Multi-Objective Decision-Making In Supplier Selection: An Application Of Visual Interactive Goal Programming

Birsen Karpak, (E-mail: birsen.karpak@ysu.edu), Youngstown State University
Rammohan R. Kasuganti, (E-mail: rrkasuga@cc.ysu.edu), Youngstown State University
Erdoğan Kumcu, (E-mail: ekumcu@bsu.edu), Ball State University

Abstract

Supplier selection by purchasing teams in a supply chain management environment is inherently a multi-objective problem. The authors discuss one of the multiple criteria decision support systems; Visual Interactive Goal Programming (VIG), to assist purchasing teams in their vendor selection decisions. VIG is based on a multi-criteria technique known as Pareto Race. Two examples illustrate the application of VIG in different multi-objective supplier selection environments. The first example demonstrates the allocation of a single product among multiple vendors, while the second example focuses on a multiple-replenishment purchasing problem in selecting suppliers and allocating orders among them. The authors conclude with a discussion of VIG's benefits and limitations.

Introduction

Global competitive environment continues to force many companies to make strategic changes in managing their business. Numerous manufacturers have been downsizing, concentrating on their core competencies, moving away from vertical integration, and outsourcing more extensively (Goffin, Szwej-czewski and New, 1997; Leenders, Nollet, Ellram, 1994). According to Leenders et al. (1994), in this process, the need to gain a competitive edge on the supply side has increased substantially. Particularly for companies which spend a high percentage of their sales revenue on parts and material supplies, and whose material costs represent a larger portion of total costs, savings from supplies are of particular importance. Krajeweski (1996) reported, for instance, that the percentage of sales revenues spent on materials varies from more than 80 percent in the petroleum refining industry to 25 percent in the pharmaceutical industry. Most firms have spent 45 to 65 percent of sales revenues on materials. Moreover, the emphasis on quality and timely delivery in today's globally competitive marketplace adds a new level of complexity to outsourcing and supplier selection decisions. Many companies have attempted to streamline the number of suppliers from which they purchase. Goffin and his colleagues (1997) found

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that in a variety of industries in the United Kingdom between 1991 and 1996, the number of suppliers decreased as much as 36 percent. Collectively, these developments make the supplier selection decisions more critical.

Weber and his colleagues argue that "given the complexity and economic importance of vendor selection it is somewhat surprising how little attention has been paid in the literature to the application of quantitative methods to vendor selection. [...] Such techniques would enable purchasers to select the vendors who best satisfy the requirements necessary to implement management strategy" (Weber, Current and Benton, 1991, p. 16). A survey by these authors indicated that companies show a growing interest in multiple criteria methods when selecting suppliers (Weber, et al., 1991).

The purpose of this article is to present an alternative decision support system, termed Visual Interactive Goal Programming (VIG). VIG is based on a multi-criteria technique known as Pareto Race (Korhonen and Wallenius, 1988). VIG facilitates the introduction of a decision support vehicle that helps improve the supplier selection decisions of materials/purchasing teams by allowing them to evaluate trade-offs among their goals interactively and graphically.

An overview of the complexity and importance of supplier selection problem within the broader context of logistics and supply chain management is presented first. Second, problems are discussed that are related to the application of conventional solutions to supplier selection including goal programming. Third, VIG is introduced as an alternative approach to remedy these problems. Next, two examples are presented to compare and contrast VIG with goal programming in solving supplier selection problems. Finally, we discuss the benefits and limitations of VIG.

Supplier Selection: A Multi-Objective Decision Problem

With the emergence of global competitive challenges and resulting shifts in business paradigms, academics and practitioners alike have identified the growing importance of purchasing in corporate profitability (Goffin et al., 1997; Markland, Vickery and Davis, 1998, Ch. 10). Many companies have changed their focus from short-term purchasing transactions to logistics or supply chain management where they concentrated on developing long-term relations with suppliers including forming partnerships that resulted in improved coordination of supplier networks (Guinipero and Brand, 1996). There are predictions that in the decade ahead the purchasing of goods and services will move out of purchasing's domain. Like customers, suppliers will be considered to be everyone's business (Leenders et al., 1994). In other words, it is expected that more than one functional department will be involved with suppliers. Already, many companies seem to be using supplier selection/purchasing teams to replace the buyers or purchasing departments in the logistics and supply chain management era.

In this new business environment, purchasing's role is one of the most significant strategic elements of the physical supply component of a logistics system (Morash, Dröge, and Vickery 1996; Markland et al. 1998). According to Goffin et al. (1997), purchasing is not a purely tactical exercise anymore, instead it is now recognized as a strategic function, because external suppliers now exert a major influence on a company's success or failure (Goffin et al. 1997). Therefore a key issue that purchasing must address is effective management of the supplier network, including identification of supplier selection criteria, supplier selection decisions, and monitoring of supplier performance.

Supplier selection decisions determine how many and which vendors should be selected as supply sources and how order quantities should be allocated among the selected vendors. Supplier selection is inherently a complex decision. There are three main reasons for this complexity. First, such a decision involves more than one selection criterion when choosing among the available suppliers. Products of suppliers have many attributes such as price, quality, and service. Additionally, members of purchasing teams bring diverse criteria to the purchasing decisions driven by their departmental interests such as cost, quality, and delivery reliability. In studying supplier selection literature, Dickson (1960) identified 23 factors as meaningful in supplier selection decisions. While Lehmann and O'Shaughnessy (1974) included 17 criteria in their study, Rao and Kiser (1980) developed a list of 60 items that they later categorized into six groups. Hence, in practice, purchasing teams' decisions may be influenced by multiple decision criteria that are context specific (Goffin, et., al 1997).

Second, criteria included in the supplier selection process may frequently contradict each other. Wind and Robinson (1968) identified possible contradictions such as the vendor with the lowest price may not have the best quality, or the vendor with the best quality may not deliver on time. Therefore, the purchasing teams must take into consideration the trade-offs among the criteria they would like to use. If the vendor selection problems were approached with single-objective models, these trade-offs may not be apparent (Weber and Current, 1993).

Third, within the supply chain management environment the implementation of modern production strategies such as JIT and TQM may increase the importance of the analysis of trade-offs among the selection criteria. This analysis may necessitate the addition of new criteria and a reordering of existing ones (Weber and Ellram, 1993). Purchasing in the supply chain management environment emphasizes a fundamentally different buyer-seller relationship compared to traditional supplier interaction. The trend today is toward fewer but higher quality suppliers, reflecting the recognition that suppliers are business partners (Markland et al. 1998, p. 394). This new relationship is largely based on a long-term cooperative buyer-seller partnership, and calls for sharing the long-run benefits between the partners in alliances (Krause and Ellram, 1997). Mutual dependence becomes the key to this partnership. Under this new arrangement, short-term supplier performance in cost, quality, and delivery is viewed as the natural result of long-term supplier capabilities. Therefore, the development of long-term supplier capabilities in terms of cost savings, quality improvement, and delivery reliability is critical for their mutual success (Watts, Kim and Hahn, 1995). In their review article focusing on publications between 1966-1991, Weber et al. (1991) contend that all thirteen articles specifically on JIT logistics strategy recognized the fact that supplier selection is a multi-objective task. Several authors find that trade-offs among price, product reliability, service, delivery reliability and other factors are particularly important in a supply chain management environment (Ansari and Modarres, 1986; Rao and Scheraga, 1988). The incorporation of criteria such as quality, service, and delivery in supplier selection decisions in addition to price explicitly recognizes the interdependence of the three logistics system components -- supplier network, manufacturing system, and customer network. The performance of the supplier network has a direct effect on the performance of the other two components. Hence, the goals of the supplier network are guided by the performance requirements of the entire logistics system.

Conventional Solutions to Supplier Selection

Supplier selection questions have always been encountered as multiple criteria problems, but multiple criteria techniques have not been used exclusively in their solution. Instead, the problem has been converted to a single objective formulation, and the resulting single criterion model has been solved to deliver an optimal solution. In this context, the most frequently utilized approach has been the application of linear weighting models (Willis and Huston, 1990). The linear averaging or weighted point method assigns subjective weights to the selection criteria based on their relative importance. The suppliers are then rated on each criterion according to a numerical scale. The scores on each criterion are multiplied by that criterion's weight and summed to provide an overall score for each vendor. The supplier with the highest score is then selected. Steuer (1986, pp. 198-199) discusses complications in using weights. He contends that there may be "good" weights producing bad solutions and "bad" weights producing good solutions. For example, it can be shown that the optimal solution can be found by placing a zero weight on the purchasing manager's most important criterion. Moreover, these methods provide a single optimal solution whereas the purchasing team may have a set of preferred solutions given the trade-off among the criteria as discussed earlier. In other words, there may be more than one adequate solution to the same problem.

Among the few multi-criteria applications in purchasing, goal programming is the most frequently used approach (Buffa and Jackson, 1983; Chaudhry, Forst and Zydiak, 1991; Sharma, Benton and Srivastava, 1989). Goal programming takes vendor selection a step further than the traditional methods by incorporating multiple goals. The technique requires that purchasing teams must decide on a pre-emptive priority order of their goals, i.e. they must first specify the goals for selected criteria and set priorities for the attainment of these goals (Buffa and Jackson, 1983). Although the resulting solution may sometimes be acceptable to the purchasing manager, many times, it may not be adequate. If the solution is unacceptable, the priority structure may be re-organized and the problem re-solved once more. In this fashion, it may be possible to generate a solution iteratively that finally satisfies the decision-maker. Unfortunately, the number of potential priority reorderings may be very large. A problem with five selection criteria has up to one hundred-twenty (5!) priority reorderings. The purchasing manager or purchasing team would have to be very confident in their priority structure to generate good solutions, because trial and error is a laborious process at best.

There are a variety of multiple criteria methods that can be used in the supplier selection process that address these concerns. Review articles and chapters that provide background on these methods can be found in Ignizio (1976), Zeleny (1982), Yu (1985), Steuer (1986), Aksoy (1990). Among the available approaches we chose Visual Interactive Goal Programming (VIG), because it overcomes some of the limitations of goal programming. It is a decision support system available as a PC based software package.

An Alternative Technique: Visual Interactive Goal Programming

Visual Interactive Goal Programming (VIG) is a decision support system (Korhonen 1987) based on a multi-criteria technique known as Pareto Race (Wallenius and Korhonen, 1988). This method treats constraints as a subset of purchasing teams' goals. Constraints of the problem define the feasible but not necessarily optimal solutions. Among these, there are some solutions such that no other feasible solution will yield an improvement in one goal (objective) without degrading the value of at least another goal (objective). These feasible solutions are referred to as "non-inferior," "efficient," "non-dominated, or "pareto optimal" solutions. The method asks the decision-maker to give target values for each goal. It then finds the deviation of each goal from the target value, thereby defining a reference direction. Finally, it projects the reference direction on the set of non-dominated, efficient solutions. Therefore, in multiple criteria problems the notion of the optimal solution is replaced by the concept of the "best compromise solution." Best compromise solution is the efficient and non-dominated solution that is selected by decision-makers as their preferred solution among alternative courses of action provided by the technique.

In VIG, while the goals of the decision-maker are termed flexible goals, constraints are called inflexible goals. This helps to formulate both goals and constraints similarly and to examine them simultaneously. The goal functions can be specified to be minimized (≤) or maximized (≥). VIG starts by finding the best possible value for flexible goals. If some goals are defined as inflexible, VIG may not be able to find a feasible solution during the initial process. However, the method still gives the current achievement levels for the inflexible goals, although some of these goals may not be satisfied. The inflexible goals (constraints) can be relaxed by changing the status of the goal from "inflexible" to "flexible." This helps to obtain feasible and non-dominated solutions. If the solution is still infeasible, we recommend that the decision-maker continue relaxing inflexible goals consecutively.

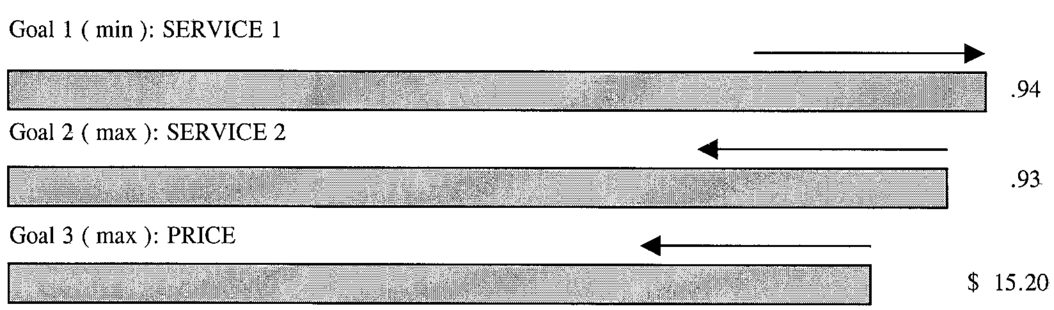
As a decision support system, VIG can assist purchasing teams in solving the supplier selection problem interactively on the personal computer and in identifying their best compromise solution. The values of the goals to be optimized are displayed on a computer monitor in numeric form as well as bar graphs in different colors whose lengths dynamically change as the user travels on the efficient surface, i.e., explores alternative courses of action (Figure 1). On the respective bar graph of each goal, the software indicates whether this goal has been defined to be minimized (min) or maximized (max). The right and left arrows indicate the direction in which the decision maker has to start moving in the beginning to search for alternative efficient non-dominated solutions. At the right hand side of each bar, their corresponding numerical values are displayed indicating the current achievement level of each goal.

The ability to "relax" or "tighten" the goals (constraints) in an interactive manner on the screen and graphically see the tradeoffs between the goals is a unique feature of VIG. This gives the ability to do tradeoff analysis and to answer "what if" questions in an interactive manner without the necessity for reformulating the problem. A number of alternative solutions can be developed and evaluated by the supplier selection team without the need for an analyst's intervention during the problem solution process.

VIG has been implemented in a variety of problems such as pricing decisions, input-output models for emergency management, and media selection. However, to the best of the authors' knowledge it has not yet been applied to purchasing decisions. The availability of VIG for personal computers should encourage the use of this decision support system also by purchas-

Figure 1: A Sample Solution for Vendor Allocation: Single Product
(Current Achievement 3)

VIG Solution on the Screen



ing teams and managers.

Application of Visual Interactive Goal Programming

Two examples serve to show the application of VIG in different purchasing environments. The first example is a multiple criteria supplier selection problem borrowed from the literature (Chaudhry, et al., 1991) to demonstrate the use of the decision support system in single-product supplier allocation problems. The second example is the simplified adaptation of a VIG application originally developed by the authors to solve a complex purchasing problem of a Midwestern manufacturing company. In this problem, suppliers are selected along with the allocation of orders among them. In this application, we extend the implementation of VIG to a multiple-replenishment purchasing problem. These examples serve to compare and contrast VIG to conventional goal programming in supplier selection decisions.

Single Product Vendor Allocation Problem

This example represents a purchasing situation in which a single product is allocated among multiple vendors, originally solved by conventional goal programming by Chaudhry, Forst, and Zydiak (1991). These authors describe the problem as follows. Consider a company that purchases blended gasoline from a network of three vendors. Vendor characteristics are given below.

The company wants to purchase 10,000 barrels (bls) of blended gasoline **(ORDERQ)**, while meeting the following goals in descending order of priority:

1. **Quality Goal (QUALITY)**: The aggregate octane level of the blended gasoline purchased should be at least 100.
2. **Lead-time Goal (LEADT)**: All of the gasoline bought should arrive in 28 days.
3. **Service Goal (SERVICE)**: The service level of each vendor should be at least 95%.
4. **Price Goal (PRICE)**: The aggregate cost of the gasoline purchased should be no more than $15 per barrel on average.
5. **Ration Limit (VENDOR)**: Ration limits show each vendor's maximum delivery capacities.

Original goal programming formulation of the problem and its solution can be found in Chaudhry et al., (1991). The initial goal programming solution to the problem satisfied the quality (octane level of 100.2) and lead time (≤ 28 days) goals. The solution involved buying 4000 barrels from the first vendor, 6000 barrels from vendor 2, and no purchases from vendor 3. However, the service and price goals were not satisfied. This was in accordance with the specified preemptive priorities. At this point, however, if the supplier selection team wishes to examine alternate solutions involving trade-offs between the quality and service goals, or the lead time and price goals, the priority structure needs to be re-specified and the problem re-solved for each of the trade-offs. In each of these cases, the mathematical formulation needs to be modified. The greater the number of tradeoffs the team likes to explore, the greater the amount of time and effort expended in re-formulation and

Vendors	Unit Price ($/bl)	Octane Rating (Quality)	Lead Time (days)	Service Level (%)	Ration Limit (bls)
1	17. 00	102	27	94	5,000
2	14. 00	99	28	93	6,000
3	18. 00	110	29	96	12,000

re-solving of the problem. In addition, this may inhibit the exploration of trade-offs.

Solution of Example One by VIG

We provided the formulation suitable for VIG in Appendix 1:A. Initially, the problem was solved by defining all of the constraints as inflexible goals. Although this first attempt did not produce a feasible solution as given in the column labeled Current Achievement 1" in Table 1, VIG provided achievement levels for all goals. Except the price goal, none of the other goals have been satisfied. For example, aggregate octane level of the blended gasoline was 99 that did not satisfy the target value of the quality goal (100).

In the second step, we solved the problem by relaxing only the two lowest priority goals-- service and price goals. The solution is given in Table 1, "Current Achievement 2" column. This solution provided a 100.3 octane rating for a $15.32 average price per barrel, which was higher than the price goal of $15 per barrel. Service levels were below the original goal of 95%. In contrast, quality and lead-time goals were satisfied for this trial.

We found another alternative non-dominated solution by traveling on the efficient surface starting from the results listed in the "Current Achievement 2" column. The new solution produced a lower price ($15.20) as shown in "Current Achievement 3" column in Table 1 and Figure 1. In this solution, vendor 3 is not selected as a supplier. This corresponds to the solution found by Chaudhry et al. (1991).

Using conventional pre-emptive goal

Table 1: Vendor Allocation Problem: Single Product
(Target Values and Current Achievement Levels of Goals)

Row	*Goals*	*Type of Goal*	*Target Values of Goals*	*Current Achievement 1*	*Current Achievement 2*	*Current Achievement 3*	*Current Achievement 4*	*Current Achievement 5*
1	QUALITY	≥	100.00	99.00	100.32	100.20	100.25*	100.50*
2	LEAD1	≤	28.00	0.00	0.00	0.00	0.00	0.00
3	LEAD2	≥	0.00	-0.00	0.00	0.00	0.00	0.00
4	SERVICE1	≥	0.95	0.93	0.94*	0.94*	0.94*	0.94*
5	SERVICE11	≥	0.00	5,979.97	5,164.04	6,000.00	5,830.97	5,000.00
6	SERVICE2	≥	0.95	0.93	0.93*	0.93*	0.93*	0.93*
7	SERVICE21	≥	0.00	3,968.37	4,385.96	4,000.00	4,169.03	5,000.00
8	PRICE	≤	15.00	15.00	15.32*	15.20*	15.25*	15.50*
9	VENDOR1	≤	5,000.00	3,882.35	4,385.96	4,000.00	4,169.03	5,000.00
10	VENDOR2	≤	6,000.00	6,000.00	5,614.04	6,000.00	5,830.97	5,000.00
11	VENDOR3	≤	12,000.00	0.00	0.00	0.00	0.00	0.00
12	ORDERQ	=	10,000.00	9,882.35	10,000.00	10,000.00	10,000.00	10,000.00
13	L3INT	≤	1.00	0.00	0.00	0.00	0.00	0.00
14	S1INT	≤	1.00	0.99	1.00	1.00	1.00	1.00
15	S2INT	≤	1.00	0.997	1.00	1.00	1.00	1.00

Signifies flexible goal

programming, Chaudhry and his colleagues (1991) obtained one of the efficient solutions--the one corresponding to the intersection of constraints that is called efficient extreme solution. However, when optimization of multiple conflicting goals are sought, all efficient non-extreme solutions, the ones that are on the efficient surface, are as good as the efficient extreme ones, the ones that are at the intersection of constraints. In other words, goal programming leaves out several efficient solutions to the problem.

Using VIG, the purchasing team members were able to see the trade-off between quality and price. They easily changed the status of the quality goal from inflexible (constraint) to flexible (goal) and were able to see the resulting prices for different quality levels of the blends. Two additional examples demonstrate this trade-off as shown in columns "Current Achievement 4" and "Current Achievement 5" in Table 1. These two solutions correspond to octane ratings (quality) of 100.25, and 100.5; and prices of $15.25 and $15.5 per barrel, respectively. The purchasing manager now easily sees the extent to which higher octane ratings, or better quality, push prices higher. At this point, purchasing team members must exercise their managerial judgement and experience to decide which result should be selected.

In this example, VIG assisted us in finding each of these additional solutions instantaneously on the efficient surface in an interactive manner without the need for re-formulating and re-solving the problem. The ability to generate alternative solutions easily was conducive to the exploration of a number of trade-offs by the supplier selection team. In contrast, if the selection team members were to search for alternative solutions using the goal programming formulation, they had to re-formulate the problem for each of the cases, and re-solve it repeatedly.

Vendor Selection for Multiple Products

The following example shows the application of the VIG decision support system to a multiple-replenishment purchasing problem adapted for this case. The example is developed by the authors for the hydraulic gear pump division of a manufacturing company. The formulation and data are modified to maintain anonymity of selected suppliers and the allocation scheme.

This Midwestern manufacturing company employs an elaborate screening process to identify eligible suppliers for purchasing. Those vendors who successfully passed the company's screening process are eligible for procurement. Allocation of orders among the final set of vendors has been completed by using VIG. In consultation with the purchasing team, the authors took into consideration vendors' capacity limitations, and price, quality and delivery reliability criteria in the problem formulation.

The hydraulic gear pump division buys three different kinds of castings from five suppliers who already passed the screening process. Because it is necessary to decide what and how much to buy from each supplier, amounts to be bought from different suppliers are decision variables. $GRAYIRON_i$(i= 1-4) designates the gray iron castings bought from supplier I. Supplier 5 cannot produce gray iron castings. Likewise $GRAPHIRON_i$ (i=1, 2) indicates compacted graphite iron castings bought from suppliers 1 and 2 only, and $DUCTIRON_i$ (i=2-5) defines the ductile iron castings bought from supplier I excluding supplier 1. Cost, quality and delivery reliability of each product bought from different suppliers are given in Table 2. Delivery reliability for different products bought from the same supplier is different because of the quality problems.

Table 2: Supplier Information

Suppliers	*Decision Variables*	*Cost ($/Unit)*	*Quality* (%)*	*Delivery Reliability** (%)*
Supplier 1	$GRAYIRON_1$	30	99	99
	$GRAPHIRON_1$	40	90	97
Supplier 2	$GRAYIRON_2$	10	98	95
	$GRAPHIRON_2$	20	96	90
	$DUCTIRON_2$	25	95	89
Supplier 3	$GRAYIRON_3$	30	90	70
	$DUCTIRON_3$	20	89	88
Supplier 4	$GRAYIRON_4$	25	99	92
	$DUCTIRON_4$	35	99	91
Supplier 5	$DUCTIRON_5$	33	90	85

* *Quality signifies percent of the "good" quality products acceptable to the quality control department*

** *Delivery reliability shows percent of the product delivered "on time" based on the due date and delivery window specified by the purchasing department.*

Constraints/Goals

1. Cost Goal (COST)

Total purchasing cost function is expressed to be minimized (≤), because our goal is to minimize the purchasing cost (see appendix 1B). The purchasing manager was able to give a target value for this goal. If we define this goal as flexible, VIG minimizes the cost. However, a reasonable target value is important to be used in the formulation.

2. Quality of Castings Purchased (QUALITY)

Gray iron castings can be purchased from four different suppliers. Therefore, the quality of the product mix will be as follows:

$$\frac{(\Sigma \text{ QUALITY of } GRAYIRON_i) \text{ X } (\text{DEMAND of } GRAYIRON_i)}{\text{Total DEMAND of GRAYIRON}}$$

Because we want to maximize the quality of the gray iron castings purchased from respective suppliers, the type of goal is defined as maximization (≥), and a target value was assigned by the purchasing team. Quality of compacted graphite iron and the quality of ductile iron castings are defined similarly.

3. Delivery Reliability of Castings Purchased (REL)

Delivery reliability of all types of iron castings is defined like the flexible quality goals. Again, we want to maximize delivery reliability of each kind of iron casting (≥).

4. Capacities of Each Supplier (CAPACITY)

Only suppliers 1 and 2 have capacity restrictions. Each gray iron casting produced by supplier 1 takes 1 hour per unit, and each compacted graphite casting takes 1.5 hours to produce. Supplier 1 cannot produce ductile iron castings. Each gray iron casting produced by supplier 2 takes 1 hour per unit, each compacted graphite casting takes 1.25 hours and each ductile iron casting takes 1.5 hours to produce. Capacities of supplier 1 and 2 are 3,000 and 3,500 hours for the planning period, respectively.

5. Demand (DEMAND)

Demand per planning horizon for gray, compacted graphite and ductile iron castings are 2,000; 1,200; 1,800 units, respectively. Under JIT, we require that demand be satisfied exactly.

The problem formulation that was completed in consultation with the purchasing team is given in Appendix 1:B.

Solution of Example Two by VIG

Cost, quality, and delivery reliability goals are defined as flexible goals. The initial solution is given in Figure 2 and Table 3, "Current Achievement 1" column.

This solution shows that cost can be reduced and quality of compacted graphite iron casting can be increased, if the purchasing team accepts reductions in other goals (Figure 2). This is a non-dominated solution and, if desired, can be implemented by the purchasing team.

In search of better solutions, finding alternative solutions with the assistance of VIG's interactive facility was easy for the purchasing team. For this purpose, we obtained another solution which is presented in Table 3, "Current

Figure 2: Vendor Selection for Multiple Products
(Current Values of Goals 1)

VIG Solution on the Screen

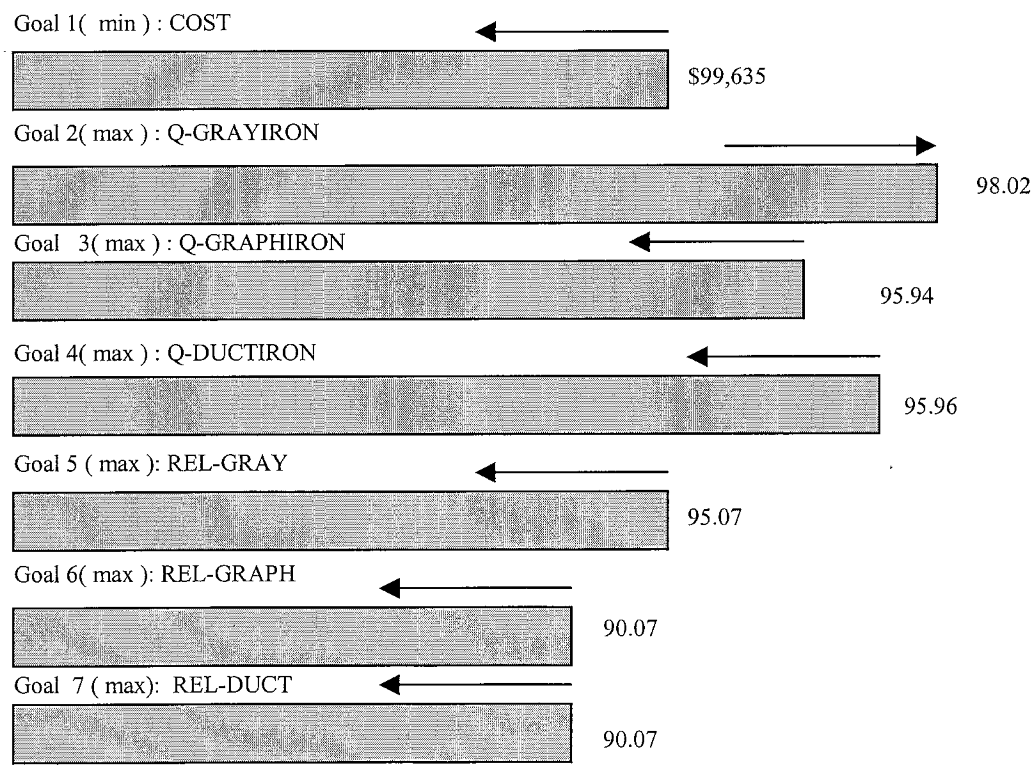


Table 3: Vendor Selection for Multiple Products
(Target Values and Current Values)

Row	*Goals*	*Type of Goal*	*Target Values of Goals*	*Current Values of Goals 1*	*Current Values of Goals 2*	*Current Values of Goals 3*
1	COST	≤ *	100,000.00	99,635.42	98,000.01	98,508.26
2	Q-GRAYIRON	≥ *	95.00	98.02	98.00	98.00
3	Q-GRAPHIRON	≥ *	90.00	95.94	96.00	96.00
4	Q-DUCTIRON	≥ *	90.00	95.96	95.67	95.86
5	REL-GRAY	≥ *	95.00	95.07	95.00	95.00
6	REL-GRAPH	≥ *	90.00	90.07	90.00	90.07
7	REL-DUCT	≥ *	90.00	90.07	90.00	90.06
8	$CAPACITY_1$	≤	3,000.00	55.21	0.00	0.00
9	$CAPACITY_2$	≤	3,500.00	3,500.00	3,500.00	3,500.00
10	DEM-GRAY	=	2,000.00	2,000.00	2,000.00	2,000.00
11	DEM-GRAPH	=	1,200.00	1,200.00	1,200.00	1,200.00
12	DEM-DUCT	=	1,800.00	1,800.00	1,800.00	1,800.00

Signifies flexible goals

Order allocation to each vendor:

	for current values of goals 2	*for current values of goals 3*
$GRAPHIRON_1$	0.00	0.00
$GRAYIRON_2$	2,000.00	2,000.00
$GRAPHIRON_2$	1,200.00	1,200.00
$DUCTIRON_2$	0.00	0.00
$DUCTIRON_3$	600.00	566.00
$DUCTIRON_4$	1,200.00	1,233.00

Achievement 2" column. In this case, the quality of graphite iron casting was increased to 96% from 95.9% and, cost was reduced to $98,000 from $99,635. To achieve these goals, the purchasing team should buy all compacted graphite as well as gray iron castings from supplier 2, and buy nothing from supplier 1, i.e., the first supplier should not be selected. The purchasing team should split the ductile iron casting order between supplier 3 and 4, buying 600 units from the third and 1,200 units from the fourth supplier. If ductile iron casting allocation between supplier 3 and 4 changed to 566 and 1,233 units, respectively, the cost will increase to $98,508 from $98,000 and the quality of ductile iron castings purchased will go up from 95.7% to 95.9% (Table 3, "Current Achievement 3" column).

The purchasing team in this particular company was able to evaluate the trade-offs among various goals in an interactive manner and to choose the best solution among the non-dominated solutions provided by VIG. Application of VIG made it possible for the purchasing team to make the best allocation among the vendors.

Discussion and Conclusion

These examples illustrate the application of VIG to single- and multiple-product supplier selection problems. VIG can be used to identify the best suppliers for a company to include in its supplier network and how to allocate purchase amounts among multiple suppliers. At the same time, this procedure permits the purchasing teams to analyze trade-offs among multiple goals such as cost, quality, and delivery reliability simultaneously and interactively.

VIG has several similarities with conventional goal programming. Both techniques can be used to solve supplier selection and volume allocation problems. In both methods, the decision-makers and analysts need to know the target level of their goals. However, these methods can handle tangible goals only, and this is a weakness for both of them.

In spite of similarities, several advantages make VIG a more preferable method over the conventional goal programming. Technically, VIG is a more advanced technique as it does not differentiate between goals and constraints, and does not require specification of preemptive priorities of multiple goals. In addition, it provides both extreme and non-extreme point solutions, and current values of goals even if there is no feasible solution to the problem. From the implementation perspective, VIG facilitates a process of finding alternative solutions without re-formulation of the problem. One can analyze trade-offs interactively once the problem is formulated with the help of an analyst. Although no mathematical assistance is needed during the later phases of decision making, because the original formulation would require an experienced analytical staff, it may be seen as a weakness also of this method. From the users' perspective, the ability to use VIG in an interactive manner and graphically on the PC screen is a unique feature of the technique. The comparison of VIG with conventional goal programming is presented in Table 4.

Suggestions for Further Implementation

The hydraulic gear pump division of the Midwestern manufacturing company has utilized the visual interactive goal programming successfully. In the future, this and similar applications could be used to help overcome managerial teams' mistrust of quantitative techniques. Once the problem is formulated with the assistance of technical support staff, managers can maintain control of examining alternative courses of action rather than facing a single solution presented to them by an analyst. It is desirable that the purchasing/logistics managers explore available alternative solutions, cost savings and quality improvements in the supply network. These improvements can be significant.

Visual Interactive Goal Programming can help the purchasing teams to make important contributions to the performance of their company. This assistance can be particularly invaluable in the logistics/supply chain management environment within which cost containment for material purchases and recruitment of high-quality suppliers play major roles.

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Table 4: Comparison of VIG with Goal Programming

	Conventional Goal Programming	VIG
Basis of Technique	a. Based on Linear Goal Programming	a. Based on Pareto Race
Similarities	b. Both techniques require target levels of goals	
	c. They can handle tangible goals only	
	d. Both can solve supplier selection and volume allocation problems	
Technical Differences	e. Need to differentiate between goals and constraints.	e. No need to differentiate between goals and constraints. Allows decision maker to change the status of goals and constraints during the solution process. This enables one to explore alternative solutions.
	f. Need to specify preemptive priorities for multiple goals	f. No need to specify preemptive priorities
	g. Provides only efficient extreme point solutions.	g. Provides efficient extreme as well non-extreme point solutions. When multiple goals are being considered extreme point solutions have no superiority over the non-extreme ones.
	h. No solution provided if there is no feasible solution for the problem.	h. Current values of goals are found even if there is no feasible solution. This helps in re-examination of model parameters (capacities, etc.) and in the selection of goals to be flexed.
Application Differences	i. Need to modify the formulation and to re-solve the linear programming problem for each alternative solution to be explored iteratively.	i. Managers can be trained to interactively analyze trade-offs among multiple goals and generate alternative solutions.
	j. Less flexibility and control for decision makers in exploring alternative solutions.	j. Gives flexibility and control to decision makers in exploring trade-offs.
	k. Analyst's involvement in initial formulation and during the trade-off exploration stages.	k. Analyst's involvement in initial formulation only.
Platform Differences	l. No graphical presentation facility	l. Graphical presentation on PC monitor is convenient and effective in exploring trade-offs among goals.

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Appendix 1

A) Generalized Integer Goal Programming Model For The Gasoline Blending Example

Let Q be the amount (in barrels) of the given order quantity (10,000) barrels to be purchased from vendor i. L_i and S_i are binary (0 or 1) integer lead time and service variables that "turn on" the effects of lead time and service respectively, only if vendor i is selected (i.e. it will take the value 1 only if $Q_1 > .0$).

Quality goal $(102Q_1 + 99Q_2 + 110Q_3) / 10{,}000 \geq 100$

Lead time goal $29L_3 \leq 28, Q_3 \leq 10{,}OOOL_3$

Service goal for vendor 1 $.94S_1 \geq .95, Q_1 \leq 10{,}000S_1$

Service goal for vendor 2 $.93S_2 \geq .95\ Q_2 \leq 10{,}000S_2$

Price goal $(17Q_1+14Q_2+18Q_3) / 10{,}000S \leq 15$

$Q_1 \leq 5{,}000, Q_2 \leq 6{,}000, Q_3 \leq 12{,}000$ (Maximum amount available from each vendor)

Order quanitity constraint $Q_1 + Q_2 + Q_3 = 10{,}000$

$Q_1 \geq 0,\ i = 1,2,3,\ L_3 = 0$ or $1, S_1 = 0$ or $1, S_2 = 0$ or 1

B) Vendor Selection For Multiple Products

Cost goal (min) $30\ GRAYIRON_1 + 40\ GRAPHIRON_1 + ... + 35\ DUCTIRON_4 + 33\ DUCTIRON_5 \leq 100{,}000$

Quality of gray iron (max) $(90\ GRAYIRON_1 + 98\ GRAYIRON_2 + 90\ GRAYIRON_3 + 99\ GRAYIRON_4)/2{,}000 \geq 95$

Quality of compacted graphite iron (max) $(90\ GRAPHIRON_1 + 96\ GRAPHIRON_2)/1{,}200 \geq 90$

Quality of ductile iron (max) $(95\ DUCTIRON_2 + 89\ DUCTIRON_3 + 99\ DUCTIRON_4 + 90\ DUCTIRON_5)/1{,}800 \geq 90$

Capacity of Supplier 1 $GRAYIRON_1 + 1.5\ GRAPHIRON_1 \leq 3{,}000$

Capacity of Supplier 2 $GRAYIRON_2 + 1.25\ GRAPHIRON_2 + 1.5\ DUCTIRON_2 \leq 3{,}500$

Gray iron demand $GRAYIRON_1 + GRAYIRON_2 + GRAYIRON_3 + GRAYIRON_4 = 2{,}000$

Compacted graphite iron demand $GRAPHIRON_1 + GRAPHIRON_2 = 1{,}200$

Ductile iron demand $DUCTIRON_2 + DUCTIRON_3 + DUCTIRON_4 + DUCTIRON_5 = 1{,}800$