to concentrate on true costs was strategic sourcing, which in many ways amounted to little more, at times, than vendor rationalization. These efforts at strategic sourcing are predictable—survey purchasing categories, trawl through the company's purchasing history in order to create a list of the vendors currently being used, reduce the number of suppliers, and then renegotiate prices with the remaining preferred vendors—if not always sustainable, and have been notoriously ineffectual over the long run. Specialist needs, new discount offers, friendly sales representatives, and urgent spot buys soon meant that vendor categories blurred and the supplier ranks grew again. Employees began to demand second-choice auto rental options and senior executives exempted themselves from restrictions on flying first class. The real problem was that no one ever understood or believed in the numbers. It is only when costs, performance measurements, and comparisons can be made accurately and in real time, with an unambiguous audit trail, that the benefits of strategic sourcing can be sustained. It is the combination of certainty of cost and performance data and the availability of decision support tools that allow companies to truly understand which sourcing options are the most effective. On the other hand, for those firms that can resolve this contradiction internally, new e-procurement strategic sourcing and decision support tools can now free up procurement specialists' time and provide them with valuable information, both on internal spending and on supplier performance. The SAS Institute, for example, provides strategic sourcing and data-mining tools that allow users to understand exactly what, how, and from whom the company is buying, and at what price. This information can then be compared with supplier financial or delivery performance. This gives procurement specialists an opportunity to understand much more clearly the total procurement costs—to look at spending patterns and to analyze where the company is being hit with major price discrepancies or transaction costs. They can then renegotiate contracts or change the purchasing practices, as necessary [27].

For leading to a long-term partnership between the buyer and the supplier Talluri and Narasimhan [28] suggest a framework for supplier selection. According to the authors Strategic factors such as "quality management practices", "cost reduction capabilities" and "collaboration potentiality" are also important and should be considered in the selection process. The authors suggest a data envelopment analysis (DEA) model that uses nonparametric statistical tests to evaluate suppliers. Fifteen models from the literature are listed in the paper, but the authors claim that the presented model is superior to the others not only because it uses both strategic and operational factors, but also because it utilizes statistical models to find out the differences between suppliers.

In this way we can reach a conclusion that without having a long-term partnership it is not useful or recommended for a buyer to outsource (in other words, the buyer should not be thinking of outsourcing from the supplier if there is no close relationship).

3.3. MIGRATION TO E-PROCUREMENT

The expected rapid growth rate of e-procurement predicted by market analysts has not taken place as desired. Therefore, companies that are already faced with many problems while implementing ERP or Supply Chain Management (SCM) solutions are acting more carefully by following a "wait and see" policy.

Davila et al. [6] conducted a survey to understand the benefits and the risks of moving procurement solutions to the Internet and mapped out the current state of e-procurement technologies.Survey results testify that e-procurement based solutions are still in their infancy and each solution provider vies to create a main solution structure that satisfies the needs of today's business world and has a flexibility to be upgraded for future needs.

In their paper, Davila et al. [6] discuss four main types of e-procurement based solutions. These are e-procurement software; Internet market exchanges, Internet B2B auctions and finally Internet purchasing consortia. Results show that each type has found acceptors from a particular kind of organizations. Overall, according to the authors, moving procurement to the Internet has not been very successful. Although some benefits emerge from using e-procurement solutions, the current situation is rather disappointing.

From a supplier's perspective, Yen et al. [29] analyzed migrating procurement to the Internet. The paper starts with the identification of a 4-phase migration model that is a composition of an 11-step procedure that helps the traditional procurement process of the supplier to be moved easily to the Internet.

The proposed migration model starts from the first phase, which aims to digitize data and upgrade its supported services.

The problem starts at the second phase: building communication infrastructures with other companies. Indeed, technical, security and financial requirements such as EDI or XML based communication framework constructions, firewall needs, and communications costs peak in this phase.

The company has to make a decision on selecting the type of e-procurement based solution which can be e-procurement software, Internet market exchanges, Internet B2B auctions or Internet purchasing consortia, depending on the type and field of the company in the third phase.

The last phase is the integration of the company with third parties such as credit card companies or logistics providers. This is an important part of the infrastructure of the migration process since it regulates the payment and transportation issues.

Knowledge is one of the most important assets that any company has and it can be easily lost or stolen while using electronic means according to Ponce and Duran [30]. Security is a very important issue, and B2B procurers have to be satisfied that there will be no harm but more benefits through using e-procurement. Security is not the only issue for deciding on different e-procurement solutions, but it is certainly one of the most strategic.

3.4. SUPPLIER SELECTION

3.4.1. Supplier Selection and Decision Criteria

The process of supplier selection is one of the most important stages in establishing a supply chain management system. Several decision-making steps make up the vendor selection process as reported by De Boer et al. [33]. The authors analyzed the literature from the perspective of supplier selection methodologies and proposed an extension to the research done by Weber et al. [34]. In their framework, the supplier selection process is divided into four phases. The first phase deals with defining the objective of supplier selection like outcomes of the supplier selection process, reasons for selecting suppliers. Once the objective is clarified, depending upon the objective, criteria are defined in the second phase and pre-selection of potential suppliers is done in the third phase. In the last phase, final selection is performed. The authors argue that the supplier selection process heavily depends on the type of goods and services to be procured. The selection process for a low valued routine item will be different from that of a strategic item.

Generally, the framework reflects the situation of supplier selection research very well but lacks the ability to be expanded if it is subjected to the introduction of new models or integration of models. The objective of the supplier selection process is to reduce risk and maximize the total value for the buyer, and it involves considering a series of strategic variables. Among these variables the time frame of the relationship with suppliers, the choice between domestic and international suppliers and the number of suppliers, i.e. choosing between single or multiple sourcing and the type of product provide the insight to the supplier selection. Formulating the problem and the different decision criteria are the research step of the vendor selection. Selection of supplier is a quantitative and qualitative process.

This is a strategic process due to long termed collaboration established between main factory and suppliers. For businesses and decision makers; selection of criteria, determination of methodologies, and evaluation process has strategic importance. Supplier selection might affect whole supply chain management and success of system implementation.

The search for new suppliers is a very important for companies to widen the typology and variety of their product range. Method of supplier selection should have a flexible structure since decision makers are facing different purchasing situations that lead to different decisions. Therefore the purchasing process should start with finding out precisely what to get by selecting a supplier in order to make right choice.

From the point of view of the outsourcing company also it is needed to be clear about the provider's criteria, and to take them into account in the selection process. In an increasingly information-driven decision-making environment, the ability to obtain and act upon performance information is often seen as a prerequisite for business success, and a buyer of outsourced products or services will not wish to be associated with a supplier imperfect in this respect. For example, if a potential supplier does not have extranet capabilities, the buyer may regard an electronic data interchange criteria as a minimum requirement for obtaining required information in the shortest, quickest and most intuitive way. Equally, previous experience and current know-how in the specific industry will usually be considered necessary criteria.

Selecting the right suppliers is influenced by a variety of factors depending on purchasing situation. Since the 1960's the focus of many papers has been the analysis of this aspect. Cordazo and Cagley [35], Monczka et al. [36], Moriarity [37], Woodside and Vyas [38], Chapman and Carter [39], Tullous and Munson [40] propose diverse experimental researches expressing the importance of different supplier quality. Dickson [41] identifies 23 different criteria to be evaluated in vendor selection. His study based on a questionnaire sent to 273 purchasing agent and managers from United

States and Canada. Since 1960 although the progress in the industrial environment changed the supplier selection criteria, the 23 ones presented by Dickson [41] still cover the majority at present like price, delivery terms, quality, production capacity, location, etc.

Verma and Pullman [42] focused on how managers effectively choose suppliers on their experimental studies. Quality is the most important point in the selection process. Cusumano and Takeishi [43] note that the choice of criteria may differ from culture.

Wind and Robinson [44] determined possible conflicts such as the vendor offering the lowest price may not have the best quality, or the vendor with the best quality may not have short delivery terms. It is necessary to swap conflicting tangible and intangible factors to find the best suppliers.

Supplier selection criteria formulation affects several activities including management, production planning and control, cash flow, product/service quality [45]. Consequently such decision must be made in the harmony of a multidisciplinary group of decision makers with various points of view and representing the different services of the company [46-47].

3.4.2. Selection of Suppliers

Pre-selection of potential suppliers process' aim is to exclude the unproductive candidates and reduce the number of suppliers since it is difficult to manage high number of suppliers in today's cooperative logistics environments.

It is possible to use an elimination method which excludes suppliers that do not satisfy the selection rule. "conjunctive" rule serves to eliminate suppliers, in respect to a criterion that is already fixed [48]. If a supplier cannot satisfy a minimum acceptable level compared to a firm criterion, it cannot be selected regardless of its other effectiveness because of intolerable possible consequences on quality or concerning other constraints of the company. The most significant criterion can be identified at the first level of the "lexicographic" rule [49].

Timmerman's [50] categorical method is very sensitive to changes in ratings and depends a lot on human judgment. It splits suppliers into three classes by considering historical data. It is a simple and low-cost qualitative rating model that needs less data. It consists of evaluating and categorizing supplier's performance on each criterion as either 'good' *(+)*, 'neutral' (0) or 'unsatisfactory' *(−)* and combining them into a total rating. This model rates all criteria equally, which rarely happens in practice. This method is inadequate for final choice phase.

Similarly, using a classification algorithm, cluster analysis (CA) allows classifying suppliers described by numerical scores in a group of comparable suppliers, reported first Hinkle et al. [51] and later Holt [52]. In this way, the difference between suppliers' performance within a group are minimal whereas it is maximal between different groups. Holt [52] claims that CA offers greatest potential for pre-qualifying all suppliers. CA reduces the probability of rejecting a 'good' supplier too early in the process. CA would enlarge the scope for rationalization of the selection process by determining the criteria concerned.

(DEA) data envelopment analysis is another method that assists decision makers in classifying the suppliers or their bids among efficient and inefficient suppliers. Due to its utility in evaluating multi-criterion systems and providing improvement targets, this method has been widely applied to various decision analysis problems. DEA is a mathematical programming technique that calculates the efficiencies (rate of subjective outputs (benefit criteria) to subjective inputs (cost criteria) of multiple decision making units. Its use in supplier selection was largely discussed by Weber and Ellram [53]. Weber and Desai [54] applied a combination of DEA and paralel coordinates representation to evaluate the performance of vendors and develop negotiation strategies with inefficient ones. They had also shown the advantages of applying DEA to such a system dealing with the procurement of a single product under multiple criteria. Later, Liu et al. [55] developed Weber and Desai's research using DEA in supplier evaluation for a single product.

Talluri and Narasimhan [56] stated that multi-factor vendor evaluation methods such as DEA have principally relied on evaluating vendors based on integrating their strengths and debility into selection process. They also added that such approaches would not be able to differentiate vendors by comparable strengths but significantly different weaknesses. Consequently, the authors proposed an approach based on *min–max* productivity methods that estimate vendor performance variability measures, which are then used in a non-parametric statistical technique in identifying homogeneous vendor groups for effective selection. In this way, buyers are provided with effective alternative choices within a vendor group. This allows the buyer to have the final decision on other intangible factors that could not be included into the analysis.

Existing methods for supplier selection is grouped into five main categories and their sub categories: Linear weighting models, total cost of ownership (TCO) models, mathematical programming models (MP), statistical and/or probabilistic models, artificial intelligence (AI)-based models.

In linear weighting models weights are given to the criteria, the biggest weight indicating the highest importance. Ratings on the criteria are multiplied by their weights and summed in order to obtain a single figure for each supplier. The supplier with the highest overall rating then be selected. The basic linear weighting model is described mostly in Purchasing textbooks, for example Zenz [31] and Timmerman [32].

TCO-based models attempt to include all quantifiable costs in the supplier choice that are incurred throughout the purchased item's life cycle. A distinction can be made between (1) pre-transaction (2) transaction and (3) post-transaction costs.

Mathematical programming models (MP) allows the decision-maker to formulate the decision problem in terms of a mathematical objective function that sub-sequently needs to be maximized or minimized by varying the values of the variables in the objective function.

Statistical and/or probabilistic models deal with the stochastic uncertainty related to the vendor choice. Even if stochastic uncertainty is present in most types of purchasing situations, e.g. by not knowing exactly how the internal demand for the items or services purchased will develop only very few supplier choice models really handle this problem.

Artificial intelligence (AI)-based models are based on computer-aided systems that in one way or another can be 'trained' by a purchasing expert or historic data. Then, non-experts who face similar but new decision situations can consult the system.

3.4.3. Electronic Reverse Auctions

Reverse auction, alternatively known as Procurement Auction or Upside Down Auction, is the opposite of a traditional forward auction [57]. Here multiple sellers of products vie for the business of a single buyer; therefore, the price is driven down. Bidding continues until a pre-established bidding period ends or until no seller is willing to bid any lower. Reverse auctions have been identified by many large organizations as an effective tool to achieve procurement savings, especially for situations where there are many suppliers and when product complexity is low. With the advent of Internet, more and more companies are adopting its online version [58].

The theory of procurement auctions traditionally assumes that the offered quantity and quality is fixed prior to source selection. Hence bidding competition is restricted to the price dimension. While such an approach may be appropriate for auctions of homogeneous goods, most procurement includes heterogeneous offerings of suppliers [51, 59]. Traditionally, these types of negotiations are resolved through bilateral bargaining or sealed-bid tenders, where a buyer asks for bids in unstructured or semi-structured format and the buyer selects one or more of these bids manually.

Recently, multi-attribute reverse auctions have become a popular means of automating this process further. The negotiable attributes are defined in advance, and suppliers can compete either in an open-cry or sealed bid fashion on multiple attributes [60]. This process allows more degrees of freedom for suppliers in formulating their bids, while at the same time leveraging the competitive forces of an auction to drive the negotiation to equilibrium. Expected gains of multi-attribute auctions are: increased speed of the negotiation, higher market transparency, and higher degrees of allocative efficiency.

Also, many critics of reverse auctions like Emiliani and Stec [61] argue that online reverse auctions rarely deliver savings that are as great as advertised by auction service providers, as savings from reverse auctions don't account for extra expenses resulting from problems such as poor quality, late deliveries and supplier non-performance [62].

Broadly, the objectives of this paper are to formulate a model for judging competitiveness in a multiattribute procurement auction.

3.4.4. Bid Evaluation Problem

A large number of authors have considered multi attribute bid evaluation in e-procurement as a complex problem. Their main observations on this problem are given below:

• Bid evaluation with limited budget in a multi-attribute selection procedure is a major problem for the buying organization [63, 64]. It creates problem on selecting most favorable bidder considering multiple number of attributes [23, 27, 36, 63, 65-69] .
• Lowest cost base selection creates problem in project completion time and quality of material [65, 67, 69, 70].
• Factors that influence a procurement process are important, but setting their priority in determining a winner is tough to deal [71, 72].
• Conversion of all the attributes to a single attribute, that is price, is not easy to do for bid evaluation [73].
• Want *et al.* [67] use unit price-based modeling approach to deal with the bid evaluation problem.
• Bid evaluation for a heterogeneous product is a major problem area [51, 74].
• Selecting the most favorable winner in a post-auction negotiation process is a problem in the presence of multiple numbers of attributes [75, 76].
• Bid evaluation is a problem of identifying a bidder that wins the bid of the highest value from a lot of winners in a combinatorial (combination of works assign to different set of suppliers) auction with configurable bid [66, 77, 78].

3.5. DECISION MODELS FOR THE FINAL CHOICHE PHASE

The enormous majority of the decision models existing in literature concern the final choice phase of the buying process. To classify them, a first distinction can be made by considering the second decision related with the supplier selection problem. That is sole-sourcing where the total demand is procured by one vendor or multiple sourcing where it is split among several vendors. Most models in the literature have assumed all problems parameters to be known with certainty. We will highlight the models that integrated uncertainty, mostly in pricing, in each of the single sourcing and multiple sourcing categories.

3.5.1. Single Sourcing Models

Single sourcing scenario is the sourcing strategy of many firms in the last decade which leads them to establish long term win-win partnership by relying largely on one source. To build more effective relationships with suppliers, enterprises are using supplier selection criteria to strengthen the selection process, and they are using supplier involvement to improve decision making in product design activities and continuous improvement efforts.

Selecting one supplier for one order to meet the total buyer's demand can be made while considering a single criterion or a multitude of criteria. The literature survey expose that except the multi-item weighting model proposed by Grando and Sianesi [79] and the mathematical programming models expanded by Benton [82] and Akinc [81], the quasi totality of published works dealing with sole sourcing concern the procurement of a single item and does not carry over into inventory management over time.

• Single Criterion Approaches

Conventionally vendor selection and evaluation were based on picking the least invoice cost supplier considering the cost as the most important and single criterion, ignoring other important indirect supplier costs related with late delivery terms, production breaks, poor quality of packaging, etc. Timmerman [50] proposed the cost ratio method to overcome such limitations and to have much better decisions. In Timmerman's model, the system chooses the supplier who minimizes the total additional costs related with purchasing decision. This evaluates supplier performances by considering indirect costs using tools of standard cost analysis. Considering an enterprise, the cost ratio method is a very complex approach, requiring a complete cost-accounting system to generate exactly the necessary data. In firm's production process, Roodhooft and Konings [82] suggest the use of the activity based costing approach (ABC) to figure out total cost caused by a supplier. Another way to evaluate to a vendor can be to compare predicted and actual scores after the delivery of the goods.

Benton [80] used mathematical programming to choose only one vendor to supply all needed items and developed a nonlinear program using the economic ordering concept (EOQ), and a heuristic procedure using Lagrangian relaxation for supplier selection and lot sizing under conditions of multiple items, multiple suppliers, resource limitations and all-unit quantity discounts. The buyer's objective is to minimize the sum of purchasing, inventory and ordering costs subject to an aggregate inventory investment constraint and an aggregate storage limitation constraint.

• **Multi-Criteria Approaches**

Several methods have been suggested in multi-criteria approaches. Most of the researches dealing with procurement decision are concerned with selecting the best supplier considering the multipurpose nature of the matter. The most common approach firstly approved by Wind and Robinson [44] in supplier selection uses linear weighting models to assess the vendor's performance. This approach produces useful and reasonably reliable data, and is relatively easy to implement. Principally Zenz [31] and Timmerman [50] made known the basic model that is described as follows: some form of scoring methods consisting by assignment of weights to each criterion as the biggest score indicates the highest importance. Then, rating the criteria multiplied by their weights and summed to obtain a single figure for each vendor and finally the supplier with the best number comparing with all weighted criteria is chosen. This method is also suitable for the pre-selection phase of the buying process. In this situation, we keep suppliers having the highest scores. These and similar methods are usually referred to balancing approaches except for Grando and Sianesi [83] that do not combine ratings of different criteria in general score and De Boer et al. [84] which propose partially balancing approach. In fact, as a result of summing of the scores, a poor performance on one score can be compensated by a high one on another.

Although giving weights to various criteria remains a subjective process, a common interesting point is weighting models. They all make some kind of exchange between tangible and intangible factors to find the best supplier. Dulmin and Mininno [85] focused on criteria weights' assessment. They propose an interesting study of most commonly used methods and claim that weights should be a dynamic vector, because of modifications in supply markets, product life cycle or changes in firm's strategies that lead decision makers to periodically update priorities in supplier performance.

Analytical hierarchy process (AHP) is more accurate scoring method that has been applied on supplier selection by using pair wise comparison. Narasimhan [45], Partovi et al. [86], Nydick and Hill [87], Barbarosoglu and Yazgaç [88],Yahya and Kingsman [89], Masella and Rangone [90], Tam and Tummala [91], Lee et al. [92], Handfield et al. [93] and Colombo and Francalanci [94] propose the use of this technique to cope especially with determining scores. It is a decision-making tool that can help describe the general decision operation by decomposing a complex problem into a multi-level hierarchical structure of objectives, criteria, sub-criteria and alternatives [95]. In a recent study, Liu and Hai [96] presented the voting analytical hierarchy process (VAHP) that is a novel easier weighting procedure in place of AHP's paired comparison. The analytical network process (ANP), a more sophisticated version of AHP, was also applied for vendor selection by Sarkis and Talluri [97,99]. In the same way, Willis et al. [99] use dimensional analyses in a model where a series of pairwise comparisons are made among suppliers using a vendor performance index such that each criterion is measured in its own units.

Classified by Degraeve et al. [100] and De Boer et al. [33] as a total cost approach, Monczka and Trecha [101] combined this approach with rating systems for criteria as service and delivery performance which are more difficult to obtain the cost figures. Consequently, it proposed multiple criteria vendor service factor ratings and an overall supplier performance index using linear weighting models to adjust the net price for non performance costs associated with the supplier.

Soukup [102] presents a method to deal with uncertain issue that focuses on requirements' uncertainty. He modified the linear weighting method by using probabilities for the criterion weights and a payoff matrix representing alternative scenarios with different performance scores and probabilities.

Precise statistical weight assessments are not being required by other approaches as proposed by Williams [103], Min [104] and Petroni and Braglia [105]. They respectively suggest the use of conjoint-analysis, indifference exchange method and principal component analysis.

Thompson [106] introduces Monte Carlo simulation to reduce the uncertainty in the rating mechanism. Then, he applied the Thurstone Case V scaling technique [108]. In this manner, setting criteria weights and assigning performance score are not required and it suffices to give ranges of scores or simply qualitative rank-order information.

Fuzzy set theory (FST) seems also as a tool for vendor selection. Being able to model human judgment and multi-criteria information, some papers (e. g., [52]) discussed its application when facing uncertainty. Consequently, it was combined in many studies with weighting models. Li et al. [109] propose a fuzzy set methodology by introducing the SUR index which considers the variation of the evaluator for each qualitative criterion. Morlacchi [109, 110] developed a model combining FST with AHP to evaluate small suppliers in the engineering and machine sectors. Later, he focused on the design process of such model, highlighting the advantages and disadvantages of using hybrid approaches of techniques [111].

It is not possible to consider some quantitative aspects or factors of the purchasing decision with linear weighting models. Mathematical programming is a good alternative to cope with this limitation. Akinc [79] proposed a decision support approach to select vendors in a single sourcing context under conflicting criteria of minimizing the annual material costs, reducing the number of suppliers and maximizing suppliers' delivery and quality performances. Mathematical programming was used to elaborate several models exploring the exchange material costs and number of suppliers in a variety of scenarios (problem instances) defined with specific quality and delivery performance standards that vendors must achieve. In this way, a first model finds the vendors that minimize the total invoice cost regardless of their numbers. After that, a second model is used to find the vendors who can supply all materials within the desired minimal quality and delivery parameters. Then, those two solutions are used as benchmarks and a third model is employed to explore the quantitative exchange these extreme solutions.

• Single Sourcing with Uncertainties

There are also other works existing in the literature that considers purchasing decisions with price fluctuations. The earliest reported works date back to 1959. Fabian et al. [112] developed a dynamic program to investigate the problem of determining monthly purchasing volumes for a single commodity when prices and consumption are random variables. Morris [113] also uses dynamic programming to analyze different purchasing strategies when future prices are considered random variables. He also provides conditions for the optimality of a single purchasing strategy. Ammer [114] suggests using decision trees to examine different decision stages and the possible probabilities in supplier negotiations. Golabi [115] extends the work of Morris [113] by considering different assumptions about price distributions, planning horizon and the holding cost function. In a similar layer, Kingsman [116] also assumes demand is deterministic and uses dynamic programming to find optimal purchase policies when prices are random, and possibly coming from different probability distributions.

3.5.2. Multiple Sourcing Models

Hong and Hayya's [117] researches have argued that the use of multiple suppliers, in a majority of cases especially in just-in-time environment, reduces the overall inventory and purchasing costs. Because of their ability to optimize the clearly stated objective subject to a multitude of constraints, mathematical programming is the most appropriate technique that allows the decision maker to formulate such decision problems. It allows considering internal policy constraints and externally imposed system constraints placed on the buying process in order to determine an optimal ordering and inventory policy simultaneously while selecting the best combination of suppliers. Gaballa [119] was the first author who applied this technique to vendor selection in a real case. He used a mixed integer programming model to formulate this decision making problem for the Australian Post Office. Until the publication of the survey proposed by Weber et al. [119], only ten articles proposed the use of mathematical programming techniques. However since that time, subsequent work in this area has been made and a great number of studies were conducted considering different aspects and instances of the problem.

As a result, to classify the published models in the situation of multiple sourcing, two distinctions can be made. The former concerns the number of different purchased items and the latter concerns the scheduling horizon.

• Single and multiple item models

Various interdependencies could exist among the different products and taking into account the different advantages of the synergy generated by the multiple products models (e.g. reducing purchasing, ordering and transportation costs) is profitable both for buyer and supplier especially in presence of quantity discounts. In contrast, when price break schedules that depend on the size of the order quantity placed are combined with the system's constraints, selecting orders quantities becomes a difficult problem to solve.

Traditional inventory models involve two main types of discounts structure: quantity discounts and business volume discounts. In the context of quantity discount, the sales volume of a product does not affect the prices and discounts of the other products. Such structure can be applied to single item models as well as multiple item models wherein products costs are considered independently, although they are offered by the same vendor. This class of discounting strategy can be either noncumulative (incremental) or cumulative (all-units) which is the case in the majority of practical situations. The linear programming model considers different forms of pricings including quantity discounts and prices that increase with order quantities. Waggener and Suzuki [120] use a similar model that is of a larger size and accounts for more pricing and supplier requirements scenarios. Later, Austin and Hogan [121] extended this model to a mixed integer program that account for cases where a supplier indicates a minimum acceptable quantity.

Gaballa [119] uses a mixed integer programming model to minimize total discounted price (all-units form) of allocated items to the vendors, under constraints of vendor's capacity and demand satisfaction. Pirkul and Aras [122] analyzed as well the problem of determining order quantities for multiple items in the presence of all-unit quantity discounts. The aim was to minimize the sum of aggregate purchasing costs, holding costs, and ordering costs subject to a linear resource constraint. They formulated their problem as a non linear program and developed a solution algorithm using Lagrangian relaxation. In addition, Chaudhry et al. [123] presented a mixed linear integer programming formulation to minimize the purchasing costs for individual items over a single period. The authors consider capacity constraints, delivery performance and quality with successively cumulative and noncumulative quantity discounts. An extension to goal programming was also proposed. In conclusion, inTempelmeier's model [124], suppliers offer for a single product all-unit and/or incremental quantity discounts which may vary over time. Consequently, Tempelmeier formulated an uncapacitated multi-supplier order quantity problem with time varying all-units discounts as a mixed integer linear optimization problem and an uncapacitated multi-supplier order quantity problem with time varying incremental discounts as a mixed integer nonlinear optimization problem. A heuristic was developed for the resolution.

In the background of business volume discount, multi-item models are considered and a vendor offers discounts on the total dollar amount of sales volume, not on the quantity or variety of the products purchased. According to Sadrian and Yoon [125] and Katz et al. [126], this strategy has many benefits to both vendors and buyers. On the other hand, the computational difficulties due to interdependence of product prices tied to a single discount schedule were the obstacle for buyers attempting to purchase needed products under the business volume discount strategy. Sadrian and Yoon [127] treated such form of discount by proposing a mixed integer programming model to optimize the total cost of purchases in the presence of business volume discounts for one period.

Apart from quantity discounts and business volume discounts, a third class of discount strategy dealt with in multi item models is the bundling. It is a scheme wherein the price of an item depends on the order quantities of other items. This occurs when two or more related items are sold together as a bundle. Several studies have identified conditions under which bundling is profitable for the seller or when it needs to be avoided (e.g. , [128–132]). Rosenthal et al. [133] were the first who applied bundling in the context of supplier selection.

The authors developed a mixed linear integer programming to minimize purchasing costs over one period with constraints addressing vendor capacities, demand satisfaction, quality and delivery requirements. The authors proposed also as extension to export the idea of product bundling to an EOQ context. Later, Sarkis and Semple [134] suggested a reformulation of the problem proposed by Rosenthal et al. [133]. Thus, they significantly reduced the computational workload and eliminated some limitations and a paradox revealing a more cost effective purchasing strategy. In recent times, Murthy et al. [135] addressed the buyer's vendor selection problem for make-to-order items where the goal is to minimize sourcing and purchasing costs in the presence of fixed costs, shared capacity constraints, shared setup costs, and volume-based discounts for bundles of items. Giving quotes in the form of single sealed
bids or facing dynamic auction involving open bids, the model has to determine the best bid among those proposed or winners at each stage of a dynamic auction. Due to the complexity of the mixed integer programming formulated, a heuristic procedure based on the Lagrangian relaxation technique was developed to solve the problem.

Minor different discount schemes also exist in literature. Treating a vendor selection problem faced by British Coal, Turner [136] discussed three types of discounts: deferred rebates based on the total value of the order, deferred rebates based on the order quantity, and marginal discounts based on the total value of the order. The problem was formulated as a mixed integer program that minimizes total contract cost, and constrained by demand satisfaction, vendor capacities, minimum and maximum order quantities and geographic region purchasing restrictions. This model relaxed, however, any dependence of unit price on size of order quantity. The linear program was costly to solve, so a quasi-optimizing heuristic routine was adopted. Sharma et al. [137] proposed a nonlinear, mixed integer, goal programming model. They considered price, quality, delivery and service as goals. The cost goal was nonlinear and the total cost of purchased materials was inversely proportional to quantity purchased and leads time, but increased linearly as the quality level increased.

When selecting suppliers related research work dealing with price breaks regimes, concerns not only discounts but also surcharges. Contrary to the discounts offers where unit price of a vendor declines as the order quantity placed increased, with surcharges, it increases. Such situation is faced whenever the ordered material is a scare source, like an energy product [138].

In conclusion, considering price discounts is a decisive factor for selection and order quantity allocation. Effectively, it influences significantly the final decision that is why it has been considered in several studies combining the supplier selection issue with other features. By way of example, Ganeshan et al. [139] strike a balance between the use of just one supplier, and the perceived cost benefits of using several while considering reliability and discounts. Crama et al. [140] presented also an interesting extension of the basic supplier selection problem that considers price discounts. It focused on procurement decisions in presence of total quantity discounts and alternative product recipes which increased the complexity of the problem. The authors consider a medium-term purchasing decision faced by a multi-plant chemical company. Assuming that each product made by the company can be processed according to several recipes, where each recipe specifies which proportion of each ingredient, the firm aims at simultaneously optimizing its procurement plan and its production plan while considering quantity discounts based on the total quantity of ingredients purchased over a year. They formulated the corresponding cost-minimization problem as a nonlinear mixed 0–1 programming problem and proposed various ways to linearize it.

3.6. EXAMPLE CRITERIA FOR SUPPLIER SELECTION

a. Performance Assessment Criteria

• Shipment quality

Shipment quality refers to the vendor's ability to meet quality specifications consistently. Shipment quality can be divided into eight categories, which include product performance features, reliability, durability, conformance, serviceability, aesthetics and perceived quality.

• Delivery

Delivery refers to the vendor's ability to meet delivery schedules. It covers compliance with quantity, compliance with packaging standards, delivery to request date and order fill lead-time.

• Modes of transportation facility

Transport facilities should be able to procure freight globally and across all modes of transportation using all bidding platforms. This will help to get considerable efficiencies and cost savings across the organizations.

• Transportation cost

Transportation costs can be categorized by the following attributes:

Distribution (Internal and External Impacts): Internal (also called *user*) costs and benefits are borne or accrue directly by a good's consumer. *External* costs and benefits are borne or accrue by others. *Social* costs are the total of both internal and external impacts. External impacts do not directly affect consumers' decisions, and so are a form of market failure

Variable and Fixed: Variable (also called *marginal*) costs increase with consumption. *Fixed* costs do not. For example, fuel, travel time and crash risk are variable vehicle costs because they increase directly with vehicle mileage, while depreciation, insurance, and residential parking are considered fixed, because vehicle owners pay the same, regardless of how much a vehicle is used. The distinction between fixed and variable often depends on perspective. For example, depreciation is often considered a fixed cost because car owners make the same payments no matter how many miles a year they drive, but a car's operating life and resale value are affected by how much it is driven, so depreciation is partly variable over the long term.

Market or Non-Market: Market costs involve goods that are traded in a competitive market, such as vehicles, land and fuel. *Non-market* costs involve goods that are not regularly traded in markets such as clean air, crash injuries, and quiet. A number of techniques can be used to determine the value that consumers place on non-market goods.

Perceived or Actual: There is often a difference between *perceived* and *actual* automobile costs. Motorists tend to perceive immediate costs such as travel time, stress, parking fees, fuel, and transit fares, while costs that are paid infrequently, such as insurance, depreciation, maintenance, repairs and residential parking, are often underestimated.

Price: Price refers to what a consumer pays in exchange for a particular good, or *perceived-internal-variable cost*. In general, a market is most efficient if prices reflect marginal costs.

• Safety and security of components

Before implementing any electronic procurement solution, organisations should conduct an assessment of all risks to information and services. This will determine the security levels: inconvenience, financial loss, damage to standing or reputation, distress, release of personally or commercially sensitive data to third parties, assistance in the commission or of hindrance to the detection of a serious crime, risk to personal safety.

b. Human Resources Criteria

• Number of employees

Number of employees refers to the total number of the firm and the clarity of employee job definitions.

• Organizational structure

It refers to the organizational structure of the firm and the clarity of employee job definitions.

- **Performance Assessment**
  - **Shipment Quality**
  - **Delivery**
  - **Modes of Transportation Facility**
  - **Transportation Cost**
  - **Safety and Security of Components**
- **Human Resources**
  - **Number of Employees**
  - **Organizational Structure**
  - **Training**
  - **Number of Technical staff**
- **Quality System Assessment**
  - **Management Commitment**
  - **Inspection**
  - **Inspections Methods and Quality Planning**
  - **Quality Assurance**
  - **Adherence to Quality Tools**
- **Manufacturing**
  - **Production Capacity**
  - **Managing Inventory**
  - **Predictive and Preventive Maintenance**
  - **Lead-time**
  - **Transportation-Storage and Packaging**
  - **Up-to-date Techniques and Equipment**
  - **New Product Development**
- **Business Structure**
  - **Reputation**
  - **Geographical location**
  - **Price**
  - **Patent**
  - **Engineering and Technical Capability**
  - **History**
  - **Knowledge of Market**

Fig 3.1. Supplier Selection Criteria and Sub-criteria

• Training

It refers to the availability of professional educational activities and a scheduled yearly training program. This criterion necessitates that all personnel, whose work may create a significant impact on the supply chain process, have received appropriate training.

• **Number of technical staff**

This criteria refers to the technical capability and availability of the staff in more technical oriented departments in the supplier firm.

c. Quality System Assessment Criteria

• **Management commitment**

Management commitment refers to the preparation of the documentation system regarding the quality assurance system, which encourages work force participation, emphasizing the importance of the role of the quality function in the firm, the establishment and implementation of quality improvement programs, appropriate environmental policy and regular management reviews.

• **Inspection**

The purpose of inspection is to assure the buyer that the supplier has delivered an item, which corresponds to the description furnished. Inspection and the control procedure can involve measurement, testing, touching, weighing or testing of the product. Its goal is to detect the bad process immediately. Inspection and control take place in every stage of manufacturing process ranging from inbound logistics to final production stage.

• **Inspections methods and quality planning**

Quality planning includes compliance with control specifications, prototype control, traceability and quality cost.

• **Quality assurance**

The responsibility of the quality assurance group is to implement the method of the purchasing activities with lot certification; to establish quality assurance; and to help in designing, implementing and monitoring the quality improvement program.

• **Adherence to quality tools**

The quality of the products and services is influenced directly and indirectly by every single one of the employees and each or the activities.

d. Manufacturing Criteria

• Production capacity

Production capacity involves the design capacity and effective capacity. The former is expressed as the number of units produced in a specific time-period such as per week, per month or per year, whereas the latter is the capacity that a firm expects to achieve given the current operating constraints. Effective capacity is often lower than design capacity.

• Managing inventory

Inventory of management is the function of understanding the combination of products of a company and the different demands on that stock.

• Predictive and preventive maintenance

In this stage, preventive and breakdown maintenance were considered. Preventive maintenance involves performing routine inspections, servicing and keeping facilities in good repair. These activities are intended to build a system that will detect potential failures to prevent them. Breakdown maintenance, however, occurs when the equipment fails and it must be repaired on an emergency or priority basis.

• Lead-time

Lead-time includes inventory management, inventory level of raw materials, work in process and finished goods, production planning, scheduling and just in time.

• Transportation-storage and packaging

This criterion includes the effectiveness of the transportation, storage, and packaging function.

• Up-to-date techniques and equipment.

It involves the technological compatibility and manufacturing infrastructure resources.

• **New product development**.

New product development includes market research, product and market testing, new product development and business analysis.

e. Business Structure Criteria

• **Reputation**

It refers to the reputation or brand image of the supplier.

• **Geographical location**

It refers to the location of the supplier's firm.

• **Price**

It includes price of the product, payment terms, price deviation or differences, quantity discount.

• **Patent**

The patent right of the product, which is procured by the supplier.

• **Engineering and Technical capability**

It includes engineering/technical support sources, similar product experience, understanding of technology, technical know how know why, project management skills and value management concepts.

• **History**

Previous experience and past performance with the product/service to be purchased.

• **Knowledge of market**

Knowledge of market is a mechanism for distributing knowledge resources.

4. METHODOLOGY

4.1. MULTICRITERIA DECISION ANALYSIS

When considering a discrete set of alternatives described by some criteria, there are four different kinds of analyses that can be performed in order to provide significant support to decision-makers [141]: (1) to identify the best alternative or select a limited set of the best alternatives, (2) to construct a rankordering of the alternatives from the best to the worst ones, (3) to classify/sort the alternatives into predefined homogenous groups, (4) to identify the major distinguishing features of the alternatives and perform their description based on these features. The former three approaches (choice, ranking, classification/sorting) lead to a specific evaluation outcome. In deriving this outcome, both choice and ranking are based on relative judgments and consequently the evaluation result depends on the considered set of alternatives. On the other hand, taking a classification/sorting decision the decision-maker needs to perform absolute judgments. Since the groups are usually specified independently of the alternatives under consideration, the classification/sorting of the alternatives requires their comparison to some reference profiles that distinguish the groups.

While both classification and sorting refer to the assignment of a set of alternatives into predefined groups, they differ with respect to the way that the groups are defined. In that sense, classification refers to the case where the groups are defined in a nominal way. On the contrary, sorting (a term which is widely used by multicriteria decision aiding (MCDA) researchers) refers to the case where the groups are defined in an ordinal way starting from those including the most preferred alternatives to those including the least preferred alternatives. Both kinds of problems have numerous practical applications, included but not limited to:

• Medicine: performing medical diagnosis through the classification of patients into diseases groups on the basis of some symptoms [142-145].

• Pattern recognition: examination of the physical characteristics of objects or individuals and their classification into appropriate classes [146-148].

• Human resources management: assignment of personnel into appropriate occupation groups according to their qualifications [149, 150].

• Production systems management and technical diagnosis: monitoring the operation of complex production systems for fault diagnosis purposes [151-153]

• Marketing: customer satisfaction measurement, analysis of the characteristics of different groups of customers, development of market penetration strategies, etc. [154, 155].

• Environmental and energy management, ecology: analysis and measurement of the environmental impacts of different energy policies, investigation of the efficiency of energy policies at the country level [156-158]

• Financial management and economics: business failure prediction, credit risk assessment for firms and consumers, stock evaluation and classification, country risk assessment, bond rating, etc. [159-165].

This wide range of real-world applications of the classification/sorting problem has constituted a major motivation for researchers in developing methodologies for constructing classification/sorting models. The development of such models necessitates the consideration of a realistic framework that accommodates the multidimensional nature of real-world decision-making problems. The development of multidimensional classification models can be traced back to the work of Fisher [166] on the linear discriminant analysis, that was later extended to the quadratic form by Smith [167]. Both linear and quadratic discriminant analysis have dominated the field of classification model development for several decades, along with logit/probit analysis [168, 169] which gained the research interest during the 1970s after the work of McFadden [170]. While these statistical techniques have been heavily criticized for their statistical assumptions [159]), they provided the necessary basis for understanding the nature and the peculiarities of the classification/sorting model development process and the objectives that this process should accommodate, thus constituting a helpful basis for further research.

The recent research in developing classification/sorting models is based on operations research and artificial intelligence techniques. Methodologies such as neural networks, machine learning, rough sets, fuzzy sets and MCDA are considered by researchers both at the theoretical and practical levels. The research made at the theoretical level focuses on different aspects of the model development and validation process. At the practical level, researchers focus on the use of classification/sorting methodologies to analyze real-world problems and provide decision support, or on the investigation of the performance of different methodologies using real-world data. While all methodologies have advantages and disadvantages, their discussion is out of the scope of this thesis.

4.2. GENERAL FRAMEWORK AND MEASUREMENT SCALES

The set criteria is denoted by $N=\{1,\ldots,n\}$. Min and max are denoted by $\wedge$, $\vee$ respectively. For convenience, subsets of N will be denoted by uppercase letters, e. g. , $A \subset N$, and their cardinality by the corresponding lowercase, e.g. , $a = |A|$.

We consider a set $X = X_1 \times \ldots \times X_n$ of potential alternatives (e.g. candidates, cars, etc), each alternative $x = (x_1, \ldots, x_n)$ being described by a vector of n descriptors or attributes (e.g., technical ability, purchase price, performances, etc.) taking values in sets $X_1, \ldots, X_n$. The decision maker is supposed to have a preference over X, expressed by a binary relation $\succeq$, that is reflexive and transitive (possibly complete). The fundamental problem of decision theory is to build a numerical representation of $\succeq$. In the framework of this paper, this representation has the form

$$x \succeq y \Rightarrow F\big(u_1(x_1), \ldots, u_n(x_n)\big) \geq F\big(u_1(y_1), \ldots, u_n(y_n)\big), \tag{4.1}$$

where F is the Choquet integral (or the Sugeno integral in the ordinal case), $u_i : X_i \rightarrow S \ (i = 1, \ldots, n)$ are called *utility functions* or *value functions* (the latter term will be used in the sequel, since the former refers more to decision under uncertainty and risk), and $S \subseteq \mathbb{R}_+$ is a common scale on which the preferences of the DM are represented.

We call the pair (X_i, u_i) a *criterion* (abusing terminology, X_i is also sometimes called a criterion). For convenience, we define the *overall value function* $U : X \to S$ by $U(x) = F\big(u_1(x_1), \dots, u_n(x_n)\big)$.

More generally when *F* is any increasing function from S^n to S, Eq. (4.1) is the so-called *decomposable model* of measurement theory [171], and *F* is called an *aggregation* function. For details about the justification of the use of Choquet integral for *F*, see [172,173].

We can distinguish two types of scales when dealing with nonnegative real numbers:

Bounded unipolar scale: This is the case when *S* is a closed bounded interval, e.g. , [0,1]. Two typical examples of such scales are the scales of credibility of an event (belief or certain degree, probability, etc.), and the scale of membership degree of an element to a fuzzy set [174] . The boundaries 0 and 1 represent respectively the absence of the property (no credibility, no membership), and the total satisfaction of the property (full credibility, that is, the event is true; full membership, that is, the element belongs to the set in the classical sense). By contrast to bipolar scales, there is no opposite nor symmetric notion to the considered property. Coming back to our framework of MCDA, saying that u_i is a bounded unipolar scale implies the existence in X_i of two elements denoted by U_i and P_i, which have an absolute meaning: U_i is an element of X_i which is thought by the DM as completely unsatisfactory relatively to his concerns w.r.t. criterion i, and P_i is an element of X_i that is considered as perfectly satisfactory [172, 173, 175].

Unbounded unipolar scale: in this case *S* is no more bounded from above, hence *S* is taken to be $\mathbb{R}_+$. Typical examples are the scales of priority and importance (e.g. , of obligations, laws, things to do, etc.). These notions are unipolar because no opposite notions exists. Moreover, it is always possible to find obligations more prioritary or more important than a given one, so that no upper bound exists. In the framework of MCDA, the difference with the previous bounded case is that the element P_i does not exists in X_i. Instead we assume the existance in X_i of an element denoted by S_i, which the DM considers as good and completely satisfying if he could obtain it on criterion i, even if more attractive elements could exist. This special element corresponds to the *satisfying level* in the theory of bounded rationality of Simon [176]. We set for convenience $u_i(S_i) = 1$.

For ease of notation, the unsatisfactory element on attribute X_i will be denoted by 0_i, and the notation 1_i will indicate either the upper bound P_i (bounded unipolar scale) or the satisficing element S_i (unbounded unipolar scale).

We introduce the following convenient notation: for two alternatives $x, y \in X$ and a subset $A \subseteq N$, the compound alternative $z = (x_A, y_{-A})$ is defined by $z_i = x_i$ if $i \in A$, and $z_i = y_i$ otherwise.

4.3. FROM THE WEIGHTED SUM TO THE CHOQUET INTEGRAL

Most MCDA methods use as aggregation function the weighted arithmetic mean (weighted sum), i.e., $F(a_1, \ldots, a_n) = \sum_{i=1}^{n} w_i a_i$, with $w_i \geq 0$ and $\sum_{i=1}^{n} w_i$=1. It is well known however that in many situations, the weighted sum cannot represent the preferences of the decision maker. Let us try to illustrate this, and to motivate the definition of the Choquet integral [177].

***Example* 4.1.** Let *a, b, c* be three alternatives evaluated on two criteria as follows:

$$u_1(a) = 0.4, \quad u_1(b) = 0, \quad u_1(c) = 1$$
$$u_2(a) = 0.4, \quad u_2(b) = 1, \quad u_2(c) = 0,$$

where scores are given in [0, 1]. Suppose that the decision maker (DM) says $\succ b \sim c$. Let us find w_1, w_2 so that the weighted sum represents the preference. We get;

$$b \sim c \Leftrightarrow w_1 = w_2$$
$$a \succ b \Leftrightarrow 0.4(w_1 + w_2) > w_2$$

equivalent to $0.8w_2 > w_2$, which is impossible.

To understand the underlying reason of this failure, we should notice that for the weighted sum, w_1 is the overall score achieved by an alternative having a totally satisfactory score on the first criterion (1), and not acceptable on the others (0). Obviously, our DM is more attracted by alternatives being well balanced on the two criteria. It would be possible to take into account this preference if one allows defining weights not only on each criterion, but also on groups of criteria. In our very simple example, this amounts to defining a weight w_{12} on both criteria, which represents the score assigned to an alternative being totally satisfactory on both criteria. This alternative being obviously the best one, it is natural to assign to it the maximal score 1, hence w_{12}= 1. In order to model the fact that the DM considers alternatives being satisfactory only on one criterion as not attractive, we may set, e.g. , $w_1 = w_2 = 0.3$. Let us try to rewrite the weighted sum, taking into account this new weight w_{12}. Keeping in mind the interpretation of weights, we are led to the following computation:

- a has equal scores on both criteria, which corresponds to the situation depicted by w_{12}, up to the factor 0. 4. Supposing the model to be homogeneous, we may put $U(a) = 0.4\, w_{12} = 0.4$.
- b and c correspond respectively to the situations depicted by w_2, w_1 , hence $U(b) = w_2$=0.3, and $U(c) = w_1$= 0.3.

The model indeed represents the preference of the DM. It is easy to see that by choosing appropriate values for w_1, w_2, w_{12}, *any* preference among *a, b, c* can be represented this way.

The above example works well because the alternatives *a, b, c* fit exactly to the situations depicted by the weights. What if this is no more the case, for example considering an alternative *d* such that $u_1(d)$ = 0. 2 and $u_2(d)$ = 0. 8? We may consider that the DM prefers *d* to *b* and *c*, and *a* to *d*. To solve the problem, we consider that *d* is the sum of two fictitious alternatives d', d'' defined by:

$$u_1(d') = 0.2, \quad u_1(d'') = 0$$
$$u_2(d') = 0.2, \quad u_2(d'') = 0.6.$$

Supposing that our model is additive for such alternatives, the overall score of d is the sum of the overall scores of d' and d''. But it is possible to compute them, because d' and d'' correspond to situations depicted by the weights. We obtain:

$$U(d') = 0.2, \quad w_{12} = 0.2$$
$$U(d'') = 0.6, \quad w_2 = 0.18$$
$$U(d) = U(d') + U(d'') = 0.38.$$

Observe that we obtain the desired ranking: $a \succ d \succ b \sim c$.

This method of computing the overall score is in fact nothing else than the Choquet integral, and the weights on groups of criteria define a capacity or fuzzy measure. [178].

Definition 4.1. 1. A function $v : 2^N \to \mathbb{R}$ is a *game* if it satisfies $v(\emptyset) = 0$.
2. A game μ which satisfies $\mu(A) \leq \mu(B)$ wherever $A \subseteq B$ (monotonicity) is called a *capacity* [179] or *fuzzy measure* [180] . The capacity is *normalized* if in addition $\mu(N) = 1$.

A capacity is *additive* if for all disjoint $A, B \subseteq N$, we have $\mu(A \cup B) = \mu(A) + \mu(B)$.
A capacity is *symmetric* if for any subsets A, B, $|A| = |B|$ implies $\mu(A) = \mu(B)$.
The *conjugate* or *dual* of a capacity μ is a capacity $\bar{\mu}$ defined by

$$\bar{\mu}(A) = \mu(N) - \mu(A), \forall A \subseteq N. \tag{4.2}$$

Definition 4.2. Let us consider $f : N \to \mathbb{R}_+$ (or equivalently a vector in $\mathbb{R}_+^n$). The *Choquet integral* of f w. r. t. a capacity μ is given by

$$C_\mu(f) = \sum_{i=1}^{n} [f_{\sigma(i)} - f_{\sigma(i-1)}]\mu(\{\sigma(i), \ldots, \sigma(n)\}), \tag{4.3}$$

where f_i stands for $f(i)$, σ is a permutation on N such that $f_{\sigma(1)} \leq \cdots \leq f_{\sigma(n)}$, and $f_{\sigma(0)} = 0$.

The above definition is also valid if μ is a game. A fundamental property is:

$$C_\mu(1_A, 0_{-A}) = \mu(A), \ \forall A \subseteq N. \tag{4. 4}$$

Two particular cases are of interest.

- If μ is additive, then the Choquet integral reduces to a weighted arithmetic mean:

$$C_\mu(f) = \sum_{i \in N} \mu(\{i\}) f_i. \tag{4. 5}$$

- If μ is symmetric, the Choquet integral reduces to the so-called ordered weighted average (OWA) introduced by Yager [179]:

$$C_\mu(f) = \sum_{i \in N} (\mu_{n-i+1} - \mu_{n-1}) f_{\sigma(i)} \tag{4. 6}$$

with $\mu_i = \mu(A)$, such that $|A| = i$, and σ is defined as before.

Definition 4.3. Let us consider : $N \rightarrow \mathbb{R}_+$. The *Sugeno integral* [180] of f w. r. t. a capacity μ is given by

$$S_\mu(f) = \vee_{i=1}^{n} \left[f_{\sigma(i)} \wedge \mu(\{\sigma(i), \dots, \sigma(n)\}) \right] \tag{4. 7}$$

with the same notation as above. Note that the above definition also works if f and μ are valued on some ordinal scale (possibly finite). We introduce two important linear transformations over capacities.

Definition 4.4. Let v be a game on N.

1. The *Möbius transform* of v, denoted by m^v, is the unique solution of the equation

$$v(A) = \sum_{B \subseteq A} m^v(B), \quad \forall A \subseteq N, \tag{4.8}$$

given by

$m^v(A) = \sum_{B\subseteq A}(-1)^{|A\setminus B|}v(B).$ (4.9)

2. The *interaction transform* of v , denoted by 1^v, is defined by

$$I^v(A) = \sum_{B\subseteq A\setminus A}\frac{(n-b-a)!b!}{(n-a+1)!}\sum_{K\subseteq A}(-1)^{|A\setminus K|}v(B \cup K), \quad \forall A \subseteq N. \quad (4.10)$$

All details concerning these transformations as well as others can be found in [180-182]. The values of I^v for singletons plays a special role, and is called the *Shapley value* [185], usually denoted by $\emptyset_i(v), i \in N$:

$$\emptyset_i(v) = I^v(\{i\}) = \sum_{A\subseteq N\setminus i}\frac{(n-a-1)!a!}{n!}[v(A \cup i) - v(A)]. \quad (4.11)$$

4.4. PARTICULAR SUBMODELS

There are two main drawbacks of the Choquet integral, which are interrelated: its exponential complexity (2^n -2 real values are needed to define a normalized capacity), and the difficulty to interpret these values, and consequently to analyze the behaviour of the Choquet integral. Several particular families of capacities, hence introducing submodels, have been proposed to solve this issue, the most important ones being the *k* –additive capacities [182]), the *p*-symmetric capacities [184]), and the *k*-tolerant and *k*-intolerant capacities [185].

4.4.1. k-Additive Capacities

Definition 4.5. A capacity μ is *k-additive* if its Möbius transform satisfies $m^\mu(A) = 0$ for all $A \subseteq N$ such that $|A| > k$, and there exists $A \subseteq N$, $|A| = k$, such that $m^\mu(A) \neq 0$ [184].

An important property is that μ is k-additive if and only if $f(i)$ for all $A \subseteq N$, $|A| = k$, we have $I^\mu(A) = m^\mu(A)$, and (ii) for all $A \subseteq N$, $|A| > k$, we have $I^\mu(A) = 0$.

1-additive capacities are ordinary additive capacities. The *k*-additivity property fixes the degree of interaction between criteria: 1-additivity does not permit interaction, 2-additivity allows interaction up to two criteria, etc.

A *k*-additive capacity needs only $\sum_{i=1}^{k}\binom{n}{i}$ coefficients to be defined, instead of 2^n - 2. In practice, 2-additivity is probably the best compromise between low complexity and richness of the model.

As we already know, the Choquet integral w. r. t 1-additive capacities is a weighted arithmetic mean.

The expression of the Choquet integral w. r. t 2-additive capabilities is of particular interest. For any 2-additive capacity, and any real-valued function *f* on *N*, we obtain [188].

$$C_\mu(f) = \sum_{i,j\,\in N|I_{ij}>0}(f_i \wedge f_j)\, I_{ij} + \sum_{i,j\,\in N|I_{ij}<0}(f_i \vee f_j)\, |I_{ij}| + \sum_{i\in N} f_i \left[\phi_i - \frac{1}{2}\sum_{j\neq i}|I_{ij}|\right] \quad (4.12)$$

where ϕ_i is the Shapley value of μ, and $I_{ij} := I^{\mu}(\{i,\})$ is the interaction index between criteria *i* and *j* . The formula is remarkable for two reasons:

- It explains well the meaning of the interaction index and Shapley value: a positive interaction induces a conjunctive aggregation of scores (*necessarily both* scores have to be high to produce a high overall score), while a negative interaction induces a disjunctive aggregation (it is *sufficient that one* score is high). Clearly, the Shapley value is the linear part of the model, while interaction is the nonlinear part.

- Coefficients are nonnegative, and moreover, if the capacity is normalized, they sum up to 1. In other words, this means that the Choquet integral is a convex combination of the scores f_i on all criteria, and of all disjunctive and conjunctive combinations of scores on pairs of criteria. Hence, the coefficient of a given term can be interpreted as the percentage of contribution of such term to the overall score. This feature is highly appreciated in practice.

There is an alternative expression of the Choquet integral w. r. t. 2-additive capacities:

$$C_\mu(f) = \sum_{i=1}^{n} \phi_i f_i - \sum_{\{i,j\}\subseteq N} \frac{I_{ij}}{2} | f_i - f_j |. \tag{4.13}$$

Remarkably the weights of the linear part are the coefficients of the Shapley value. One sees that if $I_{ij} > 0$, the more f_i is different from f_j, the more the interaction phenomenon penalizes the overall assessment $C_\mu(f)$. More precisely, if $f_i > f_j$, the good evaluation of f on criterion i is *penalized* to a degree I_{ij} / 2 by the worse evaluation on criterion j. If $I_{ij} < 0$, the more f_i is different from f_j, the more the interaction phenomenon increases the overall assesment. More precisely, if $f_i < f_j$, the bad valuation of f on criterion i is *saved* to a degree $|I_{ij}|$ / 2 by the better evaluation on criterion j.

4.4.2. p-Symmetric Capacities

k-additive capacities generalize the notion of additivity. Similarly, *p*-symmetric capacities, introduced by Miranda et al. [184], generalize symmetric capacities, and also offer a hierarchy of more and more complex models.

A subset A is a *subset of indifference* for μ if for all $B_1, B_2 \subseteq A$ such that $|B_1| = |B_2|$, we have $\mu(C \cup B_1) = \mu(C \cup B_2)$, for all $C \subseteq N/A$. Observe that any subset of a subset of indifference is also a subset of indifference, and that any singleton is a subset of indifference.

Definition 4.6. A capacity μ on *N* is *p-symmetric* if the (unique) coarsest partition of *N* into subsets of indifference contains exactly p subsets $A_1, \dots, A_p$. The partition $\{A_1, \dots, A_p\}$ is called the *basis* of μ.

In the above definition, a partition π is coarser than another partition π if all subsets of π are union of some subsets of π.

Clearly, a 1-symmetric capacity is a symmetric capacity. Considering a basis $\{A_1, \dots, A_p\}$, any subsets $B \subseteq N$ can be identified witn a *p*-dimensional vector $(b_1, \dots, b_p)$, with $b_i = |B \cap A_i|$. Hence, *p*-symmetric capacity needs $\prod_{i=1}^{p}(|A_i| + 1)$

coefficients to be defined. The Choquet integral for 1-symmetric capacities is just an OWA. For p-symmetric capacities with basis $\{A_1, \dots, A_p\}$, the formula becomes:

$$C_\mu(f) = \sum_{i=1}^{p} \mu(A_i) C_{\mu A_i}(f) + \sum_{(B \mid B \nsubseteq A_j, j=1,\dots,p)} m(B) \wedge_{i \in B} f_i \,, \tag{4.14}$$

where m is Möbius transform of the p-symmetric capacity, and

$$\mu_{A_i}(C) = \frac{\mu(A_i \cap C)}{\mu(C)}, \quad \forall C \subseteq N \,. \tag{4.15}$$

4.4.3. k-Intolerant Capacities

Suppose a Choquet integral C_μ is used to aggregate scores on criteria, and suppose that the output value $C_\mu(f)$ of f is always bounded above by the kth lowest coordinate $f_{\sigma(k)}$ of f. Then, clearly, this Choquet integral has a somehow intolerant behavior.The lower of the value of k, the more intolerant the behavior. This suggests the following definition [185]), where as before σ is a permutation on N such that $f_{\sigma(1)} \leq \cdots \leq f_{\sigma(n)}$.

Definition 4.7. A Choquet integral C_μ (or equivalently its underlying capacity μ) is at *most k-intolerant* if $C_\mu(f) \leq f_{\sigma(k)}$. It is *k-intolerant* if, in addition, $C_\mu(f) \nleq f_{\sigma(k-1)}$, where $f_{\sigma(0)} = 0$ by convention.

It can be shown that C_μ is at most k-intolerant if and only if $\mu(A) = 0$, $\forall A \subseteq N$ such that $|A| \leq n - k$. The dual notion of *k-tolerant* capacities can be introduced as well: then $C_\mu \geq f_{\sigma(k)}$, which is equivalent to $\mu(A) = 1$, $\forall A \subseteq N$ such that $|A| \geq k$. Another form of intolerance can be expressed through the concept of *veto criterion* [186].

Definition 4.8. A criterion $i \in N$ is a *veto* for a Choquet integral C_μ (or equivalently its underlying capacity μ) if $C_\mu(f) \leq f_i$, for all $f \in \mathbb{R}_+^n$.

It can be shown that i is a veto for μ if and only if $\mu(A) = 0$ whenever $A \not\ni i$.
More generally, a coalition A of criteria is a veto if $C_\mu(f) \leq \wedge_{i \in A} f_i$, for all $f \in \mathbb{R}_+^n$, which is equivalent to $\mu(B) = 0$ whenever $B \not\supseteq A$. The dual notion of veto is called

favor. A coalition A of criteria i is a favor for μ if $C_\mu(f) \geq \vee_{i \in A} f(i)$, for all $f \in \mathbb{R}_+^n$, which is equivalent to $\mu(B) = 1$ whenever $A \cap B \neq \emptyset$.

4.5. EXTENSION TO THE OPERATORS OF THE CHOQUET INTEGRAL FAMILIY

We consider that, the collective decision strategy of the selection of the solutions is modeled by a non-linear of type Choquet integral. In this section, we will describe the extension to the operators of the non-linear Choquet integral type denoted by C_μ .

In the decision stage as for the linear case, we suppose that X^k has been chosen as it is the best following strategy identified by the operator C_μ . We obtain :

$$C_\mu(X^k) \geq C_\mu(X^l) \text{ , } l = 1,\ldots,\text{p}. \quad (4.\ 16)$$

For the proof we take the expression of the Choquet Integral in functions by fuzzy measures μ for $f = (f_1, f_2, \ldots, f_n)$, we obtain:

$$C_\mu(f_1, \ldots, f_n) = \sum_{\mathrm{i=1}}^{\mathrm{n}} \left(f_{\sigma(\mathrm{i})} - f_{\sigma(\mathrm{i-1})}\right) . \, \mu(\mathrm{A}_{\sigma(\mathrm{i})}) \quad (4.\ 17)$$

with $\sigma(.\ )$ a permutation on set of criterion $\{1,\ldots,n\}$ like :

$$0 \leq f_{\sigma(1)} \leq \cdots \leq f_{\sigma(n)} \leq 1 \text{ and } A_{\sigma(i)} = \{\sigma(i), \sigma(i+1), \ldots, \sigma(n)\} \quad (4.\ 18)$$

To be able to apply the functionality of the explanation on C_μ it is needed to present $C_\mu(f)$ by sum of marginal contributions. We rewrite then (4. 17) in the following way:

$$C_\mu(f) = \left(\mu\left(A_{\sigma(1)}\right) - \mu\left(A_{\sigma(2)}\right)\right) . f_{\sigma(1)} + \cdots + \left(\mu\left(A_{\sigma(i)}\right) - \mu\left(A_{\sigma(i+1)}\right)\right) . f_{\sigma(i)} + \cdots + \mu\left(A_{\sigma(n)}\right) . f_{\sigma(n)} \quad (4.\ 19)$$

then

$$C_\mu(f) = \sum_{i=1}^{n} \Delta\mu_{\sigma(i)}.x_{\sigma(i)} \tag{4. 20}$$

with $\Delta\mu_{\sigma(i)} = \mu(A_{\sigma(i)}) - \mu(A_{\sigma(i+1)})$, $A_{\sigma(i)} = \{\sigma(i), \sigma(i+1), K, \sigma(n)\}$, $A_{\sigma(i+1)} = (i+1)$, $\{\sigma(i+1), \sigma(i+2), K, \sigma(n)\}$ and $A_{\sigma(n+1)} = \emptyset$: The equation (4. 20) shows clearly that Choquet Integral is partly linear: for a given order of partial scores of Choquet Integral, it is linear to the evaluation criterions mutually.

We are giving some properties verified by the factors $\Delta\mu_{\sigma(i)}$. We observed firstly :

$$\sum_{i=1}^{n} \Delta\mu_{\sigma(i)} = \sum_{i=1}^{n}\left(\mu(A_{\sigma(i)}) - \mu(A_{\sigma(i+1)})\right) = \sum_{i=1}^{n} \mu(A_{\sigma(i)}) - \sum_{i=1}^{n} \mu(A_{\sigma(i+1)})$$
$$= \left[\mu(A_{\sigma(1)}) + \mu(A_{\sigma(2)}) + \cdots + \mu(A_{\sigma(n)})\right]$$
$$- \left[\mu(A_{\sigma(2)}) + \mu(A_{\sigma(3)}) + \cdots + \mu(A_{\sigma(n)}) + \mu(A_{\sigma(n+1)})\right]$$
$$= \mu(A_{\sigma(1)}) - \mu(A_{\sigma(n+1)})$$

Now, we have in essence : $\mu(A_{\sigma(n+1)}) = 0$ and $\mu(A_{\sigma(1)}) = \mu(\{1,2,\dots,n\}) = \mu(C) = 1$. Eventually :

$$\sum_{i=1}^{n} \Delta\mu_{\sigma(i)} = 1 \tag{4. 21}$$

As the fuzzy measure μ is monotone in set of inclusions sense, it results:

$$\Delta\mu_{\sigma(i)} = \mu(A_{\sigma(i)}) - \mu(A_{\sigma(i+1)}) \geq 0 \tag{4. 22}$$

From (4.20 - 4.22), the factors $\Delta\mu_{\sigma(i)}$ have been deduced to be interpreted locally as the coefficients (local/individual) of consequence criterions $c_{\sigma(i)}$, i.e. C_μ is linear in the hyper plan H_σ defined by the permutation σ associated to :

$$H_\sigma = \left\{f \in [0,1]^n | 0 \leq f_{\sigma(1)} \leq K \leq f_{\sigma(n)} \leq 1\right\} \tag{4. 23}$$

Essentially, the $\Delta\mu_{\sigma(i)}$ react like the measures associated to a balanced method where they stay in hyper plan H_σ. Moreover $\Delta\mu_{\sigma(i)}$ is an assessment of marginal contribution (local) of the criterion $c_{\sigma(i)}$ in the evaluation f in H_σ.Therefore,

$$\Delta\mu_{\sigma(i)} = \frac{\partial C_\mu(f)}{\partial x_{\sigma(i)}} | f \in H_\sigma \qquad (4.\,24)$$

We can extend the functionality of the explanation of the Choquet Integral to a strategy by using the formula (4. 20) and (4. 22)

These are mostly used 2-additive measures and the representation of the Choquet Integral with Sharpley indices and interaction. The consequential local factors $\Delta\mu_{\sigma(i)}$ are the values obtained by the measure.

Proposition. μ is a measure 2-additive :

$$\Delta\mu_{\sigma(i)} = v_{\sigma(i)} + \frac{1}{2}\sum_{j>i} I_{\sigma(i)\sigma(j)} - \frac{1}{2}\sum_{j<i} I_{\sigma(j)\sigma(i)} \qquad (4.\,25)$$

With $v_{\sigma(i)}$ Shapley index of criteria $c_{\sigma(i)}$ and $I_{\sigma(i)\sigma(j)}$ the interaction factor between the criterias $c_{\sigma(i)}$ and $c_{\sigma(j)}$.

$$C_\sigma(x) = \sum_{i=1}^{n} \left[v_{\sigma(i)} + \frac{1}{2}\sum_{j>i} I_{\sigma(i)\sigma(j)} - \frac{1}{2}\sum_{j<i} I_{\sigma(j)\sigma(i)} \right] . x_{\sigma(i)} \qquad (4.\,26)$$

where $\sigma(.)$ is a permutation such that $x_{\sigma(1)} \leq K \leq x_{\sigma(n)}$.

We observe that if the fuzzy measure μ is a additive, the interaction factors are null and (4.25) is simplified to the expression :$\Delta\mu_{\sigma(i)} = v_{\sigma(i)} = v_i = \mu_i$. In this case, the $\Delta\mu_{\sigma(i)}$ are constant in every hypercube $[0,1]^n$ and coincident with weight verctor associated to a balanced way.

a. Absolute Explanation

As in the linear case, we are seeking to identify the contributions of partial scores which are the most important for the solution X^k. X^k is the best solution that we have in a given stage of decisional process.

Before giving equivalent expressions to introduced concepts in linear case, we observe that the formula (4. 25) and the $\Delta\mu_{\sigma(i)}$ don't depend on consequent factors of criteria but on the order of partial scores scores of a given profile. In other words for a given alternative X^k , we can write :

$$C_\mu(X^k) = \sum_{j=1}^{n} \Delta\mu_j^k \cdot f_j^k \ . \qquad (4.\ 27)$$

Consequently, we are following the same synthesis applied to linear case. Basically to find the partial contribution of every criteria in global evaluation of X^k by C_μ, it is enough to reorder at the first step, the terms of the sum (4.27) :

$$\Delta\mu_{\tau(j)}^k f_{\tau(j)}^k \geq \Delta\mu_{\tau(j+1)}^k f_{\tau(j+1)}^k \quad ,j=1,\ldots, n\text{-}1. \qquad (4.\ 28)$$

Then we can deduce the absolute potentials PA_μ^k relative to criteria $c_{r(j)}$:

$$PA_\mu^k(j) = \Delta\mu_{\tau(j)}^k f_{\tau(j)}^k. \qquad (4.\ 29)$$

For the classification of the criteria we can use :

$$RPA_\mu^k(j) = \frac{\Delta\mu_{\tau(j)}^k f_{\tau(j)}^k}{\Delta\mu_{\tau(1)}^k f_{\tau(1)}^k} \qquad (4.\ 30)$$

If this ratio is close to 1, the contribution according to criteria $c_{\tau(j)}$ is very important and partial score according to criteria $c_{\tau(j)}$ represents an essential dimension of the decision.

b. Relative Explanation

Similar to the linear case, we are seeking the dimensions according to the solution X^k which creates the difference upon another competitor X^l, the objective is to give the response concerning the contributions of the partial scores of the criteria according to why X^k is preferred to X^l.

To answer this question, we develop the difference between global scores of X^k and X^l as a sum of marginal contribution differences. Basically we have:

$$\forall l, \Delta C_{\mu R}(X^k, X^l) = C_\mu(X^k) - C_\mu(X^l)$$
$$= \sum_{j=1}^{n} \left(\Delta\mu_j^k f_j^k - \Delta\mu_j^l f_j^l\right)$$
$$= \sum_{j=1}^{n} PR_\mu^{k,l}(j)$$

$$PR_\mu^{k,l}(j) = \Delta\mu_j^k f_j^k - \Delta\mu_j^l f_j^l \quad (4.31)$$

The values to analyze are the sum of individual relative potentials $PR_\mu^{k,l}(j)$. Then, we can order individual relative potentials $PR_\mu^{k,l}(j)$ decreasingly. Thus, we can classify every criterion in its own class in terms of justification level. We observe that if the fuzzy measure is additive we have the formula $\Delta\mu_j^k = \Delta\mu_j^l = w_j$ and $PR_\mu^{k,l}(j) = w_j(f_j^k - f_j^l) = PR_w^{k,l}(j)$

c. Explanation on the Average

The objective of this section is to give the equivalent formulas to suggested ones for the linear case in Choquet Integral. We underline the partial scores for which the best alternative has a better score with respect to the mean of other solutions with an identified strategy by an operator C_μ. We have the following analysis:

$$\Delta C_{\mu R}(X^k, X^{l\neq k}) = \sum_{l\neq k} C_\mu(X^k) - C_\mu(X^l)$$
$$= \sum_{l\neq k} \sum_{j=1}^{n} \left(\Delta\mu_j^k f_j^k - \Delta\mu_j^l f_j^l\right)$$
$$= \sum_{j=1}^{n} \left[\left((p-1)\Delta\mu_j^k f_j^k - \sum_{l\neq k} \Delta\mu_j^l f_j^l\right)\right]$$
$$= \sum_{j=1}^{n} PRM_\mu^k(j)$$

$$PRM_\mu^k(j) = \left((p-1)\Delta\mu_j^k f_j^k - \sum_{l\neq k} \Delta\mu_j^l f_j^l\right) \quad (4.32)$$

These are the mean relative potentials associated to the operator C_μ . Now, we need to analyze the terms $PRM_\mu^k(j)$. Higher values for these terms correspond to criteria for which X^k is clearly distinguished with respect to the mean.

5. APPLICATION: BID EVALUATION FOR IT SYSTEM PROCUREMENT

This study has been implemented in a market research company located in Turkey. The reason behind the selection of this company lies on the fact that it already has an e-procurement system. Procurement issue will be the computers that are for daily-use. And as they will be purchased at high quantity, it is very important to select the best appropriate price and quality combination.

At the first phase, criteria have been chosen for the evaluation of the computers. A committee composed of five people who have been selected from IT and Purchasing Departments, has been gathered together to realize the evaluation process. With two phases Delphi studies, the criteria and accordingly its weights have been set, as shown in Table 5.1. Besides, interactions between the criteria were also determined, as shown in tables 5.2 and 5.3.

Table 5.1. Evaluation criteria and their weights

Main Criteria	**Weight**	**Sub Criteria**	**Weight**
Price	0.35	-	
Warranty	0.20	-	
Technical Features	0.45	CPU	0.28
		Mainboard	0.06
		RAM	0.11
		Harddisk	0.18
		Monitor	0.11
		Case	0.06
		Others	0.03
		Operating System	0.11
		Antivirus Soft.	0.06

Table 5.2. Interactions among main criteria

	Tech. Fea.	Price	Warranty
Technical Features		0.30	0.05
Price			0.10
Warranty			

Table 5.3. Interactions among technical features

	CPU	Mainboard	RAM	Harddisk	Monitor	Case	Others	Operating Sys	Antivirus Soft.
CPU		0.06	0.10						
Mainboard			0.02	0.01					
RAM				0.07					
Harddisk									
Monitor						0.07	0.02		
Case							0.01		
Others									
Operating Sys.									0.05
Antivirus Soft.									

It can be observed from Table 5.2 that the interaction between main criteria technical features and price is positive and quite high. This indicates that a solution with both low price and high technical value is more preferred than any solution with a very low price or very high technical value but not simultaneously efficient on both. In the following, we will present the details of bidding stages.

Table 5.4. Bids for Auction Stage 1

(a) Bid of Company 1

CPU	AMD ATHLON 64 LE1640 (2.6 GHz)
Mainboard	ASUSTEK M2NCM DVI GeForce 7025 DDR2 VGA+GLAN+SATA
RAM	HI-LEVEL 1 GB DDR2 800 MHz
Harddisk	MAXTOR 250GB 7200 SATA 8MB
Screen Card	
Case	AOPEN QF50-J02 ATX SİYAH
CD/DVD Reader	
CD/DVD Writer	PHILIPS SPD2414BM 48XCDRW 20XDVDRW IDE
Voice Card	
Speakers	
Monitor	LG L1734S-BN 17' LCD Siyah 5ms
Keyboard	A4TECH KB-21 Q PS/2 SİYAH
Mouse	A4TECH OP-50D OPTİK MOUSE PS/2 SİYAH
Keyboard/mouse	
Floppy	ALPS 1.44MB
Oper. Sys.	MICROSOFT VISTA BUSINESS 32-BIT TÜRKÇE
Antivirus Soft.	
Price	$573,20
Warranty	2 years

(b) Bid of Company 2

CPU	INTEL C2DUO E8500 3.16GHz 1333MHz 6MB 64BIT
Mainboard	INTEL DQ35MPE Q35 DDR2 VGA+GLAN+SATA2
RAM	KINGSTON HYPERX 2GB 1066MHz DDR2 CL5
Harddisk	WESTERN DIGITAL WD5000AAKS SATA2 500GB 16MB
Screen Card	
Case	THERMALTAKE AGUILA SİYAH MIDTOW.
CD/DVD Reader	
CD/DVD Writer	HP TCR AH048AA 16X SATA DVD+/-RW
Voice Card	
Speakers	
Monitor	HP 19' TCR PX850AA L1906 LCD 8ms
Keyboard	
Mouse	
Keyboard/mouse	MICROSOFT 69M LAZER USB SİYAH
Floppy	HP TCR AG295AA
Oper. Sys.	MICROSOFT VISTA ULTIMATE 64-Bit TÜRKÇE
Antivirus Soft.	SYMANTE NORTON INTERNET SECURITY 2009
Price	$1.321,90
Warranty	3+ years

(c) Bid of Company 3

CPU	INTEL C2DUO E8500 3.16GHz 1333MHz 6MB 64BIT
Mainboard	INTEL DQ35MPE Q35 DDR2 VGA+GLAN+SATA2
RAM	KINGSTON HYPERX 2GB 1066MHz DDR2 CL5
Harddisk	WESTERN DIGITAL WD5000AAKS SATA2 500GB 16MB
Screen Card	
Case	THERMALTAKE AGUILA SİYAH MIDTOW.
CD/DVD Reader	
CD/DVD Writer	HP TCR AH048AA 16X SATA DVD+/-RW
Voice Card	
Speakers	
Monitor	HP 19' TCR PX850AA L1906 LCD 8ms
Keyboard	
Mouse	
Keyboard/mouse	MICROSOFT 69M LAZER USB SİYAH
Floppy	HP TCR AG295AA
Oper. Sys.	MICROSOFT VISTA ULTIMATE 64-Bit TÜRKÇE
Antivirus Soft.	SYMANTEC NORTON INTERNET SECURITY 2009
Price	$1,043.30
Warranty	3 years

(d) Bid of Company 4

CPU	AMD ATHLON 64 X2 DUAL 5200+ (2.7GHz)
Mainboard	GIGABYTE MA69GMS2H AMD690G DDR2 VGA+GLAN+SATA
RAM	HI-LEVEL 4GB DDR2 800MHz
Harddisk	SEAGATE 360GB 7200 NCQ SATA2 8MB
Screen Card	
Case	FEEL Midt ATX Typhoon 0509ULA-SS FL550
CD/DVD Reader	
CD/DVD Writer	ASUSTEK 2014S1T 20X14X16 SATA DRW
Voice Card	
Speakers	
Monitor	NEC 22' LCD22WV Geniş Ekran 5ms
Keyboard	
Mouse	
Keyboard/mouse	GENIUS LuxeMate LM600 Kablosuz
Floppy	S-LINK 1.44MB
Oper. Sys.	MICROSOFT WINDOWS XP PRO TÜRKÇE
Antivirus Soft.	
Price	$712,50
Warranty	2 years

(e) Bid of Company 5

CPU	AMD ATHLON 64 X2 DUAL 4200+ (2.2GHz)
Mainboard	ECS Geforce 6100PM-M2 2000MT DDR2 VGA AM2+
RAM	HI-LEVEL 1GB DDR2 800 MHz Soğutuculu
Harddisk	WESTERN DIGITAL WD2500AAKS SATA2 250GB 16MB
Screen Card	
Case	PIRANHA CASEMASTER E TYPE 300W
CD/DVD Reader	SAMSUNG 16X DVD-ROM
CD/DVD Writer	
Voice Card	
Speakers	CREATIVE SBS 245 4W RMS 1+1
Monitor	LG 17' 713SH FLAT CRT
Keyboard	GENIUS KB-06X2 Q PS/2
Mouse	GENIUS NETSCROLL 200 LASER MOUSE PS2
Keyboard/mouse	
Floppy	S-LINK 1.44MB
Oper. Sys.	MICROSOFT VISTA HOME BASIC 32-Bit TÜRKÇE
Antivirus Soft.	
Price	$424,80
Warranty	2 years

Table 5.5. Final Evaluation of Bids for Auction Stage 1

	Bid1	**Bid2**	**Bid3**	**Bid4**	**Bid5**
CPU	0.06	0.76	0.66	0.17	0.10
Mainboard	0.23	0.67	0.61	0.28	0.10
RAM	0.06	0.58	0.60	0.47	0.11
Harddisk	0.22	0.49	0.31	0.41	0.23
Monitor	0.23	0.79	0.38	0.41	0.03
Case	0.24	0.79	0.41	0.34	0.04
Others	0.07	0.71	0.19	0.16	0.10
Operating Sys.	0.46	0.79	0.79	0.40	0.11
Antivirus Soft.	0.00	0.90	0.60	0.00	0.00
Technical Fea.	0.13	0.67	0.49	0.25	0.09
Price	0.84	0.16	0.42	0.72	0.98
Warranty	0.50	1.00	0.70	0.50	0.50
Overall Score	0.294	0.397	**0.469**	0.360	0.282

At the end of the first stage, Company 3 bid got the highest score according to the committee evaluation (Table 5.5). Then, the following suggestions are proposed to other firms to increase their scores according to our elucidation procedure. Company 1 should improve technical features, especially CPU, RAM and Hard disk, and also reduce price, increase warranty; Company 2 should decrease price; Company 4 should improve technical features, especially CPU, and also increase warranty; Company 5 should improve technical features, especially CPU, RAM, Hard disk, Monitor, reduce price and increase warranty (Table 5.4).

Table 5.6. Bids for Auction Stage 2

(a) Bid of Company 1

CPU	**AMD ATHLON 64 X2 DUAL 5600+ (2.9 GHz)**
Mainboard	ASUSTEK M2NCM DVI GeForce 7025 DDR2 VGA+GLAN+SATA
RAM	**HI-LEVEL 2 GB DDR2 800 MHz Soğutuculu**
Harddisk	MAXTOR 250GB 7200 SATA 8MB
Screen Card	
Case	AOPEN QF50-J02 ATX SİYAH
CD/DVD Reader	
CD/DVD Writer	PHILIPS SPD2414BM 48XCDRW 20XDVDRW IDE
Voice Card	
Speakers	
Monitor	**SAMSUNG SYNCMASTER 793V 17' CRT**
Keyboard	A4TECH KB-21 Q PS/2 SİYAH
Mouse	A4TECH OP-50D OPTİK MOUSE PS/2 SİYAH
Keyboard/mouse	
Floppy	ALPS 1.44MB
Oper. Sys.	**MICROSOFT VISTA HOME BASIC 32-BIT TÜRKÇE**
Antivirus Soft.	
Price	**$545,00**
Warranty	**3 years**

(b) Bid of Company 2

CPU	INTEL C2DUO E8500 3.16GHz 1333MHz 6MB 64BIT
Mainboard	INTEL DQ35MPE Q35 DDR2 VGA+GLAN+SATA2
RAM	KINGSTON HYPERX 2GB 1066MHz DDR2 CL5
Harddisk	WESTERN DIGITAL WD5000AAKS SATA2 500GB 16MB
Screen Card	
Case	**THERMALTAKE SopranoRS 101 MidTower 400 PSU**
CD/DVD Reader	
CD/DVD Writer	**NEC AD-7201S-0B 20x8x20xDVDRW SATA**
Voice Card	
Speakers	
Monitor	**LENOVO ThinkVision R44ABTK L1940 19' 5ms**
Keyboard	
Mouse	
Keyboard/mouse	**MICROSOFT B5Q KABLOSUZ OPTIK USB**
Floppy	HP TCR AG295AA
Oper. Sys.	**MICROSOFT VISTA HOME BASIC 32-BIT TÜRKÇE**
Antivirus Soft.	
Price	**$1.007,90**
Warranty	3+ years

(c) Bid of Company 3

CPU	INTEL C2DUO E8400 3.00GHz 1333MHz 6MB 64Bit
Mainboard	GIGABYTE EP45DS3L P45 DDR2 GLAN+SATA
RAM	KINGSTON HYPERX 1GB 1066MHz DDR2
Harddisk	MAXTOR 320GB 7200 SATA2 16MB
Screen Card	GIGABYTE GF7200GS (64Bit) 256/512MB TV DVI
Case	GIGABYTE GZ-X5 460W SİYAH
CD/DVD Reader	
CD/DVD Writer	LG GH20NS15 20X DVD Writer SATA
Voice Card	
Speakers	
Monitor	SAMSUNG 19' 932N LCD 5ms Siyah
Keyboard	
Mouse	
Keyboard/mouse	A4TECH RK-870D KABLOSUZ Q USB
Floppy	HP TCR AG295AA
Oper. Sys.	MICROSOFT WINDOWS VISTA ULTIMATE 64Bit Türkçe
Antivirus Soft.	KASPERSKY INTERNET SECURITY 2009 Türkçe
Price	$1.043,30
Warranty	3 years

(d) Bid of Company 4

CPU	**AMD PHENOM X3 TRIPLE-CORE 8650 (2.3GHz)**
Mainboard	**GIGABYTE MA74GMS2H AMD740G DDR2 VGA+GLAN+SATA**
RAM	HI-LEVEL 4GB DDR2 800MHz
Harddisk	SEAGATE 360GB 7200 NCQ SATA2 8MB
Screen Card	
Case	FEEL Midt ATX Typhoon 0509ULA-SS FL550
CD/DVD Reader	
CD/DVD Writer	ASUSTEK 2014S1T 20X14X16 SATA DRW
Voice Card	
Speakers	
Monitor	**LG L204WS-BF 20 LCD WIDESCREEN**
Keyboard	
Mouse	
Keyboard/mouse	GENIUS LuxeMate LM600 Kablosuz
Floppy	S-LINK 1.44MB
Oper. Sys.	MICROSOFT WINDOWS XP PRO TÜRKÇE
Antivirus Soft.	
Price	**$742,50**
Warranty	**3 years**

(e) Bid of Company 5

CPU	**AMD ATHLON 64 X2 DUAL 6000+ (3.1GHz)**
Mainboard	ECS Geforce 6100PM-M2 2000MT DDR2 VGA AM2+
RAM	**HI-LEVEL 1GB + 2GB DDR2 800 MHz Soğutuculu**
Harddisk	**WESTERN DIGITAL WD3200AAJS SATA2 320GB 8MB**
Screen Card	
Case	PIRANHA CASEMASTER E TYPE 300W
CD/DVD Reader	SAMSUNG 16X DVD-ROM
CD/DVD Writer	
Voice Card	
Speakers	CREATIVE SBS 245 4W RMS 1+1
Monitor	**SAMSUNG SYNCMASTER 793DF 17' CRT**
Keyboard	GENIUS KB-06X2 Q PS/2
Mouse	GENIUS NETSCROLL 200 LASER MOUSE PS2
Keyboard/mouse	
Floppy	S-LINK 1.44MB
Oper. Sys.	MICROSOFT VISTA HOME BASIC 32-Bit TÜRKÇE
Antivirus Soft.	
Price	**$491,20**
Warranty	**3 years**

Table 5.7. Final Evaluation of Bids for Auction Stage 2

	Bid1	**Bid2**	**Bid3**	**Bid4**	**Bid5**
CPU	0.23	0.76	0.66	0.41	0.28
Mainboard	0.23	0.67	0.61	0.26	0.10
RAM	0.52	0.58	0.60	0.47	0.31
Harddisk	0.22	0.49	0.31	0.41	0.32
Monitor	0.12	0.45	0.38	0.32	0.05
Case	0.24	0.52	0.41	0.34	0.04
Others	0.07	0.22	0.19	0.16	0.10
Operating Sys.	0.11	0.46	0.79	0.40	0.11
Antivirus Soft.	0.00	0.00	0.60	0.00	0.00
Technical Fea.	0.18	0.49	0.49	0.33	0.18
Price	0.87	0.45	0.42	0.69	0.92
Warranty	0.70	1.00	0.70	0.70	0.70
Overall Score	0.379	**0.517**	0.469	0.457	0.384

At the end of the second stage, Company 2 bid got the highest score according to the committee evaluation (Table 5.7). Then, the following suggestions are proposed to other firms. Company 3 should improve technical features such as hard disk, monitor and operating system and decrease price; Company 4 should improve technical features, especially CPU, Hard disk, CD/DVD writer, Monitor and Operating system and also reduce price, Company 5 should improve technical features such as CPU, Mainboard, RAM, Hard disk and warranty conditions (Table 5.6). Company 1 having the lowest score in the current stage is eliminated from the auction.

Table 5.8. Bids for Auction Stage 3

(b) Bid of Company 2

CPU	INTEL C2DUO E8500 3.16GHz 1333MHz 6MB 64BIT
Mainboard	INTEL DQ35MPE Q35 DDR2 VGA+GLAN+SATA2
RAM	KINGSTON HYPERX 2GB 1066MHz DDR2 CL5
Harddisk	WESTERN DIGITAL WD5000AAKS SATA2 500GB 16MB
Screen Card	
Case	THERMALTAKE SopranoRS 101 MidTower 400 PSU
CD/DVD Reader	
CD/DVD Writer	NEC AD-7201S-0B 20x8x20xDVDRW SATA
Voice Card	
Speakers	
Monitor	LENOVO ThinkVision R44ABTK L1940 19' 5ms
Keyboard	
Mouse	
Keyboard/mouse	MICROSOFT B5Q KABLOSUZ OPTIK USB
Floppy	HP TCR AG295AA
Oper. Sys.	MICROSOFT VISTA HOME BASIC 32-BIT TÜRKÇE
Antivirus Soft.	
Price	$1.007,90
Warranty	3+ years

(b) Bid of Company 3

CPU	INTEL C2DUO E8400 3.00GHz 1333MHz 6MB 64Bit
Mainboard	GIGABYTE EP45DS3L P45 DDR2 GLAN+SATA
RAM	KINGSTON HYPERX 1GB 1066MHz DDR2
Harddisk	**WESTERN DIGITAL WD5001AALS Caviar Black 500GB 32MB SATA2**
Screen Card	GIGABYTE GF7200GS (64Bit) 256/512MB TV DVI
Case	GIGABYTE GZ-X5 460W SİYAH
CD/DVD Reader	
CD/DVD Writer	LG GH20NS15 20X DVD Writer SATA
Voice Card	
Speakers	
Monitor	**SAMSUNG 19' 933NW LCD 5MS**
Keyboard	
Mouse	
Keyboard/mouse	A4TECH RK-870D KABLOSUZ Q USB
Floppy	HP TCR AG295AA
Oper. Sys.	**MICROSOFT VISTA BUSINESS 32-Bit TÜRKÇE**
Antivirus Soft.	KASPERSKY INTERNET SECURITY 2009 Türkçe
Price	**$961,10**
Warranty	3 years

(c) Bid of Company 4

CPU	**AMD PHENOM X3 TRIPLE-CORE 8750 (2.4GHz)**
Mainboard	GIGABYTE MA74GMS2H AMD740G DDR2 VGA+GLAN+SATA
RAM	HI-LEVEL 4GB DDR2 800MHz
Harddisk	**MAXTOR 500 7200 SATA2 32MB STM3500320AS**
Screen Card	
Case	**ASUSTEK TAB41 ATX KASA**
CD/DVD Reader	
CD/DVD Writer	**PHILIPS SPD2514BM 48xCDRW 20XDVDRW SATA**
Voice Card	
Speakers	
Monitor	**LG W1934S-SN 19' LCD Wide**
Keyboard	
Mouse	
Keyboard/mouse	GENIUS LuxeMate LM600 Kablosuz
Floppy	S-LINK 1.44MB
Oper. Sys.	**MICROSOFT WINDOWS VISTA HOME PREMIUM 32 TÜRKÇE**
Antivirus Soft.	
Price	**$690,40**
Warranty	**2+ years**

(d) Bid of Company 5

CPU	**AMD PHENOM X3 TRIPLE-CORE 8750 (2.4GHz)**
Mainboard	**ECS A740GM-M DRR2 VGA 16X PHENOM AM2+**
RAM	**HI-LEVEL 4 GB DDR2 800 MHz KIT (2X2GB)**
Harddisk	**WESTERN DIGITAL WD5000AAJS SATA2 500GB 8MB**
Screen Card	
Case	PIRANHA CASEMASTER E TYPE 300W
CD/DVD Reader	SAMSUNG 16X DVD-ROM
CD/DVD Writer	
Voice Card	
Speakers	CREATIVE SBS 245 4W RMS 1+1
Monitor	SAMSUNG SYNCMASTER 793DF 17' CRT
Keyboard	GENIUS KB-06X2 Q PS/2
Mouse	GENIUS NETSCROLL 200 LASER MOUSE PS2
Keyboard/mouse	
Floppy	S-LINK 1.44MB
Oper. Sys.	MICROSOFT VISTA HOME BASIC 32-Bit TÜRKÇE
Antivirus Soft.	
Price	**$568,30**
Warranty	**3+ years**

Table 5.9. Final Evaluation of Bids for Auction Stage 3

	Bid2	Bid3	Bid4	Bid5
CPU	0.76	0.66	0.48	0.48
Mainboard	0.67	0.61	0.26	0.16
RAM	0.58	0.60	0.47	0.47
Harddisk	0.49	0.71	0.50	0.48
Monitor	0.45	0.31	0.26	0.05
Case	0.52	0.41	0.22	0.04
Others	0.22	0.19	0.09	0.10
Operating Sys.	0.46	0.46	0.21	0.11
Antivirus Soft.	0.00	0.00	0.00	0.00
Technical Fea.	0.49	0.50	0.34	0.29
Price	0.45	0.49	0.74	0.85
Warranty	1.00	0.70	0.80	1.00
Overall Score	**0.517**	0.514	0.486	0.501

At the end of the third stage, Company 2 got the highest score according to the committee evaluation (Table 5.9). Then, the following suggestions are proposed to other firms to increase their scores. Company 3 should improve technical features, especially mainboard and screencard, and also decrease price; Company 5 should improve technical features, especially Speaker, Operating system and include an antivirus program (Table 5.8). Company 4 having the lowest score in the current stage is eliminated from the auction.

Table 5.10. Bids for Auction Stage 4

(a) Bid of Company 2

CPU	INTEL C2DUO E8500 3.16GHz 1333MHz 6MB 64BIT
Mainboard	INTEL DQ35MPE Q35 DDR2 VGA+GLAN+SATA2
RAM	KINGSTON HYPERX 2GB 1066MHz DDR2 CL5
Harddisk	WESTERN DIGITAL WD5000AAKS SATA2 500GB 16MB
Screen Card	
Case	THERMALTAKE SopranoRS 101 MidTower 400 PSU
CD/DVD Reader	
CD/DVD Writer	NEC AD-7201S-0B 20x8x20xDVDRW SATA
Voice Card	
Speakers	
Monitor	LENOVO ThinkVision R44ABTK L1940 19' 5ms
Keyboard	
Mouse	
Keyboard/mouse	MICROSOFT B5Q KABLOSUZ OPTIK USB
Floppy	HP TCR AG295AA
Oper. Sys.	MICROSOFT VISTA HOME BASIC 32-BIT TÜRKÇE
Antivirus Soft.	
Price	$1.007,90
Warranty	3+ years

(b) Bid of Company 3

CPU	**GIGABYTE EG43MS2H G43 DDR2 VGA+GLAN+SATA2 16X**
Mainboard	GIGABYTE EP45DS3L P45 DDR2 GLAN+SATA
RAM	KINGSTON HYPERX 1GB 1066MHz DDR2
Harddisk	WESTERN DIGITAL WD5001AALS Caviar Black 500GB 32MB SATA2
Screen Card	
Case	GIGABYTE GZ-X5 460W SİYAH
CD/DVD Reader	
CD/DVD Writer	LG GH20NS15 20X DVD Writer SATA
Voice Card	
Speakers	
Monitor	SAMSUNG 19' 933NW LCD 5MS
Keyboard	
Mouse	
Keyboard/mouse	A4TECH RK-870D KABLOSUZ Q USB
Floppy	HP TCR AG295AA
Oper. Sys.	MICROSOFT VISTA BUSINESS 32-Bit TÜRKÇE
Antivirus Soft.	KASPERSKY INTERNET SECURITY 2009 Türkçe
Price	**$926,00**
Warranty	3 years

(c) Bid of Company 5

CPU	AMD PHENOM X3 TRIPLE-CORE 8750 (2.4GHz)
Mainboard	ECS A740GM-M DRR2 VGA 16X PHENOM AM2+
RAM	HI-LEVEL 4 GB DDR2 800 MHz KIT (2X2GB)
Harddisk	WESTERN DIGITAL WD5000AAJS SATA2 500GB 8MB
Screen Card	
Case	PIRANHA CASEMASTER E TYPE 300W
CD/DVD Reader	SAMSUNG 16X DVD-ROM
CD/DVD Writer	
Voice Card	
Speakers	
Monitor	SAMSUNG SYNCMASTER 793DF 17' CRT
Keyboard	GENIUS KB-06X2 Q PS/2
Mouse	GENIUS NETSCROLL 200 LASER MOUSE PS2
Keyboard/mouse	
Floppy	S-LINK 1.44MB
Oper. Sys.	**MICROSOFT VISTA ULTIMATE 32-Bit TÜRKÇE**
Antivirus Soft.	**SYMANTEC NORTON INTERNET SECURITY 2009**
Price	**$712,00**
Warranty	3+ years

Table 5.11. Final Evaluation of Bids for Auction Stage 4

	Bid2	**Bid3**	**Bid5**
CPU	0.76	0.66	0.48
Mainboard	0.67	0.58	0.16
RAM	0.58	0.60	0.47
Harddisk	0.49	0.71	0.48
Monitor	0.45	0.31	0.05
Case	0.52	0.41	0.04
Others	0.22	0.19	0.09
Operating Sys.	0.46	0.46	0.76
Antivirus Soft.	0.00	0.00	0.90
Technical Fea.	0.49	0.50	0.41
Price	0.45	0.52	0.72
Warranty	1.00	0.70	1.00
Overall Score	0.517	0.525	**0.547**

At the end of the fourth stage, Company 5 bid got the highest score and Company 2 is eliminated (Table 5.11). Company 3 should improve technical features, especially RAM, Hard disk, Keyboard, Mouse and Floopy Disk Drive and also decreasing price (Table 5.10).

Table 5.12. Bids for Auction Stage 5

(a) Bid of Company 3

CPU	GIGABYTE EG43MS2H G43 DDR2 VGA+GLAN+SATA2 16X
Mainboard	GIGABYTE EP45DS3L P45 DDR2 GLAN+SATA
RAM	**MUSHKIN Essential Serisi 2GB 1066MHz DDR2 Bellek**
Harddisk	**WESTERN DIGITAL WD7500AACS SATA2 750GB 7200rpm 16MB**
Screen Card	
Case	GIGABYTE GZ-X5 460W SİYAH
CD/DVD Reader	
CD/DVD Writer	LG GH20NS15 20X DVD Writer SATA
Voice Card	
Speakers	
Monitor	SAMSUNG 19' 933NW LCD 5MS
Keyboard	
Mouse	
Keyboard/mouse	**A4TECH KB2150D Q PS/2**
Floppy	**S-LINK 1.44MB**
Oper. Sys.	MICROSOFT VISTA BUSINESS 32-Bit TÜRKÇE
Antivirus Soft.	KASPERSKY INTERNET SECURITY 2009 Türkçe
Price	**$911,50**
Warranty	3 years

(b) Bid of Company 5

CPU	AMD PHENOM X3 TRIPLE-CORE 8750 (2.4GHz)
Mainboard	ECS A740GM-M DRR2 VGA 16X PHENOM AM2+
RAM	HI-LEVEL 4 GB DDR2 800 MHz KIT (2X2GB)
Harddisk	WESTERN DIGITAL WD5000AAJS SATA2 500GB 8MB
Screen Card	
Case	PIRANHA CASEMASTER E TYPE 300W
CD/DVD Reader	SAMSUNG 16X DVD-ROM
CD/DVD Writer	
Voice Card	
Speakers	
Monitor	SAMSUNG SYNCMASTER 793DF 17' CRT
Keyboard	GENIUS KB-06X2 Q PS/2
Mouse	GENIUS NETSCROLL 200 LASER MOUSE PS2
Keyboard/mouse	
Floppy	S-LINK 1.44MB
Oper. Sys.	MICROSOFT VISTA ULTIMATE 32-Bit TÜRKÇE
Antivirus Soft.	SYMANTEC NORTON INTERNET SECURITY 2009
Price	**$712,00**
Warranty	3+ years

Table 5.13. Final Evaluation of Bids for Auction Stage 5

	Bid3	Bid5
CPU	0.66	0.48
Mainboard	0.58	0.16
RAM	0.70	0.47
Harddisk	1.00	0.48
Monitor	0.31	0.05
Case	0.41	0.04
Others	0.06	0.09
Operating Sys.	0.46	0.76
Antivirus Soft.	0.00	0.90
Technical Fea.	0.53	0.41
Price	0.54	0.72
Warranty	0.70	1.00
Overall Score	0.550	0.547

It can be remarked that company 3 and 5 systems have quite similar score (Table 5.13). Both systems have their own advantages and disadvantages (Table 5.12). Then, it is the evaluation committee decision to select the winning company.

6. CONCLUSION

This thesis addresses the need for a supplier selection and evaluation analysis model to assist management in e-procurement, to be able to control inventories more effectively, reduce purchasing agent overhead, improve manufacturing cycles and thus supply chain management.

In this work, the auction of Hardware and prices of computers of a firm in Turkey has been evaluated with the Choquet Integral method to support multicriteria decision analysis to select a limited set of the best alternatives, to construct a rank ordering of the alternatives from the best to the worst ones, to sort the alternatives into predefined homogenous groups and to identify the major distinguishing features of the alternatives and perform their description based on these features.

With the support of this analysis, the necessary basis for understanding the nature and the peculiarities of the classification/sorting model development process and the objectives that this process become accommodate, and thus constituted a helpful basis for further research.

As mentioned above, this study has been implemented in a market research company in Turkey which already has an e-procurement system with an issue of procurement of daily-use computers that will be purchased at high quantity. At the first phase, criteria have been chosen for the evaluation of the computers with a committee composed of five people selected from IT and Purchasing Departments, gathering together for the realization of the evaluation process. With two phases Delphi studies, the criteria and accordingly its weights have been set. Besides, interactions between the criteria were also determined.

The e-procurement process had gone through five stages, at the end of which, 1st, 2nd and 4th company is out of the auction, leaving company 3 and 5 systems having quite similar score based on the multi criteria that was set forth at the beginning of the auction. It is the evaluation committee decision to select the appropriate one.

While the author believes that the presented model provides value there are also further points that can be included such as; additional interactions between and within the decision factors that will alter the auction result.

With the introduction of Choquet Integral in bid evaluation, we could be able to detected best compromise bids, in other words solutions which are best on the average on all criteria. If single criterion such as price is decisive in the acceptance, this type of selection would not be appropriate.

In the future, our analysis can be compared solutions obtained with traditional MCDM methods such as AHP or TOPSIS. Another line of research can be to model bid evaluation using ANP technique. This method also tries to model interaction among criteria, but very differently than Choquet Integral method.

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