SUPPLY CHAIN MANAGEMENT OF SAND CASTING PRODUCTS: A WEB BASED SOURCING SYSTEM USING ANALYTIC HIERARCHY PROCESS

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ABSTRACT

In today's agile business environment, manufacturing companies which are part of a supply chain, spending more amount on outsourcing to increase their competitive position by combining in-house facilities with outsourcing capabilities. This has changed the vendor selection criteria from usual practice of considering price, quality and delivery to the overall capability of a vendor in terms of product development, process, quality assurance, organization, joint relations & flexibility and finally cost & delivery. Hence, decision making for selecting a right vendor requires thorough analysis of vendor capabilities. This can be achieved either by using a linear weighing model or Analytic Hierarchy Process (AHP) methodology. Analytic Hierarchy Process has an advantage of combining tangible & intangible criteria and checking the consistency in decision making. In this project, a prototype system for web based sourcing of sand cast products using AHP methodology has been implemented. Internet technology has been leveraged to reduce the total time for decision making. The system was tested, by carrying out a case study, for a high complex sand casting product in strategic sourcing division of a large automobile company in India.

Chapter 1

INTRODUCTION

1.1 Supply Chain Management

Early in the century, many manufacturing companies were vertically integrated to include all sources of supplies and distribution systems. Now we are living in a world where product-market changes are accelerating and product life cycles are shortening. Products are becoming increasingly complex, as the complexity of both product design and production technology has increased considerably over the past 40 years. Customers demand products customized to their individual need forcing companies to go in for mass customization.

The complexity of modern products have led manufacturing companies from vertical integration to the decentralization of the production technology, because it is difficult for any one company to manage effectively the resources needed to design and manufacture such products. The definition of supply chain and its management given by various authors are as follows:

- A supply chain is a business process that links manufacturers, retailers, customers, and suppliers in the form of a chain to develop and deliver products as a single virtual organization of pooled skills and resources.

  Supply Chain Management (SCM) is the process of synchronizing the flow of physical goods and associated information from the production line of low level component suppliers to the end-customer. SCM results in the provision of early notice of demand fluctuations and synchronization of business processes among all the cooperating organizations in the supply chain. Effective SCM reduces cost and time in procurement process, as well as much lower inventory levels, thus enabling significant gains in organizational productivity (Venkatraman and Blum, 1998).

- Supply Chain Process (SCP) encompasses the full range of intra-company and inter-company activities beginning with raw material procurement by independent suppliers, through manufacturing and distribution, and concluding with successful delivery of the product to the retailer or at times to the customer.

Supply chain management is the coordination of the supply-chain process, i.e., integration of the activities/sub processes involved in procuring, producing, delivering and maintaining products/services to the customer who are located in geographically different places (Viswanadham and Raghavan, 1997).

- Supply Chain Management is used to describe the management of material suppliers, production facilities, distribution services and customer linked through together via the feed forward flow of information and feedback flow of materials. (Evans *et al* 1995)

- Supply chain is a network of facilities that performs the functions of procurement of materials, transformation of material to intermediate and finished products, and distribution of finished products to customers (Lee and Billington, 1993).

- Supply chain is the network of organizations that are involved through upstream and downstream linkages in different processes and activities that produce value in the form of products and services in the hands of ultimate customer (Christopher, 1992).

As manufacturing products becoming increasingly complex, their design and manufacturing demands increasing resources, which are being shared between the supply chain members. Thus, the large final assemblers are concentrating on those activities which center around their core competencies and outsource the rest from other members in the supply chain, providing opportunities for small and large suppliers to fill the product gaps so created.

With such re-distribution activities among the supply chain members, it is difficult to say that a finished product belongs to a particular assembler. It would be more correct to say that products belong to a supply chain. Competition is being typified less by firm versus firm and more by supply chain versus supply chain. The profitability and survival of many organizations is heavily dependent upon the effectiveness of the supply chain performance.

Thus, firms which are part of any supply chain need to look beyond their operations to be able to survive and make effective managerial decisions, and hence, it makes sense to talk about the supply chain as a whole.

This work relates to supply chain management of cast products, and before proceeding further, the metal casting process is briefly discussed here.

1.2 Metal Casting

Casting is a widely employed process and forms the first step in manufacturing a range of components varying in terms of material, size, weight, shape, complexity and application. Important steps involved in sand casting process (Fig. 1.1) are as follows (Heine, 1955; Mukherjee, 1979).

Pattern Making: Patterns, essential tooling for casting process, depend on the type of molding practice adopted, quantity and quality of castings required, type of metal cast and other factors. Depending on the casting requirements, single, gated, match-plate, cope and drag patters are used in foundries. Patterns are generally are of wood construction but may be made of metal, plaster, wax or any other suitable material.

Gating and Feeding: Gating system is a network of channels through which molten metal flows in to mold. Bottom and top gating systems are most popular systems being used in a foundry. Feeding system serves as a reservoir for the additional metal required as shrinkage takes place.

Core Making: Cores are used to create internal shapes of the castings. Most cores are made of a sand mixed with organic binders to provide green strength, baked strength and collapsibility. Cores may be made of metal, plaster and ceramic materials.

Molding: Molding involves creating the mold cavity by ramming the pattern with molding sand and then withdrawing the pattern. Sand casting uses green or dry bonded sand as the molding material.

Melting: This involves the preparation of molten metal for casting. Generally open hearth furnace is used for large tonnage and electric furnace for small heats. Induction furnaces are increasing in popularity owing to their energy efficiency and ease of control.

Pouring: This involves the introduction of molted metal in to mold cavity. This may be done manually or by using semi-automatic mechanisms for tilting the ladle.

Cleaning: Cleaning operations include the removal of adhering sand, the gating system, feeding, chaplets and excess metal. It may also include a certain amount of metal finishing or grinding.

Inspection: It comprises those operations which check the quality of the casting and reject unsatisfactory ones. Inspection procedures may be visual, dimensional or metallurgical, and either destructive or non-destructive. The later includes radiography, ultrasonic, magnetic particle and fluorescent testing.

1.3 Organization of the Report

In this chapter, basic definition of supply chain and the importance of its management, metal casting process have been discussed. The second chapter explains the decision areas in SCM, supplier management, purchasing function and souring activity, Analytic Hierarchy Process (AHP), systematic supplier selection, application of Internet in SCM and finally agent based purchasing. In the third chapter, objectives, scope, plan of approach of the project is described. The fourth chapter describes the criteria used for selecting a vendor and the application of AHP methodology, in the domain of sand casting products. Fifth chapter explains in detail web based sourcing system, web page design and file formats & user interface of the computer program. A case study is given in sixth chapter. Finally, the seventh chapter states the conclusions.

Chapter 2

LITERATURE REVIEW

2.1 Supply Chain Decisions

The activities involved in a supply chain are the procurement of raw materials from suppliers, transforming them into finished goods, transporting to distribution centers and ultimately to customers. The nature of complexity in coordinating this chain is evident by the review of material flows for a complicated product. Multiple suppliers ship to manufacturing sites with varying regularity. These subassemblies and final products, which have shared components, facilities and capacities, are made by complicated and somewhat uncertain processes. Products are then shipped to direct customers or Original Equipment Manufacturers (OEMs). The scene is further confused by the wealth of transportation options available: trains, trucks, planes and ships. Moreover, multiple carriers convey products to customers spread across the globe. Therefore, coordination between the various players in the chain is the key in its effective management.

There are some major decision areas in supply chain management: (1) Location, (2) Production, (3) Transportation, (4) Inventory, and (5) Suppliers (Copacino, 1997; Ballou 1973). Out of these, we concentrated more on suppliers in this study.

Location Decisions: The geographical placement of production facilities, stocking points, and sourcing points is the natural first step in creating a supply chain. The location of facilities involves a commitment of resources to a long-term plan. Once the size, number, and location of these are determined, so are the possible paths by which the product flows through the final customer. These decisions are of great significance to a firm since they represent the basic strategy for accessing markets, and will have a considerable impact on revenue, cost, and level of service.

Production Decisions: The strategic production decisions include what products to produce, and which plants to produce them, allocation of suppliers to plants, plants to distribution centers, and distribution centers to customer markets. These decisions assume the existence of the facilities, but determine the exact path(s) through which a product flows to and from these facilities. Another critical issue is the capacity of the manufacturing facilities and this largely depends on the degree of vertical integration within the firm. Operational decisions include the construction of master production schedules, scheduling on machines, and equipment maintenance. Other considerations include workload balancing, and quality control measures at a production facility.

Transportation Decisions: The mode of choice aspect of these decisions is the strategic ones. These are closely linked to the inventory decisions, since the choice of mode is often found by trading-off the cost of using the particular mode of transport with the indirect cost of inventory associated with that mode. Therefore, customer service level and the geographical location play vital roles in such decisions. Since transportation accounts for the substantial percentage of the logistics costs, operating efficiently makes good economic sense. Shipment sizes (consolidated bulk shipments versus Lot-for-Lot), routing and scheduling of equipment are important in effective management of the firm's transport strategy.

Inventories: Different sources of uncertainties exist along a supply chain. They include demand (volume and mix), process (yield, machine downtimes, transportation facilities and options), supply (part quality, delivery reliability). To buffer against these uncertainties in the supply chain, inventories exist at every stage of the supply chain as either raw material, semi-finished or finished goods. They can also be in-process between locations (Lee and Billington, 1993).

Inventories stored at different points of the supply chain have different impact on the cost and service performance of the chain. For example, inventories at different points have different values (more for finished goods and less for raw materials). Also inventories at various points have differing levels of flexibility (raw materials have more flexibility). Finally, inventories at various points have different levels of responsiveness (finished goods can be delivered without delay). Since holding of inventories can cost anywhere between 20 to 40 percent of their value, their efficient management is critical in supply chain operations. A major challenge to supply chain managers is, therefore, how to control inventories and costs along the chain while maximizing customer service performance.

Suppliers: After the initial make/buy decision i.e., what to produce in-house and what to outsource, companies have some more basic decisions to make: allocation of orders to the suppliers and what kind of relationship to establish with these companies from which products are sourced. Suppliers provide the subassemblies, components or raw materials just-in-time to the factory floor and play a crucial role. Their flexibility, agility, defect control and organization structure should all be compatible with the goals, objectives and vision of the manufacturing system (Viswanadham and Raghavan, 1997). For example, suppliers of companies introducing new products frequently, should have similar capabilities. Having only a few loyal suppliers and effectively communicating the product and process designs to them are some of the new successful practices that Japanese firms taught the rest of the world.

2.1.1 Supplier Management

There are fundamentally two different approaches to manage suppliers and supply chains. One is Japanese supplier management and the other is Western supplier management (Eloranta, 1995). Major differences between these two are summarized below.

Supplier Relations: For Japanese companies, trust and loyalty is most important. This does not mean that Japanese supplier companies face no competition. In fact, Japanese customer companies have extremely strict requirements for the suppliers. However, they give their suppliers support to learn and develop their operations. This approach differs fundamentally from the harsh competition of supplier companies in West, which is dominated by a short-term viewpoint and an arms-length relationship between customer and supplier companies.

Communication: In Japan, suppliers need to know what the company wants at a particular time without conforming always the needs. Communications between customer and supplier companies in the West are dominated by formal negotiations between sellers and buyers.

Quality: Supplier quality control systems are also fundamentally different in Japan and the West. In Japan, quality requirements for suppliers are unreasonable high. The requirements are not clearly specified in each design drawing or contract, but rather are given in general and abstract terms. Suppliers are expected to assume `problem-solving' attitudes and always deliver complete products of high quality. In Western countries, quality requirements to suppliers are specified in much more detail. The suppliers are expected to meet the specified quality, but nothing more.

Supplier Selection & Pricing: In the West, suppliers participate in bidding process by offering their prices, and the winner gets the deal. Thus the supplier is selected and the price is set at the same time. In Japan, suppliers are usually selected from affiliated parts manufacturers at the very beginning of the product development stage, whereas the prices offered will not be determined until detailed designs are completed, or just before the start of mass production. Thus in Japan, the selection of suppliers and price settings are clearly separated from each other.

Supplier Network: One of the main difference between Japanese and Western supplier management systems is the shape of the supplier network. In the West, shape of the supplier of network has been wide and shallow, and in Japan, it is narrow and deep.

The change from the arms-length approach to product and business lifetime customer-supplier relationships has fundamental effects not only on the inter-organizational operations and technologies, but also on the structures of the whole supplier network.

2.1.2 Supply Chain Trends

Bhattacharya *et al* (1995) studies on the supply chain trends show that viewed strategically, deciding on suppliers' roles and relationships goes far beyond the simple matter of "make or buy". The issue today is how to position the firm's manufacturing capability to maximize the benefits that can be derived from combining the strengths of their in-house skills and capabilities with the strengths of their supplier. The outcome is a number of related moves by Original Equipment Manufacturers that have multifaceted implications for both buyers and suppliers. Most common moves include the following.

At strategic level

1. Rationalization of supply chains, with OEMs, usually the large customers, going in for single/double sourcing and thus reducing their supplier base.
2. The OEMs are focussing on their core competencies and increasing out-sourced added value.
3. This out-sourcing means that the OEMs are buying systems and sub-assemblies rather than individual parts to be assembled in-house. This is leading to structuring of the supply chain in tiers, the first tier acting as systems integrator buying from second and sometimes from third tier suppliers.
4. The basis of supplier selection is changing from primary price based to collaborative/ technology/core competency based. This calls for partnership rather than the traditional western adversarial relationship between supplier and customer.
5. There is a greater information sharing and joint long-term planning for competitive priorities, volumes, pricing and developments/improvements.

At working practices level

1. Just-in-time deliveries
2. Zero quality defects- direct on line supply
3. Electronic Data Interchange
4. Open book costing, target pricing
5. Joint approach to product design- design responsibility devolved to suppliers
6. Regular feedback.

2.2 Purchasing

Purchasing can potentially influence both efficiency and effectiveness of an organization. In terms of efficiency, it has a direct two-fold effect. Firstly, it is related to profitability through an increase or decrease in purchase price and, secondly, it effects operations through a lack of supply or quality problems which can bring the production process to a halt. In terms of effectiveness, purchasing plays an active role in the design of new products.

Purchasing is the process by which organizations define their needs for goods and services, identity and compare suppliers available to them, negotiate with sources of supply, and finally place orders. The purchasing function plays an important role in shaping the competitive capability of the firm in its market place. It is also well understood that the quality and delivery capabilities of any manufacturing firm are heavily influenced by the performance of its suppliers. The principle objectives of a purchase department can be defined as the procurement of materials or supplies of the right quality, in the right quantity and at the right time, from the right supplier, for the right price (Menon, 1993). Purchasing activity is involved in the following three activities, with the later two encompassing sourcing.

(a) Determination of material or service is required, including its quality, quantity and timeliness;

(b) Selection of a source capable of providing the right quantity of goods or services at the right place and at right time;

(c) Contract management, comprising mutual understanding of buyer and supplier, motivation of supplier, monitoring of quality, requesting value analysis and assisting suppliers.

The purchasing function is one of the vital components of business excellence, as it has a significant impact on the three core performance features of business:

1. **Finance** - this embraces not only the cost of purchasing but also investment in stock/inventory, with the latter's opportunity cost implications as well as turnover;
2. **Operations** - lack of performance on the part of purchasing could bring the production process to a halt, as well as have a considerable effect on the organization's productivity;
3. **Competitiveness -** both cost and differential advantage can be gained as purchasing, potentially, is a source of competitive advantage with a particular market.

The purchasing function, which was traditionally perceived as a routine clerical function in an organization, is now an important strategic aspect that can determine the very survival of the organization (Palaniswami and Lingaraj, 1994). One major aspect of the purchasing function is vendor selection, the acquisition of required material, services and equipment for all types of business enterprises. By its very nature, the purchasing function is a basic part of business management. In today's competitive environment, it is impossible to successfully produce low cost, high quality products without satisfactory vendors. Thus, one of the most important purchasing decisions is the selection and maintenance of a competent group of suppliers.

2.3 Sourcing

Sourcing, which relates to selecting responsible and co-operative suppliers, carries significant risks as well as potential benefits. The related decisions, according to Baily and Farmer (1985), fall therefore into five major areas:

- Identification and/or development of suitable sources of supply for a given item;
- Systematic investigation, evaluation and comparison of sources of supply;
- Distribution of available business to targeted suppliers;
- Formulate terms and conditions;
- Developing a relationship with preferred sources of supply as well as potential sources, which could be used further.

Suppliers are potentially a valuable resource and therefore the source selection must become not only a question of reducing risks but also a search for strengths. Effective sourcing requires a set of procedures or operating policies on which the choice of vendors, or the continuation of purchase from a vendor, is found. These embrace three key areas (Stainer *et al* 1996):

(a) **System design** - This is concerned with strategic decision of single or multiple sources of supply, each possessing advantages and disadvantages. Management needs to balance these in formulating its policy for various groups of purchased items;

(b) **System planning** - The evaluation of the capability of the potential vendor to supply the right goods, at the acceptable quality level and at the right time, constitutes the planning step. A systematic evaluation will enable the organization to decide whether to purchase from particular suppliers or to include them on an approved supplier list. This often referred as vendor grading or supplier qualification;

(c) **System control** - It is necessary to evaluate the past performance of a supplier in order to enable the organization to systematically decide whether to purchase again from a particular vendor. Such monitoring facilities co-operation plans with the vendor, so called vendor rating.

2.3.1 Single versus Multiple Sourcing

A question that needs to be answered is whether there should be only one or more suppliers for the same product. There are several advantages and disadvantages in both the systems (Hines, 1995). If the entire supply is to be purchased from one source, there is a likelihood of getting greater quantity discounts. If the suppliers are more than one, there is a greater degree of dependability in the matter of supplies in the sense that if even one supplier fails to supply the material required for some reason, production will not suffer. One source would mean a consistency in quality. Two sources might mean a certain amount of competition and motivation towards improvement of quality.

Some Advantages of Single Sourcing

1. The supplier is ought to be able to offer price advantages because of economies of scale.
2. Personnel relationships can be more easily established, thus, making communications more effective.
3. Administrative work in buyer's office is reduced.
4. Closer relationships and a reasonable tenure can result in mutual cost reduction efforts.
5. Buyer tied research can be undertaken.
6. Tool and pattern of fixture costs are reduced and long-run tools may be used.
7. Transportation costs can be lower.
8. Quality control is made easier, since there is only one location.
9. Scheduling is made easier.

Some Advantages of Multiple Sourcing

1. With several sources there is insurance against failure at one plant as a result of fire, strikes, quality, delivery problems, etc.
2. With more than one supplier, a competitive situation can be developed; no one supplier can afford to become complacent.
3. In case of standard items, no tooling cost is involved and there are often no advantages for added volumes.
4. The buyer is protecting against a monopoly and may have the advantage of two sources of new ideas or new materials.
5. Giving orders to a number of suppliers increases flexibility in case of large additional call-off or decreased needs.
6. Part business can be used as a base load in conjunction with which a smaller supplier may be developed.
7. With two suppliers holding stock, the buyer company can reduce inventory.

These factors should be evaluated before a decision is taken as to what is most advantageous to the buyer's company. Factors like criticality of the product or its availability are the usual considerations, which influence the ultimate decision.

2.4 Vendor Selection

Materials represent a substantial part of the value of products. For, many firms, purchases from outside vendors account for a large percentage of their total operating costs. The cost of raw materials, component parts and services purchased from external suppliers is significant for most manufacturing firms. On average, manufacturers purchases of goods and services amount to 55% of revenue (Vokurka, 1998). The key objective of the purchasing department is to purchase the right quality of material in the right quantity from the right source at the right time. The right source is one which can provide the right quantity of material on time at a reasonable price. Vendor selection and evaluation is one of the most critical activities. Selection of a wrong vendor or source could potentially upset the company's financial operational position.

Traditionally, purchasing methodology is based on the conventional wisdom that the supplier is foe and the lowest bidder should win the order. Purchasing priorities are price, price, price, and may be delivery, quality, and supplier expertise. The attributes other than price are of minor importance and often times not a consideration in purchasing decisions. The more suppliers you have, the better because you should then be able to get more bids, which will increase your probability of obtaining the lowest price possible. Products are normally poorly specified from a quality standpoint and lead times are inflated to be sure there is ample inventory on hand, which overcomes unreliable supplier deliveries.

Even now, vendors are selected on their ability to meet the quality requirements, delivery schedule and the price offered. However, in modern management, one needs to consider many other factors with the aim of developing a long-term vendor relationship. Vendors are considered as the best intangible assets of any organization.

The vendor selection process involves evaluation of different alternatives based on various criteria.

2.4.1 Vendor Selection Methods

Vendor selection decisions are complicated by the fact that various criteria must be considered in the decision making process. It is an unstructured decision problem because of the following reasons (Mohanty and Deshmukh, 1993):

- The nature and structure of the supply management process are complex.
- There is often a lack of full information as the business environment is dynamic and uncertain.
- As competition in the marketplace increases, there exists a large search space for the decision-maker.
- There is often no quantifiable data because of the development nature of the supply process itself.
- There is some uncertainty in operationalizing the outcome of a selection decision because of organizational internal behavioral dynamics.
- There are a multitude of factors involved in selection decision, which are often conflicting and sometimes complementary. Many times, such factors are non-expressible in commensurable units and some factors might reflect psychological aspects such as quantitative considerations and intangibles.

In view of these, the supplier selection problem has been most often guided by subjectivism. A comprehensive review of vendor selection criteria and methods has been presented by Weber, et al (1991). According their review linear weighing models is by far the most utilized quantitative approach to vendor selection. In the linear weighting model, a weight is subjectively given for each criteria. A total score for each vendor is obtained by summing up the vendors performance on the criteria multiplied by these weights. A shortcoming of the linear weighing model is the subjective assignment of weights to each criteria. The other methodology is the Analytic Hierarchy Process. This is discussed in the next section.

2.5 Analytic Hierarchy Process

Analytic Hierarchy Process (AHP) is a decision-making method developed by Saaty (1980). AHP has been used successfully in many situations where decision making is characterized by a multitude of complementary and conflicting factors.

AHP aims at quantifying relative priorities for a given set of alternatives on a ratio scale. It provides a comprehensive structure to combine the intuitive rational and irrational values during the decision making process. AHP unites perception and purpose into overall synthesis. It is a theory of measurement for dealing with tangible and intangible criteria.

Perhaps the most creative task in making a decision is to choose the factors that are important for that decision. In Analytic Hierarchy Process, the factors once selected, are arranged in a hierarchical structure descending from an overall goal to criteria, sub criteria and alternatives in successive levels.

AHP has found many applications in real life (Zahedi, 1986); for example, technology related problems, political problems, allocation of energy to industries, vendor selection etc. The application process of AHP consists of three stages of problem solving. These are the principle of decomposition, comparative judgements and synthesis priorities.

2.5.1 Steps of AHP

1. Define the problem and determine the objective.
2. Structure the hierarchy from the top through the intermediate levels to the lowest level.
3. Construct a set of pairwise comparison matrices for each of these lower levels. An element in the higher level is said to be a *governing* element for those in the lower level, since it contributes to it or affects it. The elements in the lower level are compared to each other based on their effect on the *governing* element above. This yields a square matrix of judgements. The pairwise comparisons are done in terms of

which element dominates another. These judgements are then expressed as integers. If element A dominates over element B, then the whole number integer is entered in row A, column B and the reciprocal is entered in row B, column A. If the elements being compared are equal, number one is assigned to both positions. The scale of relative importance is given in Table A1 of Appendix A.

4. There are n*(n-1)/2 judgements required to develop the set of matrices in step 3 (reciprocals are automatically assigned in each pairwise comparison).
5. The next step consists of the computation of a vector of priorities from the given matrix. In mathematical terms, the principal vector is computed, and when normalized becomes the vector of priorities.
6. The process of comparing the elements in each level is continued down the hierarchy, comparing the set of elements in each level with respect to elements in the level above which they affect in relative importance. A set of local priorities are generated from pairwise comparison matrices.
7. At this point synthesis of priorities are carried out. Priorities are synthesized from second level down by multiplying local priorities by the priority of their corresponding criterion in the level above. The second level elements are each multiplied by one the weight of the single top level goal. This gives the composite priority of that element which is then used to weight the local priorities of elements in the level below it and so on until the bottom level.
8. We have to check the consistency for every pairwise comparison matrix. The consistency ratio should be about 10% (or) less to be acceptable. If not, the quality of the judgements should be improved.

2.5.2 Types of Measurement

The AHP is used with two types of measurement, relative and absolute (Saaty, 1990). In both, paired comparisons are performed to derive priorities for criteria with respect to the goal. In relative measurement, paired comparisons are performed throughout the hierarchy including the alternatives in the lowest level of the hierarchy with respect to the criteria in the level above. In absolute measurement, paired comparisons are performed through hierarchy with the exceptions of the alternatives themselves. In this case, the alternatives are not pairwise compared, but simply rated as to which category in which they fall under each criteria. A weighting and summing process yields their overall their ranks.

Advantages of AHP:

- AHP model is very much transparent to the users. The hierarchy structure is easy to capture by the decision-makers. The comparison between factors is also easy to capture.
- AHP is easy to apply iteratively. The hierarchy can still be increased; for example, the criteria can further be classified to encompass still lower level indicators.
- AHP is easier for the purchasing managers and other functional managers to quantify their subjective judgements and gives flexibility to verify the subjectivity of factors.
- This is especially useful when evaluating to incorporate the multiple viewpoints of different departments in an organization.
- It is very easy to incorporate sensitivity analysis in the AHP framework, for example, the model can be used to answer different "what if" questions of the type:

  What happens if the weight for quality is increased by 25 percent?
- The hierarchical structure of the AHP makes it possible to disaggregate many intangible factors into more meaningful and quantifiable factors.
- In AHP framework, it is possible to incorporate risk factors; for example, if one knows *a priori* probability distribution of some of the factors, then the expected value of the factor can be used and same model can be used to evaluate various suppliers.

2.6 Systematic Supplier Selection

The supplier selection problem for any manufacturing or service industry includes consideration of critical, as well as quantitative and qualitative factors. A particular factor could be both critical and, say, a subjective factor. Such a situation would arise when it is critical for a factor to be more than some minimum values to be considered further.

Additionally, among those suppliers meeting the minimum requirement, there might be preferences based on the values of the factor.

In the methodology developed by Houshyar and Lyth (1992), both subjective and objective are evaluated, converted to consistent, dimensionless indices, and then combined with the critical measures to yield the performance measure of a given supplier.

Critical Measures: A performance factor is classified as critical if its presence or absence precludes the supplier from further consideration, regardless of other conditions that might exist. The factor either must or must not be present for a supplier to be considered further. Typical examples include price, quality, and delivery date. For instance if quality is considered crucial, any supplier whose product quality falls below certain limit can be eliminated from further consideration.

By evaluating the Critical Factor Measure (CFM) for each supplier, those that do not meet the minimum requirement relative to each of the critical factors are eliminated from further consideration. To determine the critical measures, the analyst determines the Critical Factor Index (CFI) for each critical factor for each supplier. The index is assigned a value of either 0 or 1, depending on whether or not the supplier meets the minimum requirement with respect to the critical factor. The critical factor measure for each supplier is equal to the product of the critical factor indexes.

Objective Measures: Objective factors are those that can be evaluated in monitory terms. Examples are price of the purchased material and its cost of transportation to buyer's site. Thus, associated with each objective factor will be a cost expressed in units dimensionally consistent.

In order to ensure compatibility between objective and subjective factor measures, objective factor costs are converted to dimensionless indexes. The development of the objective factor measure is based on these restrictions:

- The supplier with minimum cost must have the maximum measure,
- The relationship of the total cost for each supplier as compared to all other suppliers must be preserved, and

- The sum of the objective factor measures must equal one.

Let the total cost associated with supplier m, is denoted by C_m. Then, to calculate the objective factor measure OFM_m, following equation is used:

$OFM_m = 1/[C_m. K]$, where $K = Sum_{m=1}^{M} [1/C_m]$.

Subjective Measures: Subjective factors are those which are difficult to quantify, but are important enough in the decision making process to warrant their consideration. Examples are the employee relations and financial position.

The Subjective Factor Measure (SFM) is a measure of the relative importance of a subjective factor in selection decision and is determined using AHP (Analytic Hierarchy Process) approach. It is used to assign weights to subjective factors in a consistent and systematic manner. It involves making a matrix whose rows and columns are the relevant factors to be included in the comparison. It uses the values 1 through 9 to represent the relative importance of one element over another with respect to the property. Preferences for the subjective factors are computed from the comparison matrix.

To compare elements, ask: how much more strongly does factor i possess (or contribute to, dominate, influence, satisfy, benefit) the property than does the factor j with which it is being compared? 1 means equal importance and 9 is extreme importance. When factor i compared to factor j is assigned a value $1 <= k <= 9$, then factor j compared to i is assigned its reciprocal 1/k.

To determine the supplier's weight, the relative desirability of each supplier with respective to each subjective factor is determined. For this evaluation, AHP is used once more. This time the suppliers performances are compared with respect to subjective factors.

Having determined the subjective factor weights and supplier weights, the Subjective Factor Measure (SFM) for each supplier can be evaluated. Mathematically, the SFM for each supplier is equivalent to the sum of the product of each subjective factor weight and the appropriate supplier's performance weight.

Now that the relative desirability of each potential supplier with respect to objective factors and subjective factors has been determined by the evaluation of the dimensionless indices termed (OFM), and (SFM), the two measures should be combined.

This can be done by the use of the Objective Factor Decision Weight, X, which is defined as the relative importance of the objective factors to the selection decision. The feasible values of X are in between 0 and 1. If the company believes that objective and subjective factors should play an equal role in the supplier selection process, then X=50% is used to average the two measures, otherwise supplier measure, S, is:

$$S = X \cdot (OFM) + (1-X) \cdot (SFM)$$

The Supplier's Performance Measure (SPM) can be determined by multiplying the Critical Factor Measure (CFM) with Suppliers Measure (S), i.e.:

$$SPM_m = CFM_m \cdot S = CFM_m \cdot [\, X \cdot (OFM_m) + (1-X) \cdot (SFM_m) \,]$$

2.7 Related Software

In traditional supply systems, suppliers and manufacturers operate in a rather autonomous manner. Suppliers have very little information on what manufacturers need until they receive orders from manufacturers. Similarly, manufacturers do not know what materials suppliers have available until they place an order, and get a correspondent response. For organizations that implement computerized supply chain management systems, the links in the supply chain become truly intertwined. Suppliers and manufacturers do not just share business relationship, but also share confidential, critical information using computer technology.

Supply Chain Management systems enable a high degree of integration between the various systems of all partners in the supply chain. The breakthrough in the supply chain management comes from the advanced computer software that falls into two categories: Enterprise Resource Planning (ERP) and Planning Engine Applications (PEA) (Venkatraman and Blum, 1998). This is made by vendors such as i2 Technologies, Manugistics, Numetrix, and Q-CIM, support and integrate transaction-based processes. Enterprise Resource Planning solutions, a popular category of enterprise software made by companies such as SAP, Baan, and Oracle, organizes and interconnects most day-to-day tasks, such as entering orders, tracking product shipments, scheduling production, and updating sales forecasts and balance sheets. With ERP software, previously incompatible systems can be tightly integrated.

Sales of PEA software i2's Rhythm amounted to US $420 million in 1996; it may reach US $1 billion by the end of 1998 at a compound annual growth of 67%. ERP software, on the other hand, is expensive. It costs about US $10 million to US $40 million and about 4 years to implement. It is estimated that it takes about 9 years to achieve a return on the investment. In contrast, planning engine applications software can be implemented in about six months, and ROI can be achieved in about one year.

Supply chain management software are currently capable of integrating the various existing software and business processes across departments within an organization, as well as across different organizations. The entire supply-chain would behave as though it were one virtual company.

2.7.1 SCM and Internet

Manufacturing companies are increasingly focussing on the use of core competencies as a competitive weapon in the emerging global economy. This has resulted in a growing trend towards outsourcing in the manufacturing industry. The emergence of Internet technologies, such as World Wide Web, and the growing use of computers by customers and manufacturing companies, is creating new paradigm for supply-web interactions. Basics concepts about Internet and World Wide Web are given in Appendix B.

Supply-web represents a collection of autonomous entities that make decisions dynamically in a highly distributed manner using local knowledge and information gained through message passing with other supply-web entities to achieve desired goals.

Research on supply-web interactions is not new. Several researchers have investigated issues pertaining to supply-chain management, mass customization, electronic commerce, collaborative design and manufacturing and so on. The focus of these research efforts can be broadly divided in to two categories. - (1) Distribution and Inventory Management Intensive, and (2) Collaborative Design Intensive (Veeramani *et al*).

(1) Research efforts in the Distribution and Inventory Management have primarily concentrated on the development of centralized decision-making models for integration of the distribution, production and inventory management decisions

across enterprises in a given supply chain through the use of information technology. The use of distributed decision-making for production planning in supply-chains has recently been drawing attention.

(2) Research efforts in the Collaborative Design category have focussed mainly on issues pertaining to collaborative design of fully customized, highly engineered, complex, low-volume products (e.g., missiles, aircraft etc.) by multiple designers at geographically distributed locations.

In addition to the above two categories of related work, researchers in the information technology area (e.g., the management information systems) have mainly been focussing on transaction management and security issues in electronic commerce for retail products.

Veeramani *et al* developed a highly distributed architecture, called SCOUT, for modeling Internet-based supply-web interactions. This SCOUT (Supply-wed Configuration and Orchestration Unified Theory) architecture is based on the view of emerging Internet-based supply-web environment. In this, customers (end users or companies) are able to custom-design (or specify) their desired product or define a variant of a standard product and post their "job announcements" via the Internet. Vendor companies will advertise their competencies, identify jobs of interest, and respond quickly to these job announcements (or requests-for-quotation) with "bids" (e.g., price and delivery-date) using up-to-date information about their resource availability.

Even if a vendor company lacks some of the necessary competencies or resources to complete a job, it can still bid on the job by forming alliances (short-term or long-term) dynamically with other companies thereby creating a supply-web capable of satisfying the customer needs. Based on the bids received, the customer will grant the job to the "best" vendor company (and the underlying supply-web). Subsequently, the coordination of the order execution will also be performed in a highly distributed manner (both among the partners in the supply-web as well as within each company's shop floor) that best achieves local and global supply-web objectives.

2.7.2 Electronic Procurement using Agents

World Wide Web (WWW) is rapidly becoming a powerful business tool because of its online commercial services and electronic commerce capability. Information content providers can supply current information with minimum administrative overhead because the database, as a back-end or data source for Web applications, can offer high-speed search capabilities, reliable data input and retrieval. With the advent of the WWW, and as more companies are becoming visible on Web, the conventional mode of purchasing has changed radically as more and more components are procured electronically. Electronic purchasing on the WWW is facilitated by a branch of artificial intelligence known as intelligent software agents (ISAs).

Although a rigorous, concrete definition of ISAs has not yet been agreed upon, they can be thought of as self-contained programs with decision making abilities which act in pursuit of one or more objectives based on their perception on environment (Khoo *et al* 1998).

Electronic procurement makes use of two entities, the *client* and *host* server. The client server is the computer where the user creates and launches the client agent, which then travels on its own accord to a supplier's server (host server). Once the client agent arrives at a host server, the later activities a host agent and transaction between the two agents commence. The client agent passes the purchasing specifications to the host agent which then searches through the product database of the host supplier. The host agent can choose to either accept or reject the client agent's inquiry. If it chooses to accept, the host agent go one step further to make its best offer. On the other hand, if the host agent decides to ignore the request, the client agent will be notified accordingly. In either case, the transaction is completed and the client agent proceeds to the next host server. After the client agent reaches the last host server on its list, it returns to the client server.

The client server ranks the relative attractiveness of the various offers from the suppliers that responded to the client agent's inquiry. The client agent assigns a weight to reflect the relative importance of each of the procurement specifications. The important the attribute, the larger the weight assigned. The suppliers offers are ranked according to the shortfall between the supplier's (host's) specification and the user's (client's) specification weighted by the significance of the attribute. A rudimentary example of sourcing for spur gears is discussed.

2.8 Casting Supply Chain

Casting supply chain begins with the customer by sending order to the foundry. The customer sends the order to the foundry along with the component drawing and other details such as metal composition, delivery date and condition - as cast or machined. The very first step is to check the component for castability and estimate the cost, which may comprises of material and tooling cost. If some minor changes in component drawing are needed then they are made with mutual understanding of the customer. Once the component drawing is finalized, casting design process begins with preparation of casting drawing. This is done by adding allowances to the component drawing followed by preparation of mold scheme, pattern and core drawing. While designing feeding and gating system, tooling manufacturing can be carried out simultaneously for pattern and cores.

After trial runs and based on inspection report, a feed back is given to modify the tooling or to adjust different process parameters to get the acceptable level of quality. The process may be improved and regularized further by designing and incorporating fixtures for checking dimensions, permanent core box, metallic pattern and gating system.

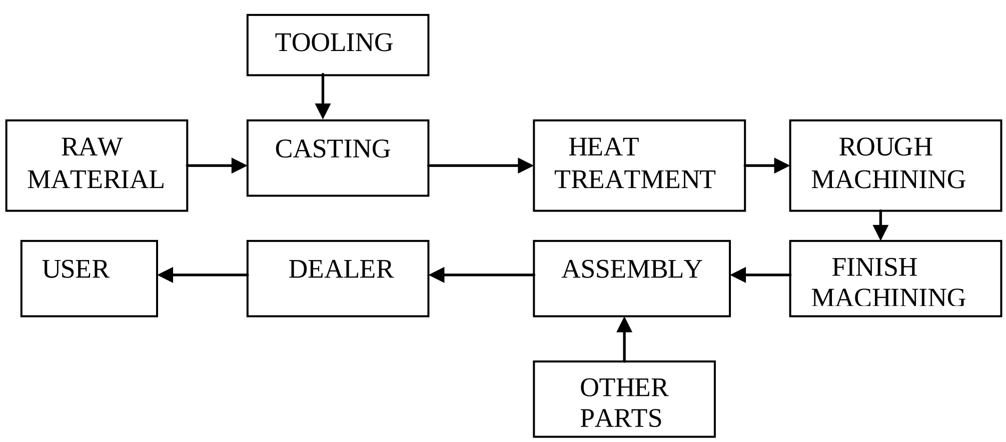


Fig. 2.1 Stages in a Typical Casting Supply Chain.

Generally, foundries do not have all the facilities such as pattern making, machining and inspection under one roof. A typical casting supply chain in this contest is shown in fig. 2.1. Successive stages in this chain are often performed by different firms. Cast components range from extremely complex shapes such as engine blocks to simple castings like flywheels. Typically, a cast component requires two or more stages of machining and is then assembled with a number of other components to form a sub-assembly.

There are a number of technical and managerial aspects in the planning and operation of casting supply chains. Soman *et al* (1998) studies various strategies for managing these supply chains. With the changing style of supplier-buyer relationships from price based to partnership type of working, resulted in a number of different initiatives by supply chain players. These initiatives are broadly aimed at achieving the competitive objectives of the supply chain as a whole. These can be broadly classified in to two groups as discussed below:

Managerial Initiatives

A good option for assemblers in managing suppliers is to retain a fraction of equity and develop new relationships with some of their suppliers who had been completely independent. Another form of financial involvement and control of supplier operations is through financial assistance so that the supplier can invest suitably.

Supplier programs are being used as a powerful communication tool by automobile assembler in the topics of mutual interest. Suppliers are encouraged to supply completed sub-assemblies or assemblies.

Technical Initiatives

Quality system certificate is seen by suppliers as one of the prerequisites for becoming a supply chain partner. In terms of integration, the trend is towards tighter control of stage-wise and pipeline inventories, which again push firms upstream in the casting supply chain to integrate. The direct supplier to the company assumes complete responsibility for providing the sub-assembly and, on its own or with assembler's guidance, selects secondary and tertiary suppliers.

Once the long-term or personal relationships have been established, suppliers do not hesitate to suggest design modifications. Suppliers need to know the way the components or sub-assemblies integrate with the final product. Sharing the design and manufacturing plans in the concept of concurrent engineering with a supplier enables him to plan his supplies.

Chapter 3

PROBLEM DEFINITION

3.1 Conclusions from Literature Review

1. The major decision areas in supply chain management, are the location, production, transportation, inventory and suppliers decisions.
2. The two different systems in managing suppliers are the arms-length approach (Western Supplier Management) and partnership approach (Japanese Supplier Management).
3. Manufacturing companies are out sourcing a large amount of business, in terms of assemblies and sub-assemblies, rather than parts.
4. The selection of competent suppliers has long been regarded as one of the most important functions to be performed by a purchasing department.
5. Traditionally, vendors are selected based on price, but in recent years, it was based on quality requirements, delivery schedule and the price offered.
6. The selection process involves evaluation of different alternatives based on various criteria i.e. typically a vendor needs to be evaluated over a number of selection criteria.
7. The linear weighing model is by far the most utilized quantitative approach to vendor selection. In this model, a weight is subjectively given for each criteria.
8. Another approach to vendor selection is by using AHP, which is a multi criteria decision-making model used in situations, where the decision is characterized by conflicting factors.
9. Vendor selection involves consideration of critical, subjective and objective factors. These factors are to evaluated in the selection process.
10. Research efforts on supply-web interactions mainly focus on (a) Distribution and Inventory Management, for the development of centralized decision-making models,

(b) Collaborative Design, for design of fully-customized, highly engineered, complex, low-volume products.

11. The initiatives taking place in casting supply chain are in terms of managerial and technical to achieve the competitive advantage.

3.2 Motivation

It is understood from the literature that manufacturing companies are outsourcing large percentage of their business, and forming alliances with the suppliers. In this aspect, selection of a supplier is very much important, because companies are going for long term relations with their suppliers.

We choose the "sand casting" as the domain, in our study, as it is one of the most important and widely used processes for producing a variety of engineering components. Certain advantages are inherent in the sand casting process. Most intricate shapes, both internal and external, can be cast. The size of sand cast products range from grams to tons or more. Almost all metals can be sand-cast.

AHP method is applied in situations, where decision making involves consideration of multiple criteria. Although, vendor selection involves the evaluation of various criteria, a limited work has been done in this area; this may be due to the complexity in structuring and evaluation of various criteria.

As vendors the spread all over globe, the time involved in the procurement activity, sending the drawing etc., is considerably high, in the present agile business environment. Information technology tools are viable option in these situations.

3.3 Objectives

Following objectives have been identified to develop a web based sourcing system for the supply chain management of sand cast products.

1. Identification and systematic classification of the criteria used in selection of supplier.
2. Design and development of a prototype system in selecting a supplier, using Analytic Hierarchy Process (AHP) as a backbone.

3. Use of Internet technology in the system, to reduce time involved in the procurement activity.
4. Implementation of the system and its testing in industry to evaluate its usefulness and potential.

3.4 Scope of the Project

This project will mainly focus on sand casting domain, as it is the most widely used process today. Both, ferrous and non-ferrous castings are expected to be handle by the web based sourcing system to be developed in this work.

This web based sourcing methodology can be applied to almost all products or components, which require outsourcing.

Information related to the casting suppliers will be handled. This includes product development capability, process capability, quality assurance, organization, joint relations & flexibility, and finally cost & delivery.

3.5 Approach and Plan of Work

The development of web based sourcing system was carried in three phases. The detailed approach and plan of work during each phase is as follows.

Phase I: This phase mainly focuses on collection, systematic classification and structuring of different types of criteria used in selection of a supplier for sand castings. For this, the literature regarding manufacture of sand casting, vendor selection procedure and Analytic Hierarchy Process (AHP) are studied. Visits to assembler are made to understand the supplier selection system in the industry.

Phase II: The next step is the application of Analytic Hierarchy Process to the structured supplier selection criteria. A web page is designed and login & password are put to the hyperlinks (documents) containing the information about casting drawing and specifications. A complete web based sourcing system is designed, using AHP methodology in the selection process.

Phase III: The final phase is to develop, implement and test the web based sourcing system. A program is developed to support the system, in the application of AHP to supplier selection. The system is tested in industry to demonstrate its utility and obtain the feedback. A case study is conducted.

Chapter 4

SUPPLIER SELECTION METHODOLOGY

4.1 Introduction

As there has been increasing emphasis on alliances and networks for the firms to achieve competitive advantage, supply chain management and purchasing performance are increasingly recognized as an important determinant. One major aspect of the purchasing function is supplier selection, the acquisition of required material, services and equipment for all types of business enterprises. By its very nature, the purchasing function is a basic part of business management. In today's competitive environment, it is impossible to successfully produce low cost, high quality products without satisfactory vendors. Thus, one of the most important purchasing decisions is the selection and maintenance of a competent group of suppliers.

The first step in developing a system for supplier selection involves identification of different types of criteria for the chosen domain, sand casting.

4.2 Collection

The different types of criteria required for vendor selection have been identified in this investigation. Various sources were explored to identify different types of criteria. These include technical literature (research journals, handbook), talk with experts, visits to an final assembler and a foundry. Visits to the assembler helped in understanding the vendor selection process, and in obtaining the details about the various criteria.

The various criteria identified from different sources were compared to find a common set which would satisfy the requirements of an assembler in selecting sand casting suppliers.

4.3 Classification

After the complete selection criteria were identified, the next step is to systematically carry out the classification and structuring of criteria, in a manner which is useful and easy to apply AHP. The problem of vendor selection is divided in to 6 groups. These are Product Development Capability, Process Capability, Quality Assurance, Organization, Joint Relations & Flexibility, and Cost & Delivery. These can be represented as shown below in Fig. 4.1.

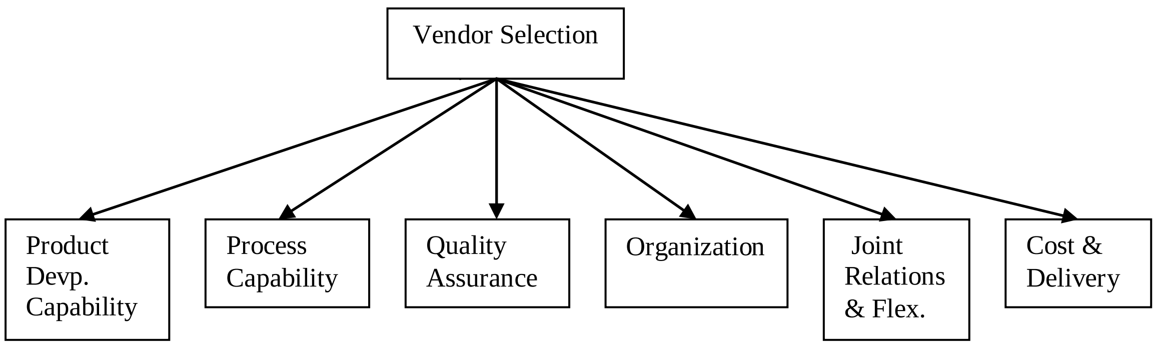


Fig. 4.1 Top Level Hierarchy in Vendor Selection

4.3.1 Product Development Capability

Products with complex shaped surfaces, intricate pockets, intersecting features and curved holes are produced by sand casting. Product development criteria should include the information about the software used in development, Research & Development, expected product development time and pattern availability. The hierarchy of product development capability is shown in Fig. 4.2.

There are many software packages available in process of designing a casting. Examples are AFSOLID, MAGMASOFT, ProCAST, SOLSTAR, SIMULOR and SoftCast. But the information required from the point of view of an assembler is the capability of the software in modeling the casting design tasks like solidification, gating/ feeding design, mold design and in calculating cost & lead time. For sand casting process, pattern, mold box, cores, core box, feeding and gating system constitute the most important elements of tooling. Of equal important to the software used, is the product development time. It involves the purchase of required raw material, making trail runs, testing, sending the samples to assembler and lastly finalizing the casting design.

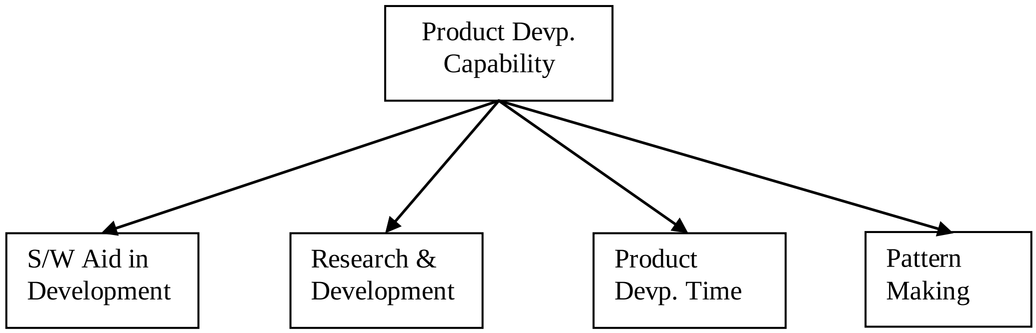


Fig 4.2 Product Development Capability Hierarchy

The facilities like Rapid Prototyping & Tooling are used in quick development of the pattern and mold. These methods drastically reduce the time involved in the development of pattern and its tooling. Foundries can either consult these R P centers or make trial runs with help of experienced engineers in the Research & Development section of the plant, for these tasks. In some cases, the final assemblers provide the pattern to the foundries.

4.3.2 Process Capability

To develop the criteria, information related to various steps in manufacture, viz., sand preparation, molding, core making, melting, pouring, fettling/machining and heat treatment is needed. Process capability hierarchy is shown in Fig. 4.3. For each of these processes, the related equipment and type of process is important.

Sand preparation could be manual, mechanized or by a separate sand reclamation plant. Sand reclamation plant will do all the activities related to sand preparation like cleaning, grading, mixing etc., either automatically or semi-automatically.

Molding involves selection of two attributes for the process. One is the process selection such as green sand, core sand, shell etc., and other is the selection of the equipment for molding such as jolt/squeeze, blower etc. Selection of attributes for molding depends on material, size & weight of the casting, number of castings required, surface finish required etc. Similar to the molding is the core making process, which also involves the selection of process (such as CO2, No bake etc.) and equipment to be used (such as manual, jolt etc.). In this case, the selection depends on the number of cores required, complexity of the core, properties required for core like hardness, porosity, refractoriness etc.

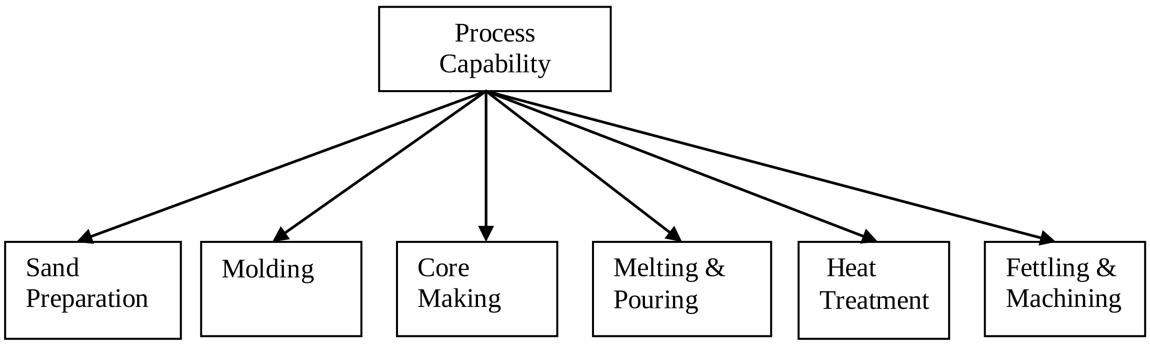


Fig. 4.3 Process Capability Hierarchy

Melting is the process of converting raw material in to molten metal. Melting is generally carried out using either cupola or induction furnace, according to the type of casting metal. This process governs the composition of the molten metal to achieve desired properties or characteristics. De-oxidation elements are to be added to the molten metal before pouring in to the mold. Molten metal may require maintenance in a controlled atmosphere, if the mold is not ready.

Pouring is the crucial and most important operation in the manufacturing of a casting. It requires special attention in terms of maintaining the temperature of molten metal, pouring temperature and its atmosphere. The various control parameters in the pouring are the amount of molten metal required, time required for pouring, speed or velocity with which the molten metal is to be poured. Because of complexity of the poring operation, now-a-days final assemblers preferring those foundries, having either the controlled or automatic pouring facility.

Heat Treatment operations are necessary for a casting depending on the properties required. Heat treatment requires a furnace, which may be gas fired, coal fired etc. The information of interest to assembler regarding heat treatment is whether the foundry is capable of carrying out the task of heat treatment in house or not. Fettling and machining can be done in house or by sub contract.

4.3.3 Quality Assurance

Quality is regarded more important than ever by manufacturers and customers. Quality can be defined as the power to accomplish or the capability of doing a certain thing. The quality assurance hierarchy consists of certification, testing facilities, quality control, quality programs and awards, as shown in fig. 4.3.

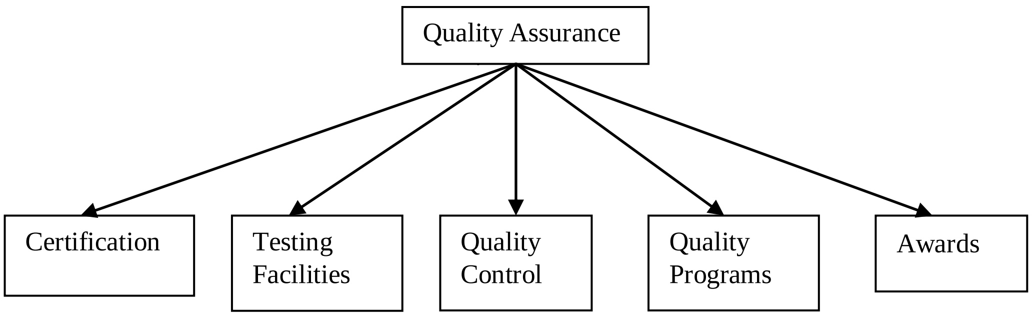


Fig. 4.4 Quality Assurance Hierarchy

Certification is an assurance by or under the supervision of a competent and independent organization, that products are consistently in conformity with a standard or specification. Many manufacturing companies are adopting the ISO 9000 series to help them and their suppliers document and demonstrate quality requirements. The ISO 9000 series is a set of international quality management and quality assurance standards and are listed below.

- ISO 9000 - Guidelines for selection and use of quality management and quality assurance standards.
- ISO 9001 - Model for quality assurance in design and development, production, installation and service.
- ISO 9002 - Model for quality assurance in production and installation.
- ISO 9003 - Model for quality assurance in final inspection and test.
- ISO 9004 - Quality management and quality system guidelines.

Majority of the foundries are either having ISO 9002 certification or planning to go for the same.

In automobile industry, QS 9000 is also emerging as a required quality system standard. QS 9000 has been developed by the three American auto giants, Chrysler, Ford, General Motors. The goal of QS 9000 is the development of an ISO 9000:1994 based system, that provides for continuous improvement, emphasizing on defect prevention system and the reduction of variance and waste in supply chain and calls for use of various methodologies like Value Analysis, Design Experiments and Cost of Quality.

Other certifications include self-certification and certification from assembler. When a manufacturing company has dealt with a supplier for some time and found that his quality level is considerably reasonable, then that supplier is awarded with "supplier certification".

Testing facilities at each stage during the casting activity, reveals characteristics of both process and product. The testing facilities in a general foundry are sand lab, physical lab, chemical lab, radiography, ultrasonic, dye penetration and spectrometer. In sand lab, testing of sand properties like strength, porosity, permeability etc. are carried out. Testing of sample test bars or pieces, to find out the physical properties like strength, elasticity and metallurgical properties like metal composition, micro structure are done in physical and chemical labs respectively. Radiography and ultrasonic comes under non-destructive tests to find out the internal defects of the casting. Spectrometer is used to find the composition of metals in molten metal.

In quality control, the first and foremost aspect is the process control. It is based on the statistical techniques and control charts and tells whether the process is in control or not. Software packages are available to maintain data and prepare reports related to process control. PL controls (programmable logic controls) are those which basically controls the process. PL controls are generally used for pouring as it is the most crucial operation. On-line monitoring and defect prevention system, are primarily to continuously monitor the process as well as the product.

Quality circles and Total Quality Management (TQM) are grouped into quality programs. Quality circle is a group of four or ten volunteers working for the same supervisor or foreman, who meets once a week, for an hour, under the leadership of the supervisor, to identify, analyse and solve their own work-related problems. TQM is about continuous performance of individuals, of groups and of organizations. To improve the quality, people needs to know what to do, how to do, have the right tools to do it, to be able to measure performance and to receive feedback on current levels of achievement. Finally, awards tell the performance history of the foundry in past.

4.3.4 Organization

Financial position, employee relations and software aid in administrative activities are the important criteria considered by an assembler in evaluating the organization structure of the foundry. Hierarchical structure of organization is shown in fig. 4.5. In addition to the above said factors, it is also important to have an information about the production capacity in tons, because it forms a critical factor in evaluating the foundry. The annual turnover and net profit of the supplier contributes in the evaluation of financial position. Similarly, important factors considered by the assembler in employee relations are total number of employees, average number of training period & number of safety programs per year, whether last worker is educated, and strikes, if any in the last 3 years.

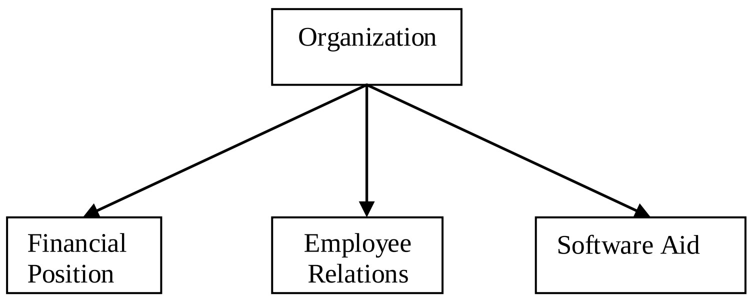


Fig. 4.5 Organization Hierarchy

Software aids in organization include not only the use of computers in administration for maintaining the records, but also the use of EDI facility in communicating with assembler. Electronic Data Interchange (EDI) is the direct electronic transmission, computers to computers, of standard business forms, such as purchase orders, shipping notices, invoices, and the like, between two organizations. In a purchasing environment, documents are transmitted "over the wire", eliminating the need to generate hard copies and to distribute them manually. By utilizing, EDI, a buyer and a supplier are operating in a rear time environment, which can reduce material delays by shortening procurement lead times.

4.3.5 Joint Relations and Flexibility

In joint relations, information sharing and desire for partnership are the important criteria. Fig. 4.6 shows the hierarchical structure of Joint Relations & Flexibility. Information sharing of cost, quality and design helps in reducing the final cost of the product by eliminating waste, improving the quality of the product, and helps in problem solving.

In developing long term relationships, the assembler wants to retain a fraction of equity in the supplier's company. Another form of financial involvement and control of supplier operations is through financial assistance, so that supplier can invest suitably. Therefore, it is important for the assembler to know the supplier's willingness in these types of relations.

Cross functional team is a group of people from materials, quality assurance and finance departments along with manufacturing personnel. Involvement of the suppliers with cross-functional team, by providing design modifications or suggestions, helps in reducing the cost and lead time of the product. This team communicates closely with different functions of the supplier side on variety of issues, there by, removes the organizational barriers and increasingly the supply chain effectiveness.

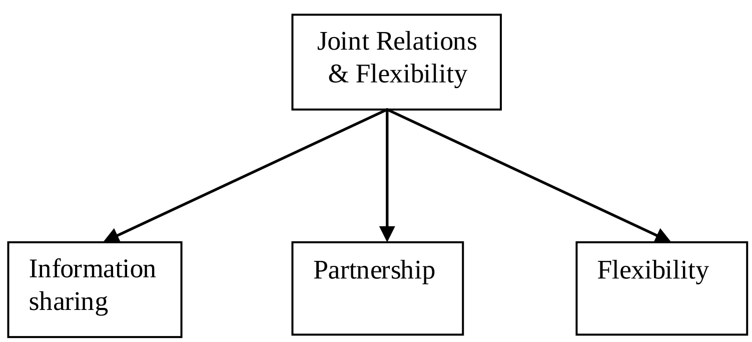


Fig. 4.6 Joint Relations and Flexibility Hierarchy

Literature defines flexibility as a system's capability to cope effectively with a wide range of environmental changes and internal variations with out deterioration in system performance in terms of cost, quality, lead time and on-time delivery. From the assembler's point of view, the important types of flexibilities, a foundry could possess, are volume, delivery and manufacturing flexibility. Volume flexibility refers to the ability of the foundry to take up the demand changes from an assembler. Delivery flexibility is the ability to reduce the order-to-delivery time. Manufacturing flexibility of the foundry is the ability to tackle changes in casting design.

4.3.6 Cost and Delivery

Total price of the casting, exact quantity, timely delivery and guarantee are the important criteria considered by an assembler in evaluating the foundry, in terms of cost & delivery. Hierarchical structure cost and delivery is shown in fig. 4.7.

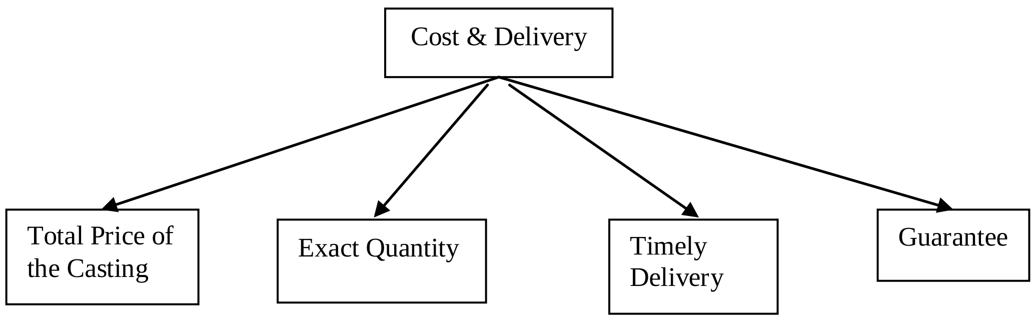


Fig. 4.7 Cost and Delivery Hierarchy

Total price of the casting is the net price of the casting after discounts and adding transportation cost. It also includes the unloading cost at the assembler's site. Exact quantity and timely delivery are the supplier evaluation measures over a period of time and for a given business in rupees. Exact quantity refers to the percentage of castings accepted out of delivered. Timely delivery refers to the supply of castings on a given due date with out delay. It's measure depends on number of days delayed and the frequency of release. Guarantee is the assurance provided by the foundry for exchanging the defective components or products, over a period of time.

The supplier selection criteria are given as the supplier information in Appendix E2.

4.4 Selection Methodology

The computations of the Analytic Hierarchy Methodology (AHP) for selecting the best vendor from among several vendors are carried out over as described below. Fig. 4.8 presents a schematic format to understand the hierarchy for the vendor selection problem.

Level 1 contains the overall objective of Vendor Selection and level 2 contains the attribute groups Product Development Capability (PD), Process Capability (PC), Quality Assurance (QA), Organization (Org), Joint Relations & Flexibility (JR&F), and Cost & Delivery (C&D).

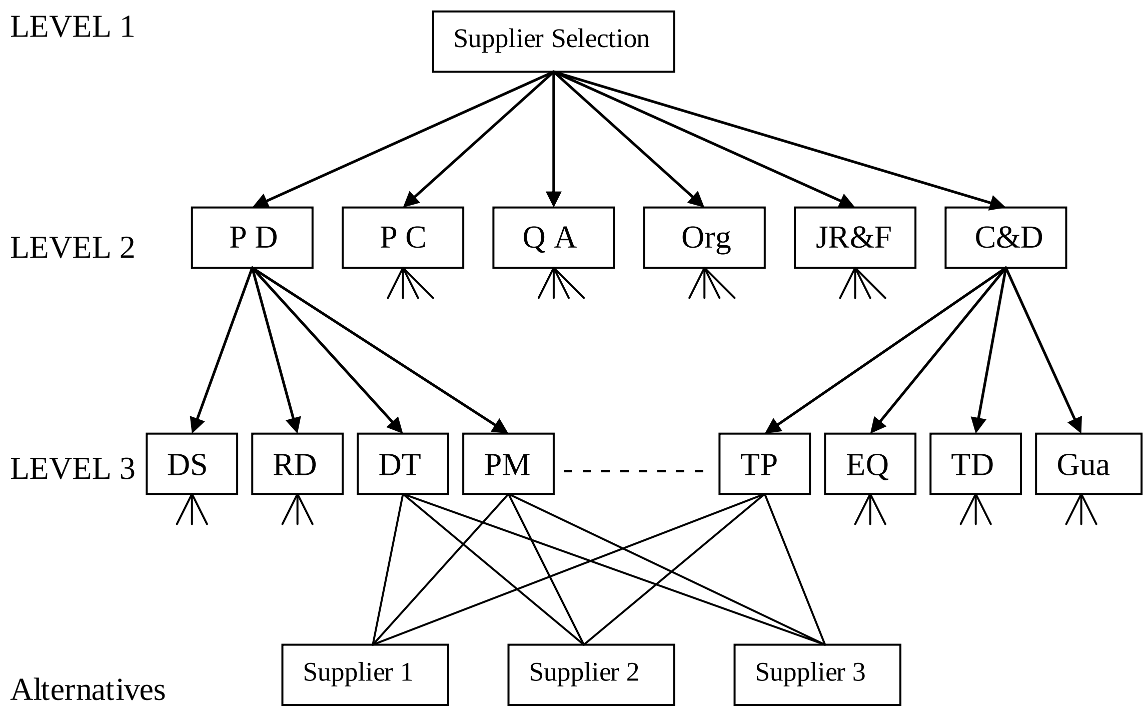


Fig. 4.8 Schematic of the AHP model

AHP is applied at level 1 to get the priorities for the elements in level 2. For this, the elements in level 2 are compared with each other, to derive the priorities. This procedure yields a square matrix of judgements. The pairwise comparisons are done in terms of which element dominates another. These judgements are then expressed as integers by using the scale of relative importance.

The next step is the computation of a vector of priorities from the pairwise comparison matrix. The crude estimates of the vector can be obtained in the following four ways (Saaty, 1980):

- **The crudest:** Sum the elements in each row and normalize by dividing each sum by the total of all the sums, thus the results now add up to unity. The entry of the resulting vector is the priority of the first activity; the second of the second activity and so on.

- **Better:** Take the sum of elements in each column and form the reciprocals of these sums. To normalize so that these sums add to unity, divide each reciprocal by the sum of the reciprocals.
- **Good:** Divide the elements of each row by the sum of that column (i.e., normalize the column) and then add the elements in each resulting row and divide this sum by the number of elements in that row. This is a process of averaging over the normalized columns.
- **Very Good:** Multiply the *n* elements in each row and take the *n*th root. Normalize the resulting numbers.

Example:

	DS	RD	DT	PM	Geometric Mean	Prioroties
S/W Aid in Develop. (DS)	1	3	1	4	1.86	0.41
Research & Development (RD)	0.33	1	1	2	0.9	0.20
Product Devp. Time (DT)	1	1	1	3	1.32	0.29
Pattern Making (PM)	0.25	0.5	0.33	1	0.45	0.10

After computing the priorities for each element in level 2, we have to check the consistency for the pairwise comparison matrix by calculating the consistency ratio. The consistency ratio should be about 10% or less to be acceptable. If not, the quality of judgments should be improved. The procedure for calculating consistency ratio (CR) of the comparison matrix, is as given below (Saaty, 1980).

Let the pairwise comparison matrix be denoted by M1 and the priority vector by M2. Calculate M3 and M4, such that M3 = M1 * M2 and M4 = M3 / M2. Then,

Maximum eigen value (λ_{max}) = Average of M4 elements.

Consistency Index (CI) = (λ_{max}-n)/ n-1 where n = size of comparison matrix

Consistency Ratio (CR) = CI / R where R = random index

(Random index table is given in A2, Appendix A)

Calculations of CR for the above said example:

$$M3 = \begin{bmatrix} 1 & 3 & 1 & 4 \\ 0.33 & 1 & 1 & 2 \\ 1 & 1 & 1 & 3 \\ 0.25 & 0.5 & 0.33 & 1 \end{bmatrix} \begin{bmatrix} 0.41 \\ 0.20 \\ 0.29 \\ 0.10 \end{bmatrix} = \begin{bmatrix} 1.69 \\ 0.82 \\ 2.00 \\ 0.39 \end{bmatrix}$$

$$M4 = \begin{bmatrix} 1.69/\ 0.41 \\ 0.82/\ 0.20 \\ 2.00/\ 0.29 \\ 0.39/\ 0.10 \end{bmatrix} = \begin{bmatrix} 4.14 \\ 4.12 \\ 4.13 \\ 3.97 \end{bmatrix}$$

$\lambda_{max} = (4.14+ 4.12+ 4.13+ 3.97)/ 4 = 4.09$

$CI = (4.09 - 4)/ (4 -1) = 0.03$

$CR = 0.03/ 0.9 = 0.033$ ($R = 0.9$, for $n=4$).

The same procedure of AHP is also applied to all the six elements in the second level of the model, to obtain priorities for elements in level 3.

Score of a particular element in level 3 is equal to the product of priority of that element and its respective performance measure by that supplier.

The elements in the level 3 are of different types. These are objective type (ex: total price etc.), subjective type (ex: financial position), and elements consisting of sub-elements (ex: product development software consists of solidification s/w, etc.). Our approach to get the performance measures for these elements in level 3 is as follows.

The objective elements in level 3 can be of two natures. Firstly, the objective factor having "minimum value" as most desirable (such as, supplier with minimum cost must have the maximum consideration). Secondly, the objective factor with "maximum value" as most desirable (such as, the supplier with highest timely delivery performance must have the maximum consideration).

If the element in level 3 is of objective type, with "minimum value" is most desirable, then for calculating objective factor measure OFM_m, the following equation is used:

$OFM_m = 1/[C_m. K]$, where C_m = Total cost associated with supplier m,

and $K = Sum_{m=1}^{M} [1/C_m]$.

Example: If the total price offered by supplier 1, supplier 2, and supplier 3 is rupees 4000, 3600 and 4300 respectively, then

K = (1/4000) + (1/3600) + (1/4300) = 0.00076

Total price measure of supplier1 = 1 / (0.00076 * 4000) = 0.329

Total price measure of supplier2 = 1 / (0.00076 * 3600) = 0.365

Total price measure of supplier3 = 1 / (0.00076 * 4300) = 0.306

If the element in the level 3 is of objective nature with "maximum value" as most desirable, then in calculating the performance measure for that particular factor, we normalized the scores got by individual supplier.

Lets say, supplier 1's timely delivery performance is 95%, and for supplier 2 and 3, the values are 85% and 90% respectively, then

Timely delivery performance measure of supplier 1 = 0.95 / (0.95 + 0.85 + 0.90) = 0.352

Timely delivery performance measure of supplier 2 = 0.85 / (0.95 + 0.85 + 0.90) = 0.315

Timely delivery performance measure of supplier 3 = 0.90 / (0.95 + 0.85 + 0.90) = 0.333

To determine the subjective factor measure at level 3, the relative desirability of each supplier is to be determined. For this evaluation, AHP methodology is applied. In this case, the suppliers are pairwise compared with respect to subjective factor, such as financial position.

For example, if the pairwise comparison of suppliers for financial position are as shown below:

	S1	S2	S3	Geo. Mean	Priorities
Supplier 1 (S1)	1	1.5	2	1.44	0.46
Supplier 2 (S2)	0.66	1	1.5	1.00	0.32
Supplier 3 (S3)	0.5	0.66	1	0.69	0.22

then,

Financial position of supplier 1 = 0.46

Financial position of supplier 2 = 0.32

Financial position of supplier 3 = 0.22

If the element in level 3 consists of sub-elements, we used linear weighting model to get the priorities. In linear weighting model, the weight is assigned subjectively. In calculating the measure for that particular element, we normalized the scores got by the individual supplier.

For example, if the user decides to give equal weights for the sub-elements in Flexibility, which is a 3rd level element, then volume flexibility, delivery flexibility and manufacturing flexibility gets equal weight i.e., 0.33. If the supplier 1 is having all the three types of flexibility, supplier 2 is delivery flexible, and supplier 3 is volume & delivery flexible, then the performance measures are calculated as follows:

Score of a supplier = 0.33 (if volume flexible, o/w zero) +
0.33 (if delivery flexible, o/w zero) +
0.33 (if manufacturing flexible, o/w zero).

Accordingly, the scores of suppliers in Flexibility are:

Score of supplier 1 = 0.33 + 0.33 + 0.33 = 0.99

Score of supplier 2 = 0.00 + 0.33 + 0.00 = 0.33

Score of supplier 3 = 0.33 + 0.33 + 0.00 = 0.66 and the

Performance measure of supplier 1 in Flexibility = 0.99 / (0.99 + 0.33 + 0.66) = 0.5

Performance measure of supplier 2 in Flexibility = 0.33 / (0.99 + 0.33 + 0.66) = 0.167

Performance measure of supplier 3 in Flexibility = 0.66 / (0.99 + 0.33 + 0.66) = 0.333

In order to ensure compatibility between the various elements in level 3, we normalized the performance of suppliers for each type of element, so that the sum of performance measures is equal to one.

The final step of the AHP methodology is to apply the principle of composition of priorities (or synthesis of priorities) to compute the composite or global priority vector of the vendors (alternatives).

The desirability index (total score) for a supplier is the sum of multiplication of

(1) performance measure for each element in `level 3',

(2) with its priority, and

(3) the respective priority at level 2.

Mathematically, it can be represented as:

$$S_k = \sum_i \sum_j P_i \; P_{ij} \; M_{ijk}$$

Where,

S_k = Total Score of k^{th} supplier,

P_i = Priority of i^{th} element in level 2,

P_{ij} = Priority of j^{th} element in level 3, belonging to i^{th} element in level 2.

M_{ijk} = Performance of measure of k^{th} supplier for j^{th} element in level 3, belonging to i^{th} element in level 2.

4.5 Conclusion

In this chapter, the vendor selection criteria, in the domain of sand casting products, are systematically classified in a hierarchical structure. The complete selection methodology using AHP is explained with examples. The next chapter deals with the complete web based sourcing system.

Chapter 5

WEB BASED SOURCING SYSTEM

5.1 Introduction

The World Wide Web (WWW), the global computer network of information databases, has experienced phenomenal growth in both the amount of information available and the total number of users accessing that information. An increasing number of organizations are now taking advantage of the incredible range of information offered by global network and, at the same time, are reaching out to Internet users who are potential clients or suppliers. Moreover, many companies now find that it makes business sense to have a web site of their own. These include both automobile assemblers and foundries. Some of them are given in Appendix C.

By surfing and searching the net, we found that the web pages maintained by these companies are customer oriented. Mostly the web pages maintained by automobile manufacturers contain the information related to types of models they developed. On the other hand, foundries are publishing on web to advertise the products in which they are specialized. For example, a foundry on Internet says that they are specialized in die casting products. Some of the foundries are also providing information about quality certifications like ISO/QS 9000 and their specialization in making specific castings.

5.2 Web Based Sourcing System

The complete system of sourcing for selecting the best vendor among several vendors is carried out by using the World Wide Wed technology as described through the following steps. The system is designed in the domain of sand cast products.

Step 1: Initially the assembler will design his own web page. It briefly tells about the assembler's company, contact addresses and description regarding cast product. This page also contains a hyperlink to another web page, called "casting information", which will have detailed specifications, casting drawing and quotation.

Step 2: The "casting information", can be accessible by foundries, only after providing the login name and password by an assembler.

Step 3: Foundries decided to bid for the casting will have to fill quotation form and submit the same.

Step 4: Based on the information received from foundries, assembler prepares supplier data files. In addition, assembler has to prepare a data file of linear weights for the sub-elements in 3^{rd} level of AHP model.

Step 5: Assembler uses a computer program of AHP methodology, in which pairwise comparisons are carried to obtain the priorities.

Step 6: Results of the AHP Program are stored into two files. One file contains the priorities obtained from pairwise comparisons. Details of the supplier scores are stored in another file.

Step 7: The supplier is selected based on the highest score obtained through the AHP program.

5.3 System Design

The web based sourcing system is classified into two parts, namely web page design and vender selection program using AHP. In this section, we will discuss web page design for displaying the casting information as well as to obtain quotations. Next section deals with programming aspects of the system.

The very first step in web based sourcing system is the publication of requirements of casting by an assembler. It will be accomplished by preparing a web page containing basic information about the company and casting. This is equivalent to a traditional advertisement inviting bids on the casting.

For the purpose of demonstration, we had taken an account in "hypermart.net", which is a real yellow pages on Internet. We named the web site as "castsourcing". Therefore, the complete address of the web page is "http://castsourcing.hypermart.net". When viewed through a browser (Netscape), the web page looks like as shown in figure 5.1. The concepts about HTML used in designing the web page are given in Appendix D.

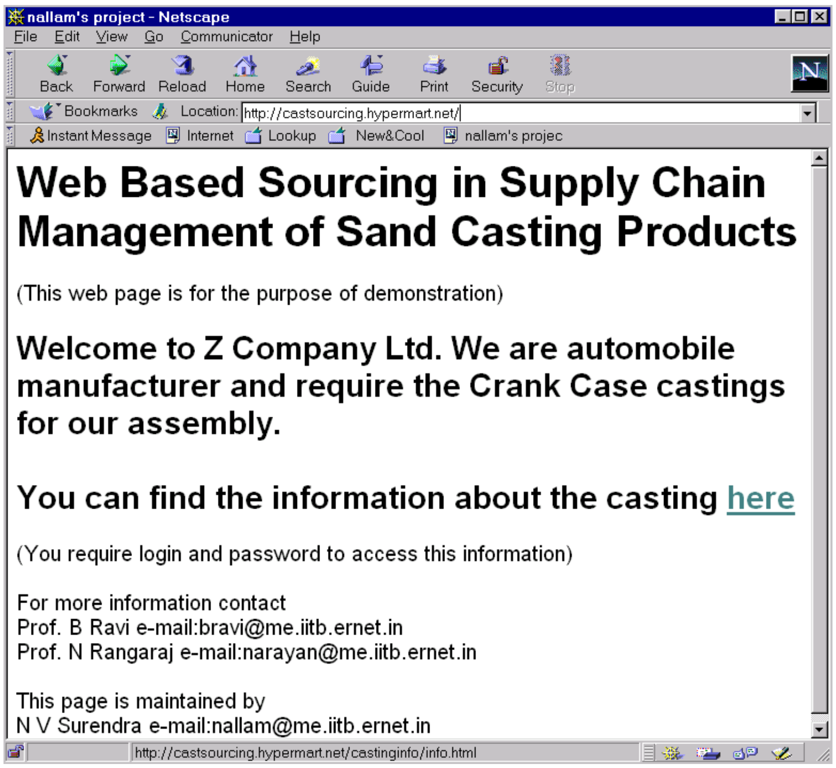


Fig. 5.1 Castsourcing web page.

The "castsourcing" page also contains the information about contact persons to get the login and password. The casting specifications and drawing can be viewed through a hyperlink by authorized login name and password. This is because the assembler may not want to freely provide the casting information to all foundries and competitors.

This web page asks the assessor (this case, foundry manager) to click on some portion of the page, to get casting information. Once the assessor clicks on that particular portion (with the help of "mouse" in case of Netscape, or simply "right arrow" button in case of Lynx), it shows a small message box asking login & password (Fig. 5.2). The system developed is capable of providing different login name and passwords for different foundries, to access the same casting information web page.

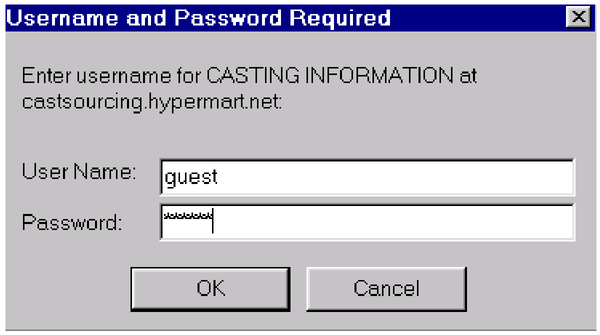


Fig. 5.2 Password Message Box for "casting information"

If some unauthorized assessor tries to view the detailed casting specification and drawing then the system will respond with an error message as shown in fig. 5.3.

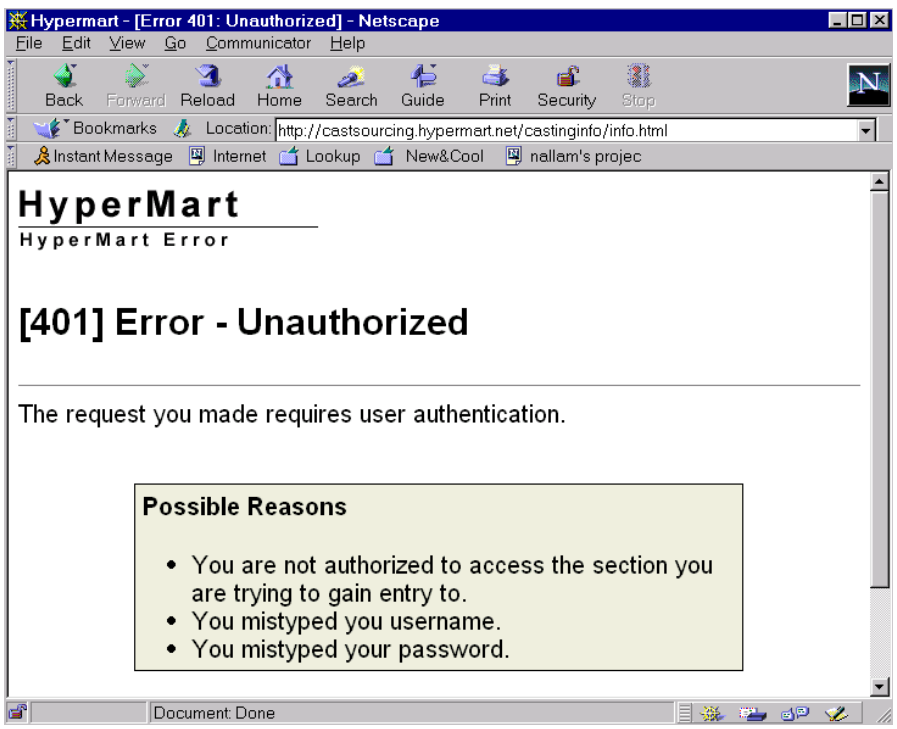


Fig. 5.3 Display of "unauthorized" web page

The system developed provides two types of security. These are

1. Access Security — proving access of the web page to restricted persons.
2. Transit Security — providing security for the information while it is in transit, so that no one can interpret and get benefit out of it.

Access security is successfully handled by the system developed using the concept of login name and password. Transit security is important in two situations. One is while accessing the casting information by a foundry; it should not be interpreted by the competitors of the assembler. In the second case, when the supplier sending the quotation, by filling the secret information like quotation price, it should not be known to the other suppliers, who are also competing for the same bid.

Fortunately, many web servers and web browsers have the capability to create secure connections so that they can communicate privately (Colburn, 1998). This enables the assembler to send required casting information to preferred foundries. Similarly, suppliers can send confidential data to assembler's site without worry.

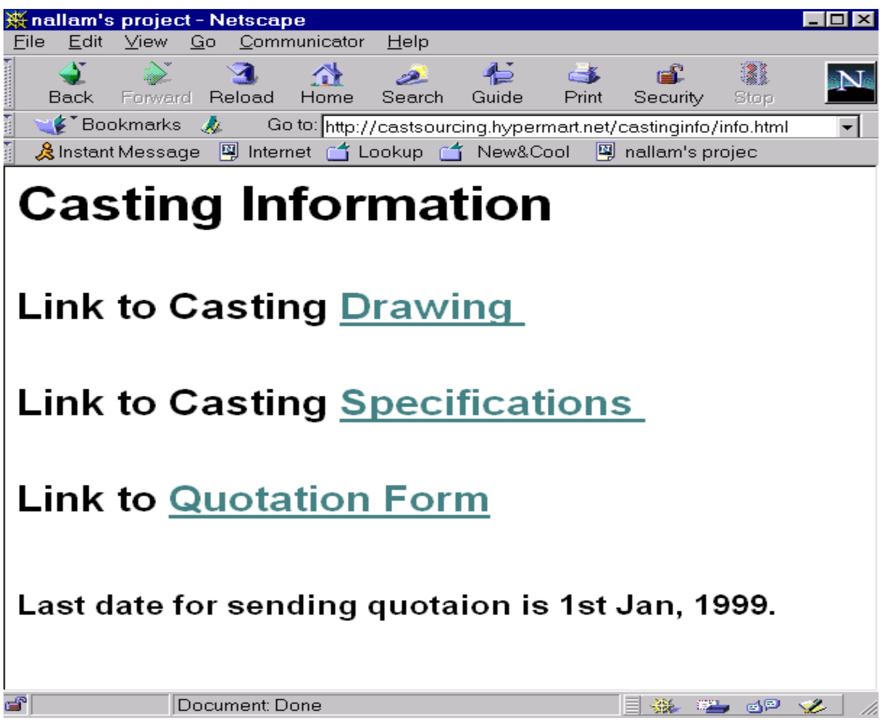


Fig. 5.4 Display of "casting information" page

The "casting information" page contains links to drawing, specifications and the quotation form (Fig. 5.4). This page also contains the "last date" for sending quotation. The contents of the page can be surfed with help simple "mouse" clicks or "arrow keys", as per the browser.

The fig. 5.5 shows the casting drawing, which was accessed from "casting information" page. Casting specifications format is given Appendix E1. After accessing the complete casting information i.e., casting drawing, specifications and last date for submitting quotation, if the foundry decides to quote for the casting, it can do so by filling and submitting the quotation form. Quotation form contains blanks to be filled by the foundry. It is to get the price offered and information the related to product development capability, process capability, quality assurance, organization, joint relations, etc.

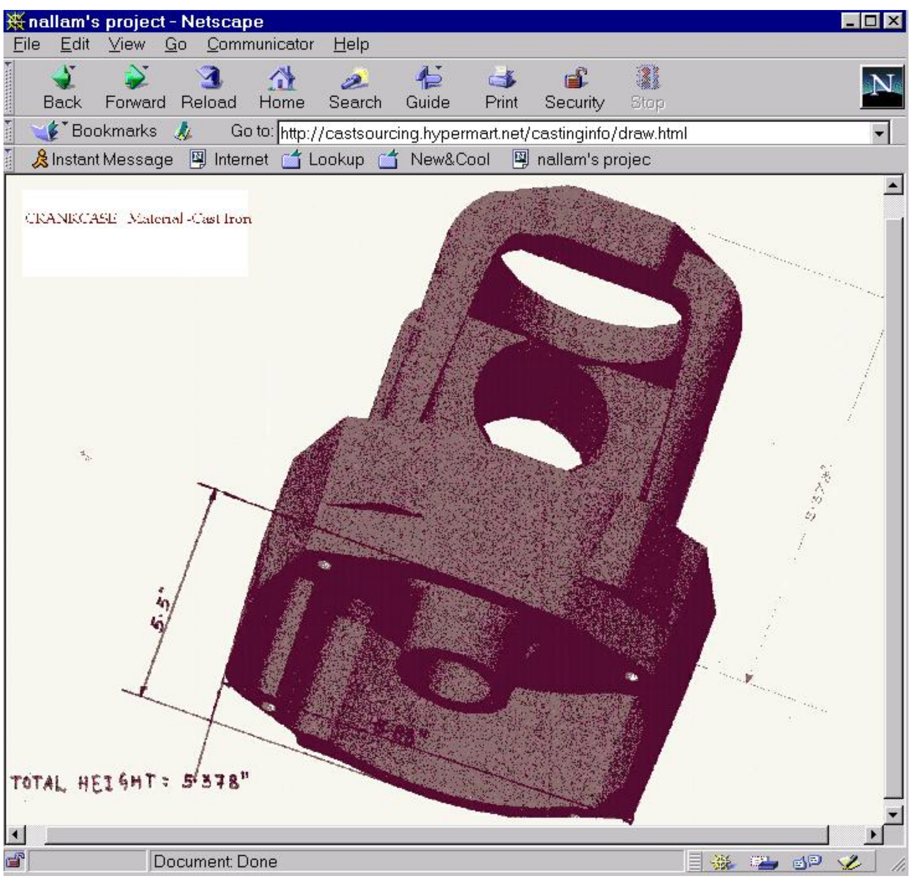


Fig. 5.5 Display of "casting drawing" web page

The format of quotation form (supplier information) is shown in Appendix E2. The "quotation form" web page is shown in fig. 5.6.

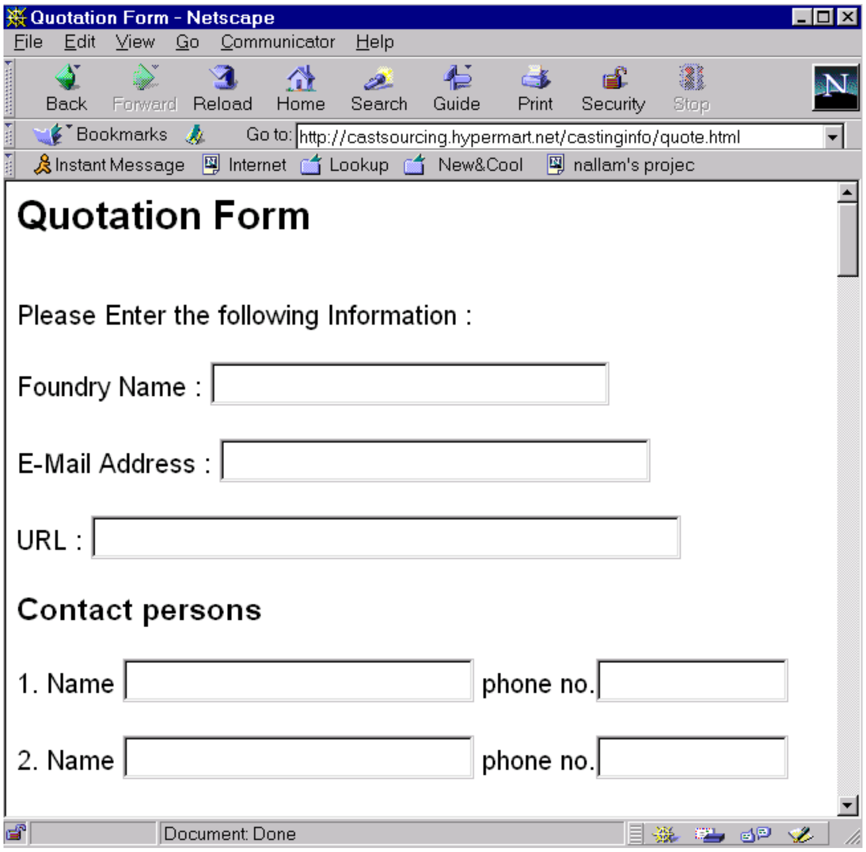


Fig. 5.6 Display of "quotation form" web page

The assembler receives quotation from the supplier in an encoded format. This is because use of mailto:URL in designing quotation form. For example, if the supplier uses cupola for melting and have manual pouring equipment, and fills accordingly. It reaches the assembler's site as: MELTING=CUPOLA&POURING=MANUAL

The assembler has to decode this data, by simple removing the "equal to" and "ampersand" to get "field name" and its respective "value". The decoded data for the above example is shown below.

Field Name	Field Value
MELTING	CUPOLA
POURING	MANUAL

Assembler has to store the data obtained from suppliers in the form of data files, separately for each supplier, as required by the computer program.

5.4 Program Design

The input required to the program are:

1. Suppliers information
2. Linear weights
3. Pairwise comparisons.

Suppliers information is the data obtained through quotation form. Linear weighs are the values given by the assembler for the sub-elements of the criteria, in the 3rd level AHP model. Assembler has to give pairwise comparisons for the elements in level 2 and 3 of the AHP model to get the priorities. The program reads the field value from supplier information, for a given field name, and assigns the respective weight to supplier score, taken from linear weights, in the process of calculating the total score.

Program is developed in Visual C++ using windows environment. For the sake of demonstration, we are assuming that there are three competent suppliers, who can win the bid. The file formats and user interface for the program are discussed in the following sections.

5.4.1 File Formats

The input data files to the program are in the form of field name and field values. The program generates output to the output files in the same format. The input required are there supplier data files (SUPPLIER1.dat, SUPPLER2.dat and SUPPLIER3.dat), and a data file containing the linear weights (LINEAR_WEIGHTS.dat). The linear weights data file also uses the same format containing fieldname and the respective value.

The program generates the priorities for the criteria in level 2 and level 3 of the model and stores in GENERATED_PRIORITIES.dat. The scores each supplier got in the evaluation process are stored in to RESULTS.dat.

Input File Formats

Supplier data file: Lets say a supplier is having mechanized sand preparation system, green sand mold with Jolt/squeeze for molding, shell process using sand blower as the equipment for core making. In addition supplier also uses induction furnace for melting, manual pouring equipment, sub contracting for heat treatment operations, and had the in-house facilities for both cleaning and machining, the information is represented in supplier data file as shown below.

SAND_PREPARATION	MECHANIZED
MOLD_MAKE	JOLT_SQUEEZE
MOLD_TYPE	GREEN_SAND
CORE_MAKE	SAND_BLOWER
CORE_TYPE	SHELL
MELTING	INDUCTION
POURING	CONTROLLED
HEAT_TREATMENT	SUB_CONTRACT
CLEANING	INHOUSE
MACHINING	INHOUSE

Liner weights data file: The assembler may assign weights for different pouring equipment, such as 0.11 for manual, 0.33 for controlled and 0.56 for automatic.
These weights are represented as shown below:

POURING_MANUAL	0.11
POURING_CONTROLLED	0.33
POURING_AUTOMATIC	0.56

Output File Formats

Generated Priorities data file: Once the program is run, it generates the output in the form of a file, based on the pairwise comparisons given by the user. If the generated weights file shows the following output,

PRODUCT DEVP CAPABILITY	0.173
PROCESS CAPABILITY	0.173

QUALITY ASSURANCE	0.293
ORGANIZATION	0.081
JOINT RELATIONS & FLEX	0.109
COST & DELIVERY	0.173

it means that priorities for product development capability, process capability and cost & delivery are 17.3%, whereas quality assurance is 29.3%, organization is 8.1% and the priority of joint relations & flexibility is 10.9%.

Results file: If the results file show the following output,

S/W AID IN DEVP	41.1 %	0.750	0.250	0.000
RESEARCH & DEVP	19.9 %	0.306	0.387	0.306
PROD DEVP TIME	29.0 %	0.333	0.250	0.417
PATTERN MAKING	10.0 %	0.333	0.333	0.333

then, for "product development time" criteria, the relative priorities of suppliers 1, supplier 2, supplier 3 are 0.333, 0.25 and 0.417 respectively. This file also shows the priorities for the criteria and the total score obtained by each supplier.

5.4.2 User Interface

User interface to the program is designed based on windows platform. A simple pull-down menu is designed to execute the various functions such as File, Edit, View, Priorities, Selection and Help of the program. Fig. 5.7 shows the pull-down menu for Priorities option.

The options available in "Priorities" pull down menu can be used to execute the functions like overall priorities, product development capability, process capability, quality assurance, organization, joint relations & flexibility and cost & delivery. A dialog box can be obtained by selecting any options from priorities pull down menu. Dialog box is a window through which the user passes input to the program for each pairwise comparison matrix.

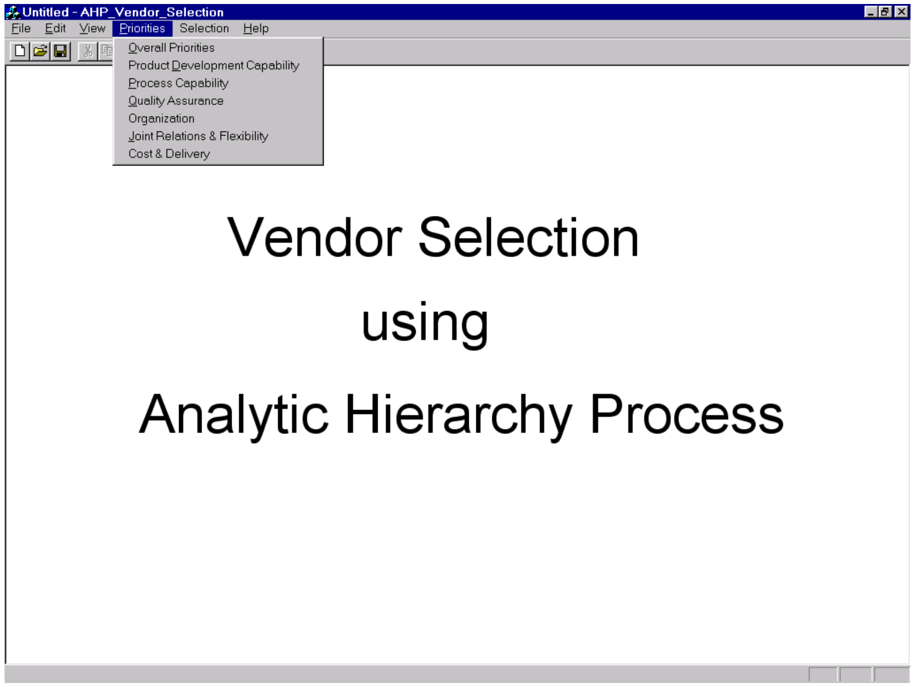


Fig. 5.7 Priorities pull-down menu

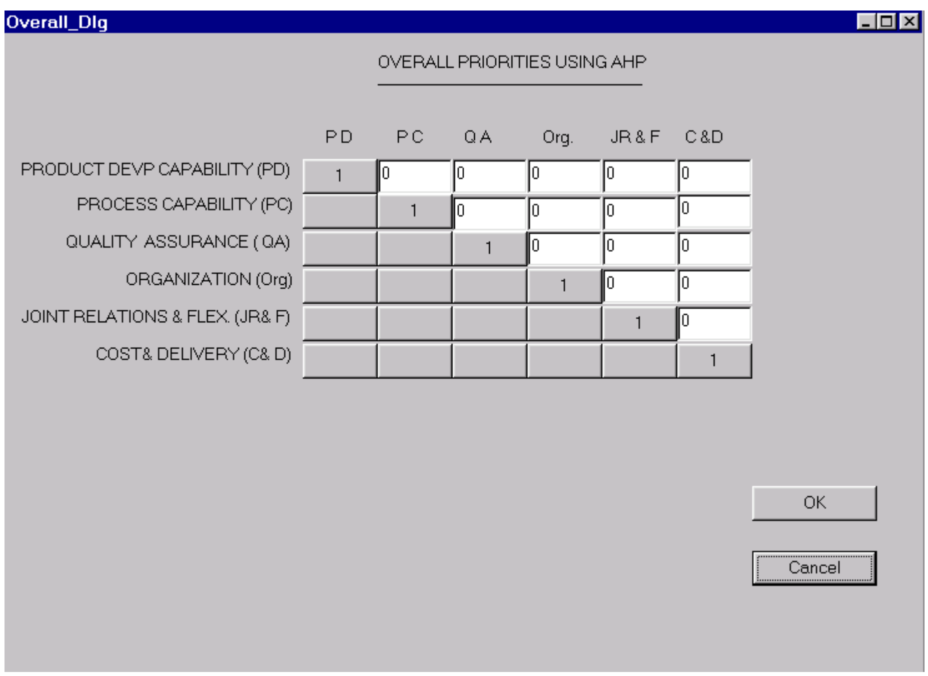


Fig. 5.8 Overall Priorities Dialog Box

Fig. 5.8 shows overall priorities dialog box. In this case, the pairwise comparisons are required with resect to criteria.

One point to observe is that the pair wise comparison matrix is symmetric and only half of the matrix is required (either upper triangular or lower triangular matrix) for the computation of the priorities. The dialog box shows zeros in the upper triangular portion of the pairwise comparison matrix, "ones" in the diagonal elements and the remaining lower triangular matrix is in the hidden form.

User has to give pairwise comparison between the elements, and enter in the respective places. After all, pairwise comparisons given in to the dialog box and user selects the "OK" button, the program shows the result on to the screen. Consistency ratio of the comparison matrix should be 10% or less to be acceptable. If it is more than 10%, a small message informs the user about the inconsistency as shown in fig. 5.9.

Fig. 5.9 Inconsistency Message Box

Similarly, the pull-down options in "Selection" menu item are functions to call dialog boxes of financial position and employee relations. The employee relations dialog box is shown in fig. 5.10. The financial position and employee relations dialog boxes show the characteristics of the respective criteria of each supplier. In this case, the assembler has to fill the relative desirability of suppliers in pairs to get the performance measure.

By choosing "About AHP Vendor Selection", in the help menu, program shows the help contents (Fig. 5.11). It briefly tells about the Analytic Hierarchy Process (AHP), how the vendor selection problem is hierarchically structured, how to use the program and finally the relative scale of pairwise comparisons.

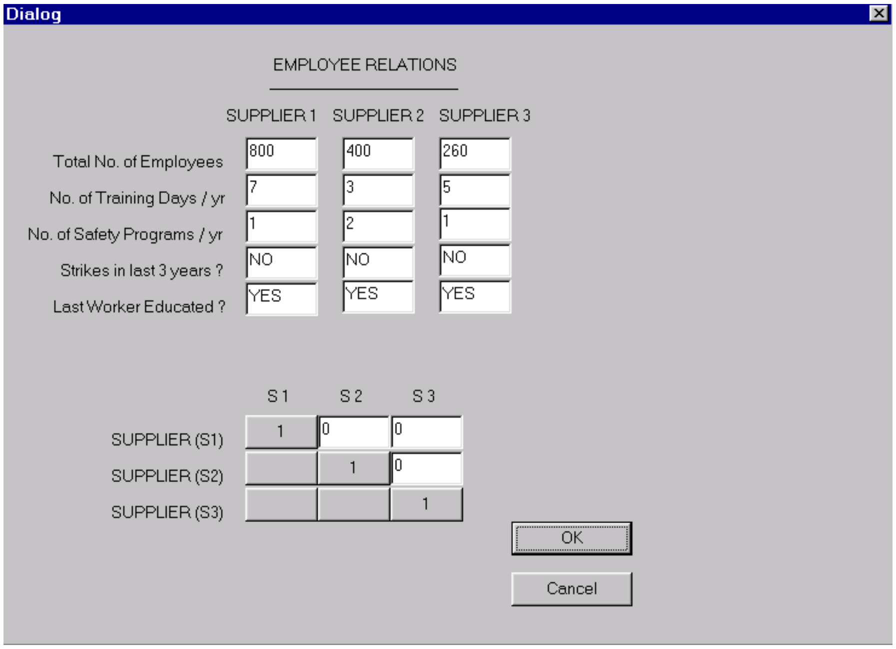


Fig. 5.10 Employee Relations Dialog Box.

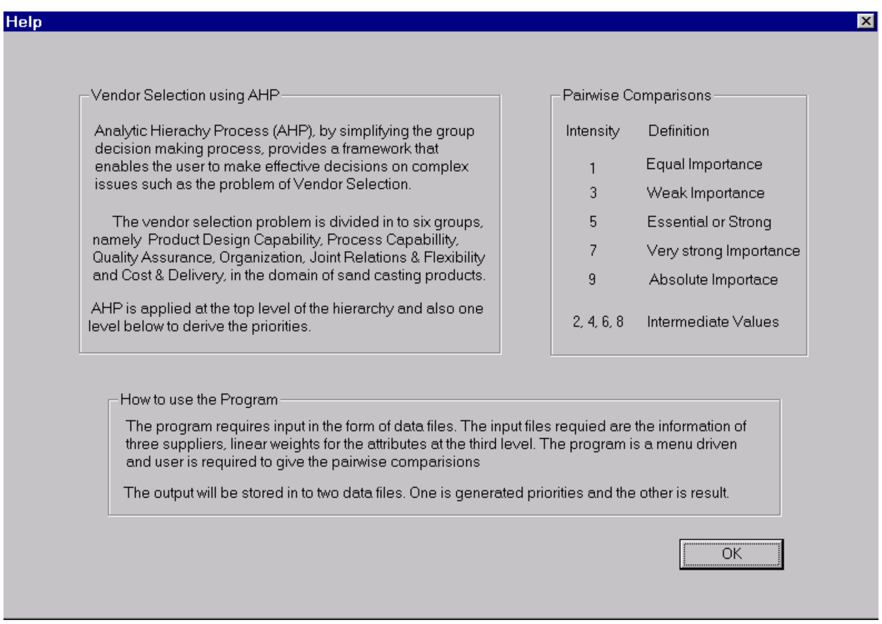


Fig. 5.11 Help on using the Program

5.5 Conclusion

In this chapter, a complete web based sourcing system developed in this project is described in a step by step procedure. The design of complete system is discussed from the very beginning of publishing the requirement by assembler on the web to the selection of supplier. The program design is explained in terms of file formats and user interface. The next chapter deals with the case study.

Chapter 6

CASE STUDY

6.1 About the Company

A case study was carried out in one of the leading automobile manufacturing company in Western Maharastra. The company is currently working on strategic sourcing of various items for their assembly division. Strategic sourcing involves restructuring the supplier base, supplier base relationships, people, process and culture to achieve improvements in total cost, quality and cycle time. It helps in creating a competitive edge over the rivals by refining and restructuring the relationships with the suppliers.

The company has a strategic sourcing team for outsourcing various components or assemblies. Outsourcing of cast components is the focus of this team because of complexity, varieties and total numbers of castings required in final product.

6.2 Present System of Supplier Selection

Presently, the manual system of linear weighing model is used for casting supplier selection. In this system, a group of people involved in assigning the weights to various criteria. If there is any conflict in assigning a weight for a specific factor, then the problem is resolved by going for a debate. The team has carried out a detailed analysis of casting supplier's capabilities to know the type of casting they can supply. The team has divided the casting products in to three main groups based on the complexity as discussed below.

- High Complex Casting: Castings containing multiple and non-planar parting lines along with the core assembly can be termed as high complex castings.

Example: engine cylinder block, exhaust manifold.

- Medium Complex Castings: Castings which can be manufactured with the help of cores and who's parting line may not be planar.
  Example: differential housing.
- Simple Castings: Castings having planar parting line and which can be manufactured without or with the help of very simple core. Symmetric castings fall into this category. Example: brake drum.

6.3 Application of the System

The web based sourcing system developed in this project was demonstrated to this strategic sourcing team. A high complex casting was selected for the case study. The product is engine block. Because of the confidentiality, the supplier names, product specifications and drawing are not disclosed. However, a blank specification form showing required casting characteristics is shown in Appendix E1. Similarly, the data of three suppliers and linear weights used in this case study are shown in Appendix F.

Initially, one of the team members was asked to provide the linear weights, as per their usual practice, for level 1 of the AHP model. The priorities are as shown below.

CRITERIA	PRIORITY (%)
Product Development Capability	15
Process Capability	20
Quality Assurance	30
Organization	10
Joint Relations & Flexibility	10
Cost & Delivery	15

Then, computer program of AHP model was used to obtain the priorities for level1 by inputting the pairwise comparisons. The pairwise comparison matrix as well as the priorities obtained for the level 1 are shown below.

Overall priorities

	PD	PE	QA	Org	JF	CD	Priority
Process Design capability (PD)	1	1	0.5	2	2	1	0.173
Process Evaluation (PE)	1	1	0.5	2	2	1	0.173
Quality Assurance (QA)	2	2	1	3	2	2	0.293
Organization (Org)	0.5	0.5	0.33	1	0.5	0.5	0.081
Joint Relations & Flex. (JF)	0.5	0.5	0.5	2	1	0.5	0.109
Cost & Delivery (CD)	1	1	0.5	2	2	1	0.173

CR = 0.014

Similarly, Pairwise comparison matrices and the priorities obtained for all elements in level 2 are as shown below.

Product Development Capability

	DS	RD	DT	PM	Prioroties
S/W Aid in Develop. (DS)	1	3	1	4	0.41
Research & Development (RD)	0.33	1	1	2	0.20
Product Devp. Time (DT)	1	1	1	3	0.29
Pattern Making (PM)	0.25	0.5	0.33	1	0.10

CR = 0.03

Process Capability

	SP	Mol	CM	MP	HT	CM	Priority
Sand Preparation (SP)	1	0.5	0.5	1	3	3	0.15
Molding (Mol)	2	1	0.5	1	4	4	0.21
Core Making (CM)	2	2	1	2	7	7	0.36
Melting & Pouring (MP)	1	1	0.5	1	4	4	0.19
Heat Treatment (HT)	0.33	0.25	0.14	0.25	1	1	0.05
Cleaning & Machining (FM)	0.33	0.25	0.14	0.25	1	1	0.05

CR = 0.007

A sample session of the AHP program, for inputting the pairwise comparisons, for process capability is as shown in fig. 6.1. The fig. 6.2 shows the results obtained from this sample session.

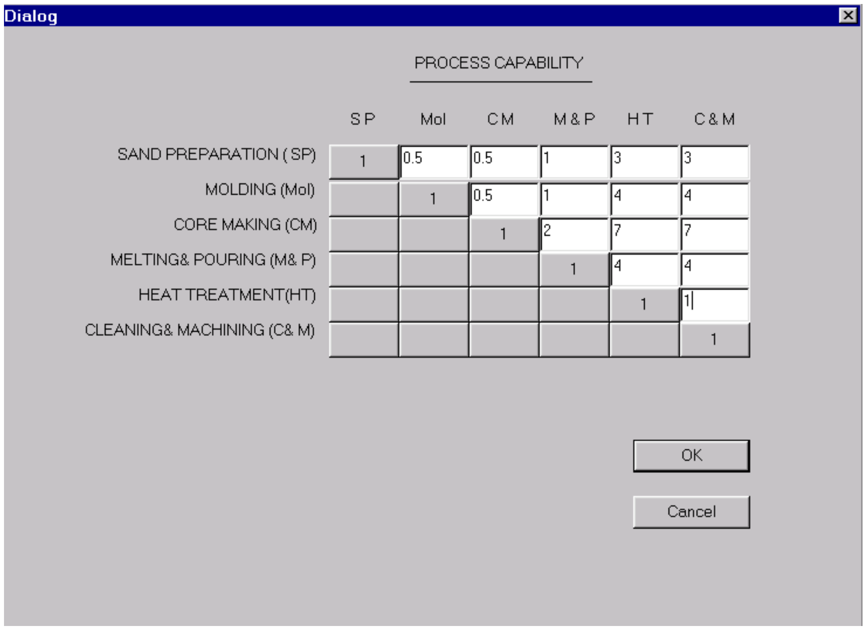


Fig. 6.1 Process Capability Dialog Box

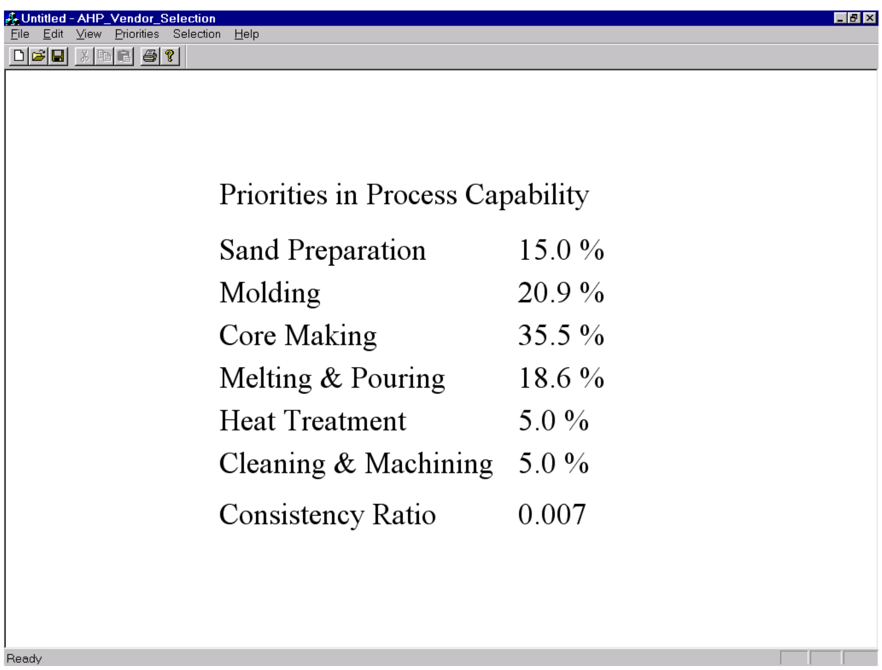


Fig. 6.2 Result of Process Capability

Quality Assurance

	Cer	TF	QC	QP	Awa	Priority
Certification (Cer)	1	0.33	0.25	1	2	0.11
Testing Facilities (TF)	3	1	1	3	4	0.31
Quality Control (QC)	4	1	1	5	9	0.43
Quality Programs (QP)	1	0.33	0.2	1	2	0.10
Awards (Awa)	0.5	0.25	0.11	0.5	1	0.06

CR = 0.013

Organization

	FP	ER	SA	Priority
Financial Position (FP)	1	2	2	0.50
Employee Relations (ER)	0.5	1	2	0.31
Software Aid (SA)	0.5	0.5	1	0.19

CR = 0.046

Joint Relations and Flexibility

	IS	Par	Fle	Priority
Information Sharing (IS)	1	2	1	0.41
Partnership (Par)	0.5	1	1	0.26
Flexibility (Fle)	1	1	1	0.33

CR = 0.046

Cost and Delivery

	TP	EQ	TD	Gua	Priority
Total Price of the Casting (TP)	1	1	2	4	0.38
Exact Quantity (EQ)	1	1	1	3	0.30
Timely Delivery (TD)	0.5	1	1	2	0.23
Guarantee (Gua)	1	0.33	0.5	1	0.10

CR = 0.017

The relative desirability of suppliers for financial position and employee relations is obtained by pairwise comparing with respect to particular criteria. The following matrices show the details of it.

Financial position

	S1	S2	S3	Priority
Supplier1 (S1)	1	1.5	2	0.46
Supplier2 (S2)	0.66	1	1.5	0.32
Supplier3 (S3)	0.5	0.66	1	0.22

CR = 0.001

Employee Relations

	S1	S2	S3	Priority
Supplier1 (S1)	1	3	4	0.63
Supplier2 (S2)	0.33	1	1	0.19
Supplier3 (S3)	0.25	1	1	0.17

CR = 0.008

The total scores obtained by the three suppliers, selected in this case study, after all pairwise comparisons are shown in fig. 6.3. Details of supplier scores for criteria in level 1 of the AHP model are shown in fig. 6.4. The results obtained in this case study are given in Appendix G.

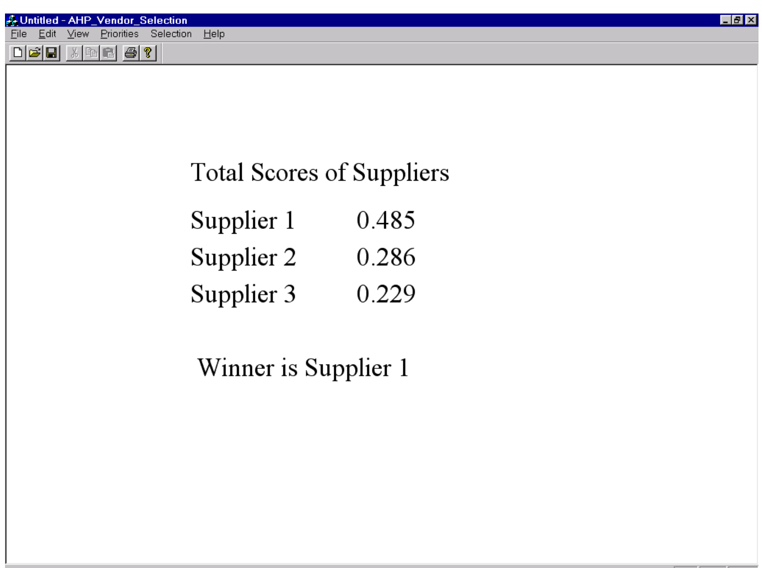
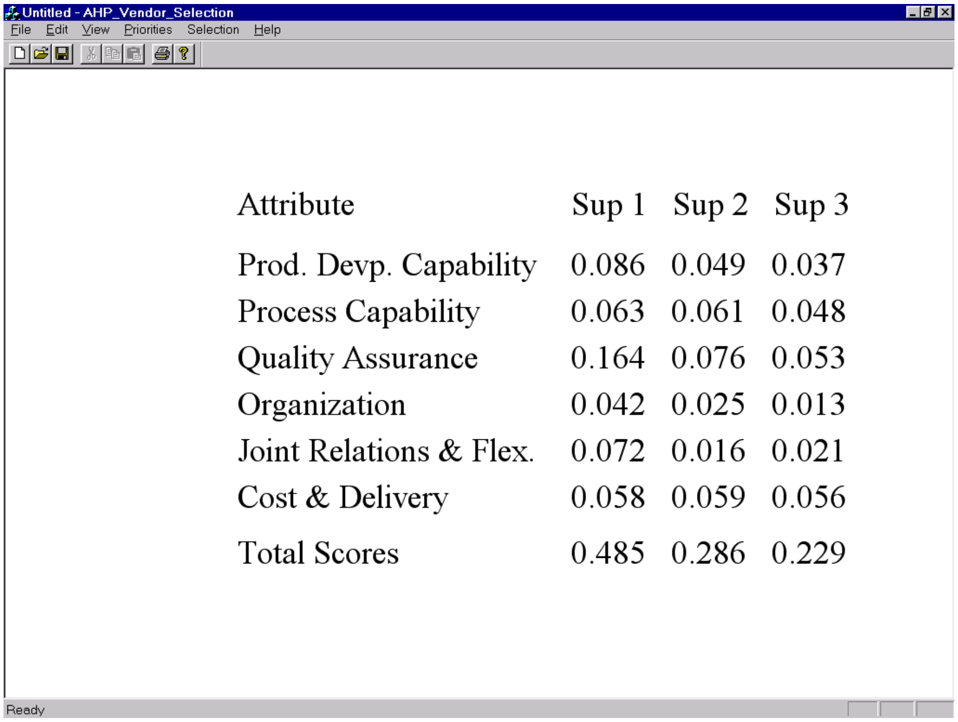


Fig. 6.3 Overall Supplier Scores.

In this case study, supplier1 has the highest total score (0.485) indicating his capability over others for the high complex product.



Attribute	Sup 1	Sup 2	Sup 3
Prod. Devp. Capability	0.086	0.049	0.037
Process Capability	0.063	0.061	0.048
Quality Assurance	0.164	0.076	0.053
Organization	0.042	0.025	0.013
Joint Relations & Flex.	0.072	0.016	0.021
Cost & Delivery	0.058	0.059	0.056
Total Scores	0.485	0.286	0.229

Fig. 6.4 Details of AHP Result

6.4 Observations from Case Study

- Comparison of priorities given by an experienced person and the priorities obtained from pairwise comparison matrix at level 1 are very close to each other.
- The advantage of AHP lies in the fact that criteria are compared in pairs, and there is no need to have *a priori* idea about the overall priorities for decision-maker. Where as in linear weighing model all the criteria are ranked (assigned weights) based on simultaneous comparison of various factors.
- It was found that the system can be easily customized to the different types of castings.

Chapter 7

CONCLUSIONS

1. Technical and managerial initiatives are taking place in supply chains to achieve competitive advantage.
2. Typical manufacturing companies spend more than 55% of their total revenue on outsourcing, and supplier selection is important both in terms of costs involved and operational performance of the company.
3. Most formal methods of vendor selection are based on linear weighing models. The Analytic Hierarchy Process is gaining popularity, because of having the capability to combine tangible and intangible factors and deriving weights of priorities by pairwise comparisons.
4. Different types of criteria used in supplier selection, in the domain of sand casting, have been identified through a detailed study of technical literature, visits to an assembler and a foundry, and discussion with experts.
5. The various criteria identified from different sources have been compared to find a common set, which would satisfy the requirements of an assembler in selecting sand casting suppliers.
6. The evaluation criteria are systematically classified under six groups - product development capability, process capability, quality assurance, organization, joint relations & flexibility and cost & delivery.
7. A web based system has been developed for sourcing of sand cast products using AHP methodology. The system is implemented using Visual C++ in Windows platform for coding the software and HTML for designing the web page.
8. The system developed in this study is a combination of the AHP methodology from Operations Research and Internet technology.

9. The system consists of two modules; namely, web based sourcing module and software program module. The web based sourcing module helps in reducing the time involved in supplier selection activity by making use of Internet. The software program module uses AHP methodology and is independent of web based sourcing module.

10. The system successfully handles "access security" by providing login name and password in accessing the web page.

11. The access and transit security aspects of the system assure confidentiality of casting information from assembler to competitors and quotation information from supplier to supplier.

12. The web based sourcing module is more applicable to
    (a) Selection of low and medium complex casting suppliers as the information required for analyzing the supplier can easily be communicated through web,
    (b) Standard and routine products, whose confidentiality is not very important.

13. The in-built consistency check for pairwise comparisons provided in AHP methodology ensures the quality of judgements for decision making.

14. The output of AHP program is the scores at each level of the hierarchy; which are indicative of supplier performances. This helps management in making a decision about supplier.

15. The system is demonstrated, by carrying out a case study for a complex sand casting product in the strategic sourcing division of a large automobile company, in India.

16. The web based sourcing system methodology developed in this project can be applied to any product, which requires out sourcing in a manufacturing company.

17. The same system can be further extended to all the members of a supply chain, beginning from the customer to the raw material supplier.

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APPENDIX A

Table A1 Scale of Relative Importance

Intensity of Importance	Definition	Explanation
1	Equal important	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgement slightly favor one activity over another
5	Essential or Strong importance	Experience and judgement strongly favor one activity over another
7	Very Strong Importance	An activity is strongly favored an its dominance is demonstrated in practice.
9	Extreme importance	The evidence of favoring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values	When compromise is needed
Reciprocals	If activity *i* has one of the above numbers assigned to it when compared to activity *j*, then *j* has the reciprocal value when compared with *i*	
Rationals	Ratios arising from the scale	If consistency were to be forced by obtaining n numerical values to span the matrix

Table A2 Table of Random Consistency Index

Order of Matrix	1	2	3	4	5	6	7	8	9	10
Random Index (RI)	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

APPENDIX B

B1 Internet

Imagine a country with highways crisscrossing all over it, connecting its many cities. Imagine again that each of these cities is a computer, and each of these highways is a computer at its ends. You have a setup whereby any computer in this "country" and communicate with any other, by sending its data through a sequence of "highways". Such an arrangement already exists, linking computers all over the world, and this is what is called the Internet. People all over the world hook up to it and are able to access any other computer that is also connected to the Internet.

The backbone of the Net is therefore the connections between the computers, with the computers themselves being the nerve centers the run the show. These connections can be through satellites, or through terrestrial connections, made through existing telephone lines or wires specially laid for this purpose. The difference between different kinds of connections is in the speed with which they move data, called the bandwidth of the link. The features of Internet are:

- It achieves tremendous connectivity. The entire world is enmeshed in this network, and connecting from one place to another is effortless.
- The network runs itself. However, there are several voluntary bodies associated with its running, like the Internet Architecture board, the Internet Assigned Numbers Authority, the Internet Engineering and Planning Group, and the Internet Engineering Steering Group and Internet Society.
- It costs next to nothing, because anyone who wants to jump on to it is adds his or her own Anna worth, extending the Net a bit. So in effect everybody pays some part, but it is negligible compared to the benefits everyone derives.
- The computers which really support the network are the universities, companies whom want their sites advertised, and companies who have made a business of the web. Much of the information content of the Internet is on these computers, and most of its resources have been paid for by them.

- The main reason why the Internet is useful is because of the wealth of information available. One can use the Internet as a powerful tool for research (either for school or business) or just a desire to learn.

There are yellow pages on the net, phone-numbers listings, email addresses of people on the net, all stored in easy-to-access, searchable databases. For reference work you can find dictionaries, thesauri, encyclopaedias, even a "virtual library", on the Net, so that any work you may need any reference for can easily be done on the computer.

The Internet is in India mainly because of two bodies, the ERNET (Educational and Research Network) and VSNL (Videsh Sanchar Nigam Limited).

B2 World Wide Web (WWW)

The World Wide Web or simply, the Web is a virtual world built on top of Internet, a world consisting of data represented in new and creative ways that are much more powerful than conventional representations. The web is a portable and fancy way to present information: text styles, bitmaps, color images and more. But much of the web is thanks to hypertext. Hypertext is what really makes the web so convenient to surf through.

Hypertext is a term used for a collection of documents containing cross-references or links which, with the aid of an interactive browser (program) allows the reader to move easily from one document to another.

The web has a huge collection of accessible documents (predictably) called web pages. They may also be referred as web pages. Visiting pages on the Web is popularly called surfing in most descriptions of Net activity. It would perhaps then be appropriate to say that a browser is the surfboard with which you can surf the Net.

APPENDIX C

Web addresses of some of the automobile manufacturers on Internet are:

- General Motors http://www.gm.com
- Chrysler http://www.chrysler.com
- Ford http://www.ford.com
- Mercedes-Benz http://www.mbusa.com
- Toyota http://www.toyata.com
- Mitsubishi http://www.mitsucars.com
- Hyundai http://www.hmc.co.kr
- Honda http://www.honda.com
- Mahindra& Mahindra http://www.mahindraworld.com
- Telco http://www.telcoexpo.com
- Bajaj http://www.bajajauto.com

Web addresses of some of the foundries on Internet are:

- Benton Foundry http://www.bentonfoundry.com
- Bremen Casting http://www.bremencastings.com
- Atchinson Casting Corp. http://www.atchisoncastings.com
- Bell Foundry Ltd. http://www.bfco.com
- Brost Foundry http://www.BrostFoundry.com
- Beaver Vally Alloys http://www.bvally.com
- Enterprize Foundry http://www.enterprizefoundry.com
- Grede Foundries http://www.grede.com
- Clark Steel Ltd. http://www.clark-steel.com
- Deeter Foundry http://www.deeter.com
- Pacific Steel Casting Co. http://www.pacificsteel.com
- Kirloskar Oil Engines Ltd. http://www.koel-in.com
- Mukund http://www.mukund.com

APPENDIX D

D1 HTML

HTML stands for Hyper Text Markup Language, which is the "language of home-pages". Hypertext documents are those documents that have text that contains links to other documents. These links are called hyperlinks. This is true of Web pages. You can "click" on certain portions of the page, and call up other Web pages. These links are intuitive interfaces to information and resources on the Internet- a virtual web of connections.

The content of Web page is viewed through software called browsers. The browser does not receive the content of the page you have requested, in the same form that it appears on your screen. When a request for a certain Web page is made, a text file called an HTML file is first received at your computer. It contains information about the HTML file, and the test that is to be displayed on the page, and a coding that tells the browser where to get the images etc. Therefore, HTML files consist of some kind of code that has to translated to get the actual content of the Web.

Browsers change confusing-looking HTML files to a well-presented document containing pictures and different fonts. Examples for browsers are Netscape, Mosaic and Lynx. The pages that the browser fetches are referred to in the form of URLs (Uniform Resource Locators). For example, http://www.iitb.ernet.in is an example of a URL. The first part of the address (http) is called the hypertext transfer protocol. The name of the machines comes next on the URL after the colon and the double slash (www.iitb.ernet.in).

D2 HTTP

HTTP (Hypertext Transfer Protocol) is a protocol - a set of rules that computers use to communicate over a network. The HTTP protocol is designed to enable HTTP clients (such as web browsers) to request information or services from HTTP servers (better known as web severs). HTTP is a connectionless protocol. What this means is that web browsers and web servers do not establish a connection to each other; instead, they just send individual messages back and forth.

Before the HTTP protocol can go to work, the computer that is running the web browser has to connect to the computer running the web server over the network. The connection is accomplished using the Transmission Control Protocol (TCP) which, along with the Internet Protocol (IP), forms the building blocks of the Internet. For this reason, Internet is referred to as a TCP/IP network. HTTP is a higher level protocol then TCP, which is, in turn, a higher level protocol than IP. As a rule, higher level protocols can not talk until a connection is established at the lower level. HTTP as an application level protocol, which means that it is at the highest level in the TCP/IP model.

D3 HTML Form

When the Web was invented, the main attractions that brought people to the medium were hypertext (the capability to link pages together) and the capability to display images inline with text. However, to make the Web a useful medium for commerce and other high-powered application, more interactivity is necessary. To fulfill this requirement, forms were added.

An HTML Form, basically looks like any paper that you might have filled for buying a ticket or filling for an examination. There are checkboxes, places where you enter text, multiple choice menus and so on. The input is given by a viewer by typing in text, or clicking parts of the form. All forms have a submit button that sends in the information given by the viewer to a program on your machine that you specify in the form.

An HTML form takes two attributes, action and method. The action attribute gives the name of the program that should handle the form input. It should either be a program stored in the cgi-bin directory of the machine where the home page is, or it can be mailto: URL, that is mailto followed by email address.

The method attribute takes one of the two values, GET and POST. GET sends the form input along with the URL that specifies the action, whereas POST sends the form input separately after notifying the program that it is sending this input. You need not bother about what the difference is, using either is just as good as using the other, as far as mailto: concerned.

APPENDIX E

E1 Product Specifications

A Identification	Company	__________	
	Address	__________	
	Contact person	__________	
	Code of the casting	__________	
B Quantity	Total no. required	__________	
	No. per release	__________	
	Frequency of release	__________	
C Delivery	Initial delivery date	__________	
	Number of pieces	__________	
	Order to be completed by ________		
	No. of sample castings__________		
	Delivery date for samples ______		
D Service Data	Service Stresses:	Max Design Load	_________
		Safety factor	_________
		Subject to mild impact	_________
		Subject to heavy impact	________
		Subject to endurance	_________
		Subject to hydraulic pr.	________
	Wear : __________	Subject to wear against ______ (name material)	
	__________	Good Lubrication	
	__________	Intermittent Lubrication	
	__________	Abrasive wear by ______ (name material)	

_________ Lump Material

_________ Fine material

Temperature: Max. service temperature ______

Steady temp. during use _______

_____ Undulating temp. ____ F to ____ F

Strength: Tensile strength of _____ psi min. using

A S T M test bar size _______

Certification is required for:

_______ Chemical Analysis

_______ Mechanical Properties

Hardness: ______ BHN max; ______ BHN min at location A

______ BHN max; ______ BHN min at location B

Machinability: Excellent machinability/Machining to be high/ Machinability unimportant

Heat Treatment: _______ Stress relief annealing required

_______ Softening required

_______ Hardening required

(details like type, location & hardness)

Casting Appearance: critical/ important/ not important

_______ Surface scaling is critical

_______ Dimensional scaling is critical

_______ Load carrying ability is critical

Corrosion: Type of material or env. ____ at ____ F

_______ Strong acid

_______ Strongly alkaline

_______ ph

_______ Exposed air or aerated liquid

_______ Submerged and relatively air-free

_______ product contamination is important

Finishing: _______ Machining, marked on drawing

_______ Painting only

_______ Filling, rubbing, and painting

_______ plating

E Casting Properties: Std. Specification no. _______ issued by _____

______ No standard specification applies

material ______, percentage _____

material ______, percentage _____

Dimensional Tolerance:

_______ Commercial Tolerances are satisfactory

_______ Close tolerance apply (marked on drawing)

_______ All dimensions critical, tolerances marked on drawing

F Inspection Methods: Pressure test- state requirements_____

X ray requirements ______

Magnetic flux - requirements ______

Customer's method of incoming inspection:

_______ Full inspection, rejection of only defectives

_______ Statistical inspection, rejection of lot on the basis of sample ratio _______ ; rejection No ____

Based on AQL (Average Quality Level) of _______

G Shipping: _______ usual procedure/Special packing required

E2 Supplier Information

GENERAL INFORMATION

1. Name of the Foundry
2. Contact Persons (a) (b)
3. Type of Organization
4. Capacity of the Foundry (in tons) ______

PRODUCT DEVELOPMENT INFORMATION

1. Software Aid in Casting Design
    - Gating / Feeding design s/w
    - Mold design s/w
    - Core design s/w
    - Solidification s/w
    - Cost and Lead Time Estimation s/w
2. Research & Development
    - R & D Investment 0-5% 5-10% more than 10%
    - Total No. of R & D staff
3. Expected Product Development Time (in weeks) _____
4. Pattern Making Pattern Available In house Making Outsourcing

PROCESS CAPABILITY INFORMATION

1. Sand Preparation Manual Mechanized Reclamation
2. Molding
    - Make Manual Jolt/ Squeeze High Pressure Flaskless
    - Type Green sand Dry sand Shell No-bake
3. Core Making
    - Make Jolter Squeezer Sand Blower
    - Type Oil sand CO2 Shell
4. Melting & Pouring
    - Melting Cupola Induction

- Pouring   Manual   Controlled   Automatic

5. Heat Treatment   In house   sub-contract
6. Fettling/ Machining
   - Fettling   In house   sub-contract
   - Machining   In house   sub-contract

QUALITY ASSURANCE INFORMATION

1. Certification   Not certified   Self Certified   Certified Supplier
   ISO Certificate   QS 9000
2. Testing Facilities
   - Sand Lab
   - Physical Lab
   - Chemical Lab
   - Radiography
   - Ultrasonic
   - Dye Penetration
   - Spectrometer
3. Quality Control
   - Process Control   Manual   Automatic
   - On-line Monitoring   Manual   Automatic
   - PL Controls   For critical operations only   For all
   - Defect Prevention System
4. Quality Programs
   - Quality Circles
   - TQM
5. Awards
   - National
   - International

ORGANIZATION INFORMATION

1. Financial Position

- Turnover
- Net Profit

2. Employee Relations
   - Total No. of Employees
   - Avg. Training Period (in days)
   - No. of Training Programs
   - Last Worker Educated
   - Strikes in Last 3 Years
3. Software Aid
   - Use of Computers in Administration
   - EDI Facility

JOINT RELATIONSHIP & FLEXIBILITY

1. Information Sharing
   - Cost
   - Quality
   - Design
2. Partnership
   - Equity
   - Financial Support
   - Cross Functional Team
3. Flexibility
   - Volume
   - Delivery
   - Manufacturing

COST AND DELIVERY

1. Total Cost of the casting
2. Exact Quantity
3. Timely Delivery
4. Guarantee

APPENDIX F

F1 SUPPLIER_1.dat

GATING_FEEDING_SW	YES
MOLD_DESIGN_SW	YES
CORE_DESIGN_SW	NO
SOLIDIFICATION_SW	NO
COST_LT_ESTIMATION_SW	YES
R&D_INVESTMENT	LT_5
TOTAL_R&D_STAFF	5
PRODUCT_DEVP_TIME	30
PATTERN_MAKING	AVAILABLE
SAND_PREPARATION	MECHANIZED
MOLD_MAKE	JOLT_SQUEEZE
MOLD_TYPE	GREEN_SAND
CORE_MAKE	SAND_BLOWER
CORE_TYPE	SHELL
MELTING	INDUCTION
POURING	CONTROLLED
HEAT_TREATMENT	SUB_CONTRACT
CLEANING	INHOUSE
MACHINING	INHOUSE
CERTIFICATION	QS_9000
SAND_LAB	YES
PHYSICAL_LAB	YES
CHEMICAL_LAB	YES
RADIOGRAPHY	NO
ULTRASONIC	NO
DYE_PENETRATION	NO
SPECTROMETER	YES
PROCESS_CONTROL	MANUAL
ONLINE_MONITORING	MANUAL
PLC	CRITICAL
DEFECT_PREVENTION_SYS	YES

QUALITY_CIRCLE	NO
TQM	YES
NATIONAL_AWARDS	YES
INTERNATIONAL_AWARDS	NO
ORGANIZATION	Dee
TONNAGE	18000
TURNOVER	100
NET_PROFIT	2
TOTAL_NO_EMPLOYEES	800
AVG_TRAINING_DAYS	7
NO_SAFETY_PROGRAMS	1
STRIKES_IN_3YEARS	NO
LAST_WORKER_EDUCATED	YES
USE_COMPUTERS_ADMN	YES
EDI_FACILITY	NO
INFO_SHARE_COST	YES
INFO_SHARE_QUALITY	YES
INFO_SHARE_DESIGN	NO
EQUITY	NO
FINANCIAL_SUPPORT	NO
CROSS_FUNCTIONAL_TEAM	YES
FLEX_VOLUME	YES
FLEX_DELIVERY	YES
FLEX_MANUFACTURING	YES
TOTAL_COST	4000
EXACT_QUANTITY	0.98
TIMELY_DELIVERY	0.95
GUARANTEE	YES

EOF

F2 SUPPLIER_2.dat

GATING_FEEDING_SW	NO
MOLD_DESIGN_SW	YES
CORE_DESIGN_SW	NO
SOLIDIFICATION_SW	NO
COST_LT_ESTIMATION_SW	NO
R&D_INVESTMENT	LT_5
TOTAL_R&D_STAFF	7
PRODUCT_DEVP_TIME	40
PATTERN_MAKING	AVAILABLE
SAND_PREPARATION	MECHANIZED
MOLD_MAKE	HIGH_PRESSURE
MOLD_TYPE	SHELL
CORE_MAKE	SAND_BLOWER
CORE_TYPE	SHELL
MELTING	INDUCTION
POURING	CONTROLLED
HEAT_TREATMENT	INHOUSE
CLEANING	INHOUSE
MACHINING	INHOUSE
CERTIFICATION	ISO_CERTIFIED
SAND_LAB	YES
PHYSICAL_LAB	YES
CHEMICAL_LAB	NO
RADIOGRAPHY	NO
ULTRASONIC	YES
DYE_PENETRATION	NO
SPECTROMETER	YES
PROCESS_CONTROL	MANUAL
ONLINE_MONITORING	MANUAL
PLC	CRITICAL
DEFECT_PREVENTION_SYS	NO
QUALITY_CIRCLE	NO
TQM	NO

NATIONAL_AWARDS	NO
INTERNATIONAL_AWARDS	NO

ORGANIZATION	Dee
TONNAGE	14000
TURNOVER	50
NET_PROFIT	1.1
TOTAL_NO_EMPLOYEES	400
AVG_TRAINING_DAYS	3
NO_SAFETY_PROGRAMS	2
STRIKES_IN_3YEARS	NO
LAST_WORKER_EDUCATED	YES
USE_COMPUTERS_ADMN	YES
EDI_FACILITY	NO

INFO_SHARE_COST	NO
INFO_SHARE_QUALITY	YES
INFO_SHARE_DESIGN	NO
EQUITY	NO
FINANCIAL_SUPPORT	NO
CROSS_FUNCTIONAL_TEAM	NO
FLEX_VOLUME	NO
FLEX_DELIVERY	YES
FLEX_MANUFACTURING	NO

TOTAL_COST	3600
EXACT_QUANTITY	0.95
TIMELY_DELIVERY	0.85
GUARANTEE	YES

EOF

F3 SUPPLIER_3.dat

GATING_FEEDING_SW	NO
MOLD_DESIGN_SW	NO
CORE_DESIGN_SW	NO
SOLIDIFICATION_SW	NO
COST_LT_ESTIMATION_SW	NO
R&D_INVESTMENT	LT_5
TOTAL_R&D_STAFF	5
PRODUCT_DEVP_TIME	24
PATTERN_MAKING	AVAILABLE
SAND_PREPARATION	MECHANIZED
MOLD_MAKE	MANUAL
MOLD_TYPE	GREEN_SAND
CORE_MAKE	JOLT_SQUEEZE
CORE_TYPE	SHELL
MELTING	CUPOLA
POURING	MANUAL
HEAT_TREATMENT	SUB_CONTRACT
CLEANING	INHOUSE
MACHINING	INHOUSE
CERTIFICATION	NOT_CERTIFIED
SAND_LAB	YES
PHYSICAL_LAB	YES
CHEMICAL_LAB	YES
RADIOGRAPHY	NO
ULTRASONIC	NO
DYE_PENETRATION	NO
SPECTROMETER	NO
PROCESS_CONTROL	MANUAL
ONLINE_MONITORING	MANUAL
PLC	NO
DEFECT_PREVENTION_SYS	NO
QUALITY_CIRCLE	NO
TQM	NO

NATIONAL_AWARDS	YES
INTERNATIONAL_AWARDS	NO
ORGANIZATION	Par
TONNAGE	10000
TURNOVER	18
NET_PROFIT	0.7
TOTAL_NO_EMPLOYEES	260
AVG_TRAINING_DAYS	5
NO_SAFETY_PROGRAMS	1
STRIKES_IN_3YEARS	NO
LAST_WORKER_EDUCATED	YES
USE_COMPUTERS_ADMN	NO
EDI_FACILITY	NO
INFO_SHARE_COST	NO
INFO_SHARE_QUALITY	YES
INFO_SHARE_DESIGN	NO
EQUITY	NO
FINANCIAL_SUPPORT	NO
CROSS_FUNCTIONAL_TEAM	NO
FLEX_VOLUME	YES
FLEX_DELIVERY	YES
FLEX_MANUFACTURING	NO
TOTAL_COST	4300
EXACT_QUANTITY	0.95
TIMELY_DELIVERY	0.90
GUARANTEE	YES

EOF

F4 LINEAR_WEIGHTS.dat

PRODUCT DESIGN SOFTWARES	
GATING_FEEDING_SW	0.2
MOLD_DESIGN_SW	0.2
CORE_DESIGN_SW	0.2
SOLIDIFICATION_SW	0.2
COST_LT_ESTIMATION_SW	0.2
RESEARCH AND DEVELOPMENT	
R&D_INVESTMENT	0.5
R&D_STAFF	0.5
INVEST_LT_5	0.15
INVEST_BT_5&10	0.30
INVEST_GT_10	0.55
PATTERN MAKING	
PATTERN_AVAILABLE	0.42
PATTERN_INHOUSE	0.33
PATTERN_OUTSOURCE	0.25
SAND PREPARATION	
MANUAL_SP	0.18
MECHANIZED_SP	0.37
RECLAMATION	0.45
MOLDING	
MOLD_MAKE	0.5
MOLD_TYPE	0.5
MOLD_MANUAL	0.08
MOLD_JOLT_SQUEEZE	0.25
MOLD_HIGH_PRESSURE	0.42
MOLD_FLASK_LESS	0.25
MOLD_GREEN	0.55
MOLD_DRY	0.15
MOLD_SHELL	0.15
MOLD_NOBAKE	0.15

CORE MAKING	
CORE_MAKE	0.5
CORE_TYPE	0.5
CORE_MANUAL	0.12
CORE_JOLT_SQUEEZE	0.38
CORE_SAND_BLOWER	0.5
CORE_OIL	0.14
CORE_CO2	0.29
CORE_SHELL	0.57
MELTING&POURING	
MELTING	0.5
POURING	0.5
CUPOLA	0.25
INDUCTION	0.75
POURING_MANUAL	0.11
POURING_CONTROLLED	0.33
POURING_AUTOMATIC	0.56
HEAT TREATMENT	
HT_INHOUSE	0.67
HT_SUB_CONTRACT	0.33
CLEANING&MACHINING	
CLEANING	0.5
MACHINING	0.5
CLEANING_INHOUSE	0.67
CLEANING_SUB_CONTRACT	0.33
MACHINING_INHOUSE	0.67
MACHINING_SUB_CONTRACT	0.33
CERTIFICATION	
NOT_CERTIFIED	0.07
SELF_CERTIFIED	0.27
CERTIFIED_SUPPLIER	0.13
ISO_CERTIFIED	0.2
QS_9000	0.33

TESTING FACILITIES	
SAND_LAB	0.16
PHYSICAL_LAB	0.16
CHEMICAL_LAB	0.12
RADIOGRAPHY	0.12
ULTRASONIC	0.12
DYE_PENETRATION	0.12
SPECTROMETER	0.2
QUALITY CONTROL	
PROCESS_CONTROL	0.25
ONLINE_MONITORING	0.25
PLC	0.2
DEFECT_PREVENTION_SYS	0.3
PC_MANUAL	0.25
PC_AUTOMATIC	0.75
ONLINE_MANUAL	0.25
ONLINE_AUTOMATIC	0.75
PLC_CRITICAL	0.45
PLC_ALL	0.55
QUALITY PROGRAMS	
QUALITY_CIRCLE	0.33
TQM	0.66
AWARDS	
NATIONAL_AWARDS	0.3
INTERNATIONAL_AWARDS	0.7
ORGANIZATION	
USE_COMPUTERS_ADMN	0.5
EDI_FACILITY	0.5
INFORMATION SHARING	
INFO_SHARE_COST	0.5
INFO_SHARE_QUALITY	0.3

INFO_SHARE_DESIGN	0.2
PARTNERSHIP	
EQUITY	0.1
FINANCIAL_SUPPORT	0.2
CROSS_FUNCTIONAL_TEAM	0.7
FLEXIBILITY	
FLEX_VOLUME	0.33
FLEX_DELIVERY	0.33
FLEX_MANUFACTURING	0.33

EOF

APPENDIX G

G1 GENERATED_PRIORITIES.dat

OVERALL PRIORITIES	
PRODUCT DEVP CAPABILITY	0.173
PROCESS CAPABILITY	0.173
QUALITY ASSURANCE	0.293
ORGANIZATION	0.081
JOINT RELATIONS & FLEX	0.109
COST & DELIVERY	0.173

PRODUCT DEVELOPMENT CAPABILITY	
S/W AID IN DEVELOPMENT	0.411
RESEARCH & DEVELOPMENT	0.199
PRODUCT DEVP TIME	0.290
PATTERN MAKING	0.100

PROCESS CAPABILITY PRIORITIES	
SAND PREPARATION	0.150
MOLDING	0.209
CORE MAKING	0.355
MELTING & POURING	0.186
HEAT TREATMENT	0.050
CLEANING & MACHINING	0.050

QUALITY ASSURANCE	
CERTIFICATION	0.105
TESTING FACILITIES	0.310
QUALITY CONTROL	0.427
QUALITY PROGRAMS	0.101
AWARDS	0.056

ORGANIZATION PRIORITIES	
FINANCIAL POSITION	0.493
EMPLOYEE RELATIONS	0.311
S/W AID IN ADMN	0.196

JOINT RELATIONS & FLEXIBILITY	
INFORMATION SHARING	0.413
PARTNERSHIP	0.260
FLEXIBILITY	0.327
COST & DELIVERY PRIORITIES	
TOTAL PRICE	0.378
EXACT QUANTITY	0.296
TIMELY DELIVERY	0.225
GUARANTEE	0.102
FINANCIAL POSITION OF SUPPLIERS	
SUPPLIER 1	0.460
SUPPLIER 2	0.319
SUPPLIER 3	0.221
EMPLOYEE RELATIONS OF SUPPLIERS	
SUPPLIER 1	0.634
SUPPLIER 2	0.192
SUPPLIER 3	0.174

G2 RESULTS.dat

ATTRIBUTE	PRIORITY	SUB-ATTRIBUTE	PRIORITY	S1	S2	S3
PROD DEVP CAPABILI	17.3 %	S/W AID IN DEVP	41.1 %	0.750	0.250	0.000
		RESEARCH & DEVP	19.9 %	0.306	0.387	0.306
		PROD DEVP TIME	29.0 %	0.333	0.250	0.417
		PATTERN MAKING	10.0 %	0.333	0.333	0.333
PROCESS CAPABILITY	17.3 %	SAND PREPARATION	15.0 %	0.333	0.333	0.333
		MOLDING	20.9 %	0.400	0.285	0.315
		CORE MAKING	35.5 %	0.346	0.346	0.307
		MELTING& POURING	18.6 %	0.429	0.429	0.143
		HEAT TREATMENT	5.0 %	0.248	0.504	0.248
		CLEANING& MACHINI	5.0 %	0.333	0.333	0.333
QUALITY ASSURANCE	29.3 %	CERTIFICATION	10.5 %	0.550	0.333	0.117
		TESTING FACILITIES	31.0 %	0.372	0.372	0.256
		QUALITY CONTROL	42.7 %	0.602	0.251	0.146
		QUALITY PROGRAMS	10.1 %	1.000	0.000	0.000
		AWARDS	5.6 %	0.500	0.000	0.500
ORGANIZATION	8.1 %	FINANCIAL POSITION	49.3 %	0.460	0.319	0.221
		EMPLOYEE RELATION	31.1 %	0.634	0.192	0.174
		S/W AID IN ADMN	19.6 %	0.500	0.500	0.000
JOINT REL & FLEX	10.9 %	INFO SHARING	41.3 %	0.571	0.214	0.214
		PARTNERSHIP	26.0 %	1.000	0.000	0.000
		FLEXIBILITY	32.7 %	0.500	0.167	0.333
COST AND DELIVERY	17.3 %	TOTAL COST	37.8 %	0.329	0.365	0.306
		EXACT QUANTITY	29.6 %	0.340	0.330	0.330
		TIMELY DELIVERY	22.5 %	0.352	0.315	0.333
		GUARANTEE	10.2 %	0.333	0.333	0.333

CRITERIA	SUPR 1	SUPR 2	SUPR 3
PROD DEVP CAPABILITY	0.086	0.049	0.037
PROCESS CAPABILITY	0.063	0.061	0.048
QUALITY ASSURANCE	0.164	0.076	0.053
ORGANIZATION	0.042	0.025	0.013
JOINT REL & FLEX	0.072	0.016	0.021
COST & DELIVERY	0.058	0.059	0.056
TOTAL SCORES	0.485	0.286	0.229

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