CAPITAL RATIONING IN THE PUBLIC SECTOR USING THE ANALYTIC HIERARCHY PROCESS

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ABSTRACT

This paper describes an application of the Analytic Hierarchy Process (AHP) to a capital rationing decision problem. The Istanbul Water and Sewerage Administration (IWSA) was granted a loan of $650 million offered by the World Bank to allocate among several water provision and waste water treatment projects. A project selection process solely based upon the benefit-cost analysis would not be sufficient to reflect the IWSA's social and political goals. Thus the AHP methodology is employed to express all quantifiable and non-quantifiable factors as a single model. Such a model provides the weights of the projects based upon the preferences and judgements of the IWSA managers. Then it becomes necessary to determine the multi-project schedule within the stated credit conditions over a 15-year planning horizon. To serve this purpose, a mixed integer linear model is formulated to provide the best project start up portfolio with a feasible credit outlay. Several IWSA managers participated both in the AHP stage of forming the hierarchical structure, assessing the matrix weights and in the mathematical modelling stage of determining project durations, cost and revenue figures. The solution presented to the IWSA management is approved to be implemented in their strategic course of action.

INTRODUCTION

The purpose of this study is to solve the capital rationing problem of the Istanbul Water and Sewerage Administration (IWSA) by employing an integration between the Analytical Hierarchy Process (AHP) and a mixed integer mathematical model. The IWSA was faced with the issue of allocating a loan of $650 million offered by the World Bank among several public projects. The AHP approach is employed to incorporate many qualitative and quantitative factors inherent in such a public organization into the project selection decision-making process. The hierarchic analysis used in this application takes into account the economic development, a project's economic and political acceptability, environmental impacts and the perceived risks to like, health and management. The priority weights of the projects, which are taken into consideration by the IWSA managers as a part of long-range planning, are determined within this context. Then a mathematical model which uses these AHP project scores and formulates the requirements of the loan offered to finance these projects, is designed to provide the final project selection schedule.

Tremendous amount of research has been done on the procedural aspect of capital investment decision problems, and many techniques based on the discounted cash flow principle have been used widely for determining the size of the budget, identifying investment opportunities and selecting projects according to some economic criterion. Proctor and Canada [37] provides an extensive summary of literature dealing with capital budgeting processes based on discounted cash flow approach. Gurnani [20], Klammer *et al* [28], Mukherjee and Henderson [34] and Wilner *et al* [65] further provide an overview of theoretical and practical aspects of these approaches. However, nowadays, the traditional methods have evolved to be inadequate in current practices because they fail to account for non-quantifiable intangible factors and to reflect the link between the capital investment decision and organizational structure as shown in Sullivan and Smith [50]. In fact, the necessity of incorporating the multiattribute nature in the management of engineering design problems is studied in Thurston [55, 59] and Thurston and Carnahan [58]. Furthermore, the question of employing the discounted cash flow approach in the evaluation of capital investments, especially those in advanced manufacturing environment, is addressed in Blank [8], Canada [11], Falkner and Benhajla [15], Huber [24], Leung *et al* [30], Mensah and Miranti [33], Noble [35], Primrose and Leonard [36], and Weber [63]. Thus a need to compensate these deficiencies has arisen, and the AHP has proven to be one of the descriptive approaches effective in structuring multiobjective capital investment decision problems. The performance of the AHP is studied in Arbel and Seidmann [1], Barbarosoglu *et al* [6], Boucher and MacStravic [9], Jensen [26], Kamath and Khaksari [27], Stout *et al* [49], Sullivan [51], Tarimcilar and Khaksari [53], Tashfeen and Leung [54], Varney *et al* [61], and Wabalickis [62]. Within this context, Liberatore *et al* [31] focuses on structuring the decision hierarchy so that the AHP can be successfully implemented in a capital budgeting decision problem.

As it is well-known, the AHP is originally introduced by T.L. Saaty and the basic process of using the eigenvector method in prioritization is described in Saaty [43] and Saaty and Vargas [40]. Its theory and the underlying axioms are further developed in Arbel and Oren [2], Aupetit and Genest [3], Fichtner [16], Harker and Millet [23], Lim and Swenseth [32], Saaty [41, 42, 44, 45, 46], Zahedi [66], and Zahir [68]. Since its first appearance, the AHP approach is applied to a wide range of decision problems in economical, managerial, political and social context. A comprehensive survey of the AHP applications is given in Shim [47] and Zahedi [67]. Vargas [60] also provides a classification of some AHP applications in industry and government. Real-world public sector applications of the AHP are brought together in Golden *et al* [18], and noteworthy public sector applications are provided in Azis [4], Bard and Sousk [7], Ehie and Benjamin [12], Erkut and Moran [14], Fuller [17], Grizzle [19], Hamalainen

[21], Hamalainen and Seppalainen [22], Imber *et al* [25], Ridgley [38], Ridgley and Rijsberman [39], Stewart and Horowitz [48], Sutardi *et al* [52], and Willet and Sharda [64].

In literature there exist some studies which contribute to the integration of multiattribute analysis and other relevant operations research concepts. A methodology to include multiple design attributes and design constraints within the framework of a mathematical model is proposed as a coupling between optimization and multiattribute analysis in Thurston [56, 57]. Korhonen and Wallenius [29] on the other hand develop a dynamic decision support system for solving multiple linear programming problem by using the weight assessment principle of the AHP. Furthermore, sensitivity analysis in the AHP is studied extensively as a tool to improve the credibility of the analytical model in Bana [5] and Erkut and Tarimcilar [13].

PROBLEM DESCRIPTION

The IWSA is the monopolistic public organization responsible for providing water and sewerage facilities to the city of Istanbul which has evolved to be one of the largest metropolitans in Europe and Middle East with a population of 7 million scattered over a 5,000 km^2 area. Thus it is a major issue to provide adequate water supply and disposal system to all citizens. Moreover, since the city is undergoing a continuous expansion due to immigration, it is an on-going process to renew and maintain the existing piping and disposal network features and to increment the network capacity by building dams, tunnels, tanks, pumps, distillation, incineration and discharge units. Thus one of the main decisions to be made by IWSA managers is to generate projects, which will allow for the network capacity expansion and to choose among these in an optimal manner.

Since the primary concern of the IWSA is to improve the public welfare, it is a non-profit organization, and an economic analysis would not be sufficient to reflect the quantifiable and nonquantifiable objectives of IWSA management in making capital rationing decisions. Political and social factors play an important role in the project selection process for such an organization and the solution procedure selected to solve this problem should allow the inclusion of human judgment and preferences, analytic thinking, systematic rationality and measurement. That is why the AHP model is chosen to express all pertinent objectives and the interaction among them. In this study, a particular capital rationing problem in which the five waste disposal and four drinking water projects are studied in consultation with the IWSA managers is analyzed within the framework of AHP. Kücükcekmece (K1), Tuzla (K2), Göksu-Riva (K3), Baltalimani (K4) and Ömerli-Elmali (K5) are water disposal projects each of which consists of a water treatment plant, discharge tunnels, pumps, incineration, biological nitrogen and phosphate processing units. On the other hand, Ömerli (S1), Terkos (S2), Asian (S3) and Elmali (S4) are drinking water provision projects which aim at expanding the capacity of the existing dams and the distribution network.

The cash flow requirement of each project is generated in consultation with the IWSA by using S-Curve analysis similar to Bullis [10] as shown in Table 1 in the Appendix.

Water projects are the only profit-generating projects and are assumed to bring revenue which depends on the percent completion and stays constant at the same level following 100% completion. It is furthermore assumed that 80% of estimated revenue is collectable. The collectable revenue profiles measured in 1991 figures are given in Table 2 in the Appendix.

To undertake these projects, a loan is granted by the World Bank over a 15-year planning horizon with the following conditions:

(i) The total amount of the loan cannot exceed US$ 650 million.
(ii) The maximum loan that can be withdrawn annually cannot exceed 40% of the total annual costs of the projects in progress.
(iii) The maturity of each annual credit withdrawal is 17 years with a 4-year grace period. The principal payments are made in 13 equal installments following the grace period.
(iv) An annual commitment fee of 0.5% is paid on the portion of the unused loan.

In short, the major problem is to choose among nine potential projects by using the above-mentioned World Bank credit over the 15 year horizon and to determine the credit withdrawal, principal and interest spread over the years, while the utmost attention is given to balance the tradeoffs between social, political and economic factors. As it will be discussed in detail in the following sections, an AHP model is integrated with a mathematical programming model to solve this issue.

DEVELOPMENT OF THE AHP MODEL

The AHP approach is used to help the IWSA managers select the desired portfolio of investment alternatives and direct the allocation of the World Bank loan among these. As it is well-known, the AHP consists of decomposing a complex problem into its components, organizing the components into sets and locating the sets into levels to generate a hierarchical structure. The purpose of constructing such a hierarchy is to determine the impact of lower-level elements on an upper level criterion, which is achieved by pairwise-comparisons provided by the decision maker(s). In fact, the decision-maker is asked to provide a consistent pairwise comparison matrix which satisfies the cardinal property and which yields the rank ordering of the elements included in the matrix. Even if the initial matrix does not satisfy the consistency condition, the decision-maker is made to review his judgements until consistency is improved gradually in an iterative manner.

To solve the capital rationing problem for the IWSA by using the AHP, the first step is to construct the hierarchy tree and thus to determine all factors affecting the decision-making process and interactions among these. This could surely be done only with the participation and the consultation of the IWSA managers. Thus the research team organized a training program for the whole group of top and middle-level managers in the IWSA to explain the capital rationing process, the multiattribute decision process, utility analysis and finally the AHP analysis. They were informed on the assessment of preferences, the tradeoff analysis, the consistency of choices and the pairwise comparison process. Many AHP applications were studied in the program as well. Then a questionnaire was designed by the research team to understand the group reaction to the AHP approach and to investigate how they esteemed the viability of using the AHP in there specific decision problem. The responses turned out to be affirmative. In fact, they were enthusiastic to use a formal and systematic procedure in the decision-making process. Most participants believed that the AHP would turn out to be an excellent tool by eliminating the deficiency of a discounted cash flow approach which they had used for a long time as the only formal decision-making technique and by incorporating intangible factors into the analysis. They were willing to cooperate with the research team and to participate in the questioning process.

Next it was necessary to determine the objectives the IWSA should possess in the short and long term. To do this, the research team selected the managers of three departments, namely the Finance Department, the Planning Department and Customer Relations Department, as the key decision-makers. The three managers were asked to specify the objectives the IWSA should pursue in making such a capital budgeting decision. It was proposed that each would undertake the objective prioritization in the form of a group decision process by negotiating the technical impact of each measure with everybody in his own department and integrating all opinions, and that each should carry out this without getting in contact with the other managers. Thus three sets of objectives were submitted to the research team. Finally, the research team analyzed, classified all the criteria under the consultancy of the general manager, and obtained the AHP hierarchy shown in Figure 1. It is designed in the form of a mission-objectives-evaluation criteria structure as proposed in Liberatore *et al* [31].

The hierarchy consists of four levels where the very top level represents the main mission in selecting the best portfolio of water and sewerage projects. The first level contains the primary categories for the objectives which affect the

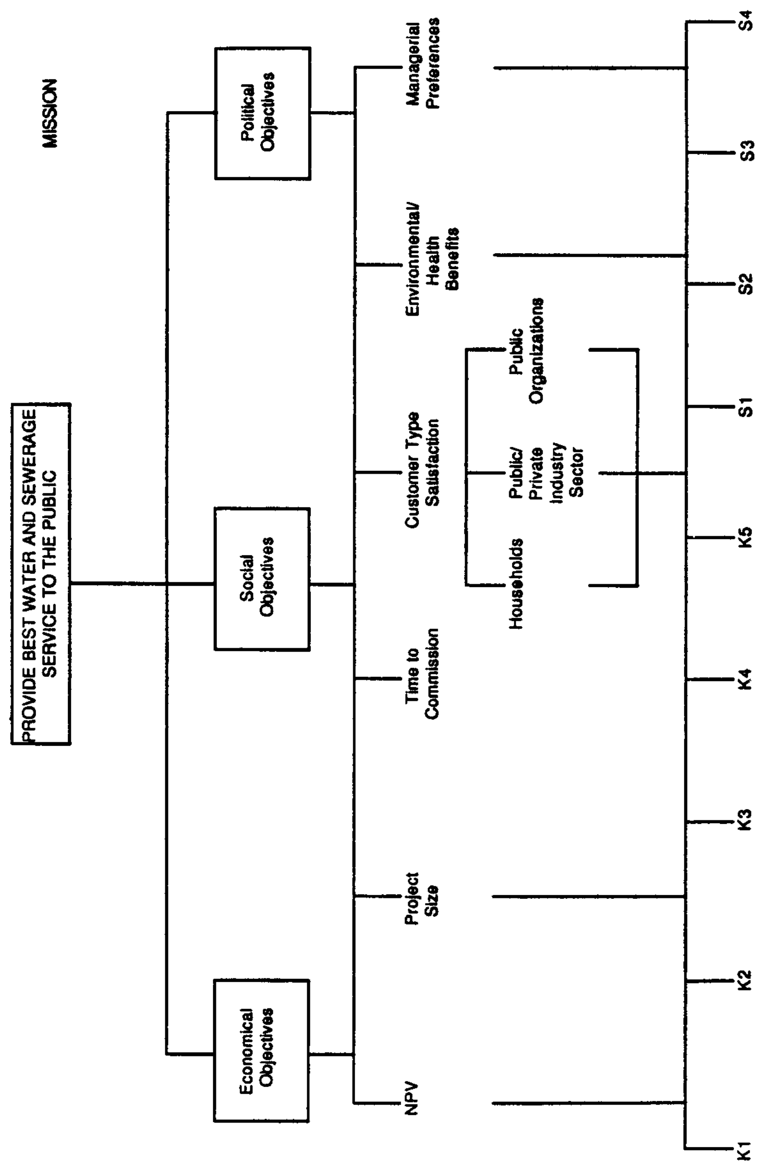

FIGURE 1. The AHP hierarchy.

IWSA decision-making process. The economic, social, and political objectives comprise these three main categories. At the second level the evaluation criteria that influence each of the primary objectives are included. The economic objective category includes net present value (NPV), project size, customer type satisfaction and environmental/health benefits. The subcriteria for the social objective include project size, time to commission, customer type satisfaction, and environmental/health benefits. The subcriteria for the political objective category, on the other hand, include NPV, project size, time to commission, customer type satisfaction, environmental/health benefits and managerial preferences.

NPV is chosen to be the primary measure of project profitability. The project size on the other hand is defined to convey both economic implications in terms of the capital requirement and social implications in terms of the population size the project will serve. Time to commission simply represents the time span required until the benefits of the project are felt by the population. The shorter it gets, the sooner the projects generate economic, social and political impact. The IWSA being a political organization, the customer satisfaction generated under each project plays an important role in the decision-making process. The deficiency in the waste water collection and treatment system poses a serious problem for environmental pollution and risk to health, which implies an economic burden quantifiable in the long run. Therefore, any improvement in the existing system brings about long-term savings and both social and political prestige. The last subcriterion included at this level is the managerial preferences which reflect the political aspiration and personal attitudes of the decision-makers in the IWSA.

The IWSA provides service to households, industrial zones, and public institutions under different tariff programs; thus different customer types bring about different economic benefits as well as different levels of social and political satisfaction. As tariff rates and revenue collectibility ratios vary among customers, the social and political impact of service provision to different customer types upon the IWSA image is different. Thus different customer types should be treated in a different manner from the preferences point of view and thus are chosen to comprise the factors at the third level. Finally, the project alternatives discussed in the previous section are included at the last level.

Next, it is necessary to obtain the scores in all comparison matrices. Thus, the three managers were asked to set up pairwise comparison matrices. At this point, the AHP tree was presented by the research team to each manager individually to obtain their own value judgements. Whenever the decision maker got indecisive, he was allowed to consult those in his department and to generate a single set of weight by the consensus of the group. At the end the arithmetic mean of the value judgements of all three managers was computed as the final figure for each matrix element. Thus as a result of long-lasting discussions, the preferences and perceptions of the group are summarized in the form of comparison matrices given in Table 3 in the Appendix. A computer software written in Pascal Turbo 5 is used to solve the resulting AHP tree. It possesses a high dimensional capability and the potential to handle the non-symmetric tree structure. The priority weights of the projects under consideration are found to be

$$w_{k1} = 0.124 \quad w_{k2} = 0.131 \quad w_{k3} = 0.146 \quad w_{k4} = 0.071 \quad w_{k5} = 0.183$$
$$w_{s1} = 0.147 \quad w_{s2} = 0.042 \quad w_{s3} = 0.087 \quad w_{s4} = 0.069$$

which implies that project K5 has turned out to be the most preferable one with the highest priority and projects S1, K3, K2 and K1 are more favorable than the others. The ratings of the projects with respect to level 2 subcriteria are also provided in Table 3 as an eigenvector adjacent to each related comparison matrix.

MODELING OF THE CAPITAL RATIONING PROBLEM

Once the project prioritization is achieved through the AHP scheme, the next step is to make capital rationing decisions by considering the quantifiable factors; thus a linear mixed integer model is designed to enable the IWSA managers to choose among potential projects. The main question is to spread the total credit offer over a 15-year planning horizon in the optimal manner according to the stated credit conditions.

The dynamic mathematical model aims at determining the projects to be undertaken each year so as to maximize the total priority score of the decision-makers in the IWSA subject to the financial constraints dictated by the foreign exchange credit limits and other technical constraints.

The decision variables in the model are defined by

$$X_{it} = \begin{cases} 1, & \text{if project } i \text{ is initiated in period } t=1,\dots,15;\ i=k1,\dots,s4 \\ 0, & \text{otherwise} \end{cases}$$

CR_t = Amount of credit required in period $t=1,\dots,15$

E_t = Equity required in period $t=1,\dots,15$

P_t = Amount of principal repayment in period $t=1,\dots,15$

I_t = Interest incurred in period $t=1,\dots,15$

O_t = Outstanding debt in period $t=1,\dots,15$

COM_t = Total amount of commitment fees accrued in period $t=1,\dots,15$

Then the model is given by

$$MAX\,Z = \sum_{t=1}^{15} \sum_{l=1}^{9} w_j X_{it} \tag{4.1}$$

subject to:

$$E_t + CR_t - \sum_{i=1}^{9} \sum_{j=\max\{0,t-d_i\}}^{t} X_{ij}.C_{i,}t - j(l+f)^t + \sum_{i=1}^{9} \sum_{j=0}^{9} X_{ij}.R_{i,t-j.}(l+f)^t$$

$$-P_t - l_t - COM_t = 0, \qquad t = 1,\dots,15 \tag{4.2}$$

$$O_t - O_{t-1}CR_t + P_t = 0, \qquad t = 1,\dots,15 \tag{4.3}$$

$$l_t - \alpha(O_t + O_{t-1})/2 = 0 \qquad t = 1,\dots,15 \tag{4.4}$$

$$COM_t - \beta\left(C - \sum_{j=1}^{t} CR_j\right) = 0, \qquad t = 1,\dots,15 \tag{4.5}$$

$$P_t - \frac{1}{13}\sum_{j=1}^{t-4} CR_j = 0, \qquad t = 5,\dots,15 \tag{4.6}$$

$$E_{t\_}E \le 0, \qquad t = 1,\dots,15 \tag{4.7}$$

$$CR_t - 0.4\sum_{i=1}^{9} \sum_{j=\max\{o,t-d_i\}}^{t} X_{ij}.C_{i,t-j}(l+f)^t \le 0, \quad t = 1,\dots,15 \tag{4.8}$$

$$\sum_{t=1}^{15} CR_t - C \le 0, \tag{4.9}$$

$$\sum_{t=1}^{15} X_{it} - 1 \le 0, \quad i = 1,\dots,9 \tag{4.10}$$

$$X_{it} - \sum_{j=0}^{t} X_{kj} \le 0, \text{ for any contingent } (i,k) \text{ project pair}$$

$$t = 1,\dots,15 \tag{4.11}$$

$$\sum_{j=1}^{t} X_{ij}.R_{i,t-j} - M\sum_{j=1}^{t-d_k} X_{kj} \leq 0 \quad \text{for any contingent } (i,k) \text{ project pair}$$

$$t = 1,\ldots,15 \qquad (4.12)$$

$$X_{it} = 0,1, \quad i = 1,\ldots,9, \quad t = 1,\ldots,15 \qquad (4.13)$$

$$CR_t, E_t, P_t, I_t, O_t, \; COM_t \geq 0, \qquad t = 1,\ldots,15 \qquad (4.14)$$

where W_i = priority of project i as obtained from the AHP model.
$C_{i,t}$ = cost of project i required t periods after start-up expressed in terms of present figures.
$R_{i,t}$ = revenue generated by project i t periods after start-up expressed in terms of present figures.
α = interest rate per period.
β = commitment fee per period.
f = inflation rate per period.
E = maximum equity available each year.
C = total credit limit over the planning horizon.
M = a very large number.

Here, the objective function given by (4.1) simply tries to maximize the satisfaction of the decision-makers by employing AHP priority weights. (4.2) basically provides the financial balance between the inflows and outflows of cash flow requirements while the debt position and the interest paid on the debt are expressed by (4.3) and (4.4), respectively. A certain percentage of the not yet used promised loan is charged as a commitment fee given by (4.5) which forces the decision-maker to use the credit as soon as possible. The credit is supposed to be paid back in 13 equal payments following the 4-year grace period; thus the principal payments are determined by (4.6) while (4.7) imposes an upper bound on the equity required each year. One major requirement of the proposed fund is to meet at most 40% of the total cost of the projects being conducted each year; thus (4.8) poses an upper bound on the amount of credit that could be requested each year while (4.9) give the total credit limit that could be used over the whole planning horizon. Constraints (4.10) are just technical constraints to guarantee that any project could be chosen only once. The contingency relations among the projects are given by (4.11). Moreover, if project i is known to be contingent upon project k, then project i cannot start generating revenue before project k is completed. The later situation is achieved by (4.12).

The model through (4.1) - (4.14) has 156 constraints and 225 decision variables and is solved by using MICROSOFT EXCEL 3.0 SOLVER in 25 minutes. Without loss of generality, α is chosen to be 8%, and β is determined to be 0.5%, and the model is solved by choosing different E, C and f values. The results for E=\$80 million, C = \$650 million and f=0.040 with an objective function of 0.766 are given in Table 4, Table 5 and Table 6. The solution reveals that projects S1 and S3 are not selected while all the others are to be undertaken in the 15-year time horizon. The start-up time of each selected project is given by

$$X_{k1,9} = 1; X_{k2,7} = 1; X_{k3.1} = 1; X_{k4,8} = 1;$$

$$X_{k5,4} = 1; X_{s2,1} = 1; X_{s4,6} = 1;$$

Table 4 in the Appendix provides the annual credit withdrawals, principal, interest and commitment fee payments, equity requirements and debt position. The cost and revenue outlays of the resulting solution are given in Table 5 and Table 6, respectively, in the Appendix. The total amount of credit withdrawn has turned out to be \$553.85 million in this solution.

CONCLUSION

Traditional capital rationing methods are mainly for profit maximizing companies and fail to account for multiple objectives, especially social and political ones which are difficult to quantify due to their descriptive and subjective nature. Because of the IWSA's non-profit seeking nature, such methods are quite inadequate to express the multiple and conflicting quantifable and nonquantifiable goals within a single model. Therefore, an integration of the AHP and mathematical programming is used to solve the IWSA's capital rationing problem. The IWSA has applied to the World Bank for the financing of projects planned to start in 1992 and received a loan of \$650 million. Then the IWSA management has felt the need of using a reliable decision making tool to assure highest utilization of the loan, while trying to satisfy the organization's social, political and economical expectations of providing water and waste disposal services for the city. This study is specifically developed to provide such a methodology for the IWSA managers, who participated in the process of generating the decision hierarchy and assessing the matrix weights. Using this AHP prioritization, a dynamic mixed integer model is formulated to select a feasible set of projects within the stated loan requirements. The fact that project K5 ranks first in the AHP model is consistent with the IWSA strategic planning, and ranking of the other projects is also found in parallel with their perception and intuition. Furthermore, the result of mixed integer model is approved by the IWSA management to be an acceptable project selection schedule in terms of their long range planning.

REFERENCES

[1] Arbel, A., and A. Seidmann, "Performance Evaluation of FMS," *IEEE Transactions on Systems, Man and Cybernetics*, Vol. 14, No. 4, 1984.

[2] Arbel, A., and S. S. Oren, "Generating Search Directions in Multiobjective Linear Programming Using the AHP," *Socio-economic Planning Sciences*, Vol. 20, pp. 369-373, 1986.

[3] Aupetit, B., and C. Genest, "On Some Useful Properties of the Perron Eigenvalue of a Positive Reciprocal Matrix in the Context of the AHP," *European Journal of Operations Research*, Vol. 70, pp. 263-268, 1993.

[4] Azis, I. J., "AHP in the Benefit-Cost Framework: A Post-Evaluation of the Trans-sumatra Highway Project," *European Journal of Operations Research*, Vol. 48, pp. 38-48, 1990.

[5] Bana, C. A., and E. Costa, "A Multicriteria Decision Aid Methodology to Deal with Conflicting Situations on the Weights," *European Journal of Operations Research*, Vol. 26, pp. 22-24, 1986.

[6] Barbarosoglu, G., D. Pinhas, B. Baskan, E. Barok, and L. Kömür, "Capital Rationing Decision in the Public Sector: An Application of the Analytic Hierarchy Process," *Research Paper*, FBE-IE-10/92-13, Bogazici University, 1992.

[7] Bard, J. F., and S. F. Sousk, "A Trade-off Analysis for Rough Terrain Cargo Handlers Using the AHP: An Example of Decision Making," *IEEE Transactions on Engineering Management*, Vol. 37, No. 3, 1990.

[8] Blank, L., "The Changing Scene of Economic Analysis for the Evaluation of Manufacturing System Design and Operation," *The Engineering Economist*, Vol. 30, pp. 227-244, 1985.

[9] Boucher, T. O., and E. L. MacStravic, "Multiattribute Evaluation within a Present Value Framework and its Relation to the Analytic Hierarchy Process," *The Engineering Economist*, Vol. 37, pp. 1-33, 1991.

[10] Bullis, J. P., "Practical Cost Control: Techniques and Timing," *AACE Transactions*, 1984.

[11] Canada, J. R., "Non-Traditional Method for Evaluating CIM Opportunities: Assign Weights to Intangibles," *Industrial Engineering*, pp. 66-71, 1986.

[12] Ehie, I. C., and C. O. Benjamin, "An Integrated Multiobjective Planning Model: A Case Study of the Zambian Cooper Mining Industry," *European Journal of Operations Research*, Vol. 68, pp. 160-172, 1993.

[13] Erkut, E., and M. Tarimcilar, "On Sensitivity Analysis in the Analytic Hierarchy Process," *IMA Journal of Mathematics Applied in Business and Industry*, Vol. 3, pp. 61-83, 1991.

[14] Erkut, E., and S. R. Moran, "Locating Obnoxious Facilities in the Public Sector: An Application of Analytic Hierarchy Process to Municipal Landfill Siting Decisions," *Socio-economic Planning Sciences*, Vol. 25, pp. 89-102, 1991.

[15] Falkner, C. H., and S. Benhajla, "Multiattribute Decision Models in the Justification of CIM Systems," *The Engineering Economist*, Vol. 35, pp. 91-114, 1990.

[16] Fichtner, J., "On Deriving Priority Vectors from Matrices of Pairwise Comparisons," *Socio-economic Planning Sciences*, Vol. 20, pp. 341-345, 1986.

[17] Fuller, S. G., "Evaluating Fire Protection Investment Decisions for Homeowners," *Socio-economic Planning Science*, Vol. 25, pp. 143-154, 1991.

[18] Golden, B. L., E. A. Wasil, and P. T. Harker, *The Analytic Hierarchy Process, Applications and Studies*, Springer-Verlag, Berlin 1989.

[19] Grizzle, G. A., "Pay for Performance: Can the AHP Hasten the Day in the Public Sector?," *Mathematical Modeling,* Vol. 9, pp. 245-250, 1987.

[20] Gurnani, C., "Capital Budgeting: Theory and Practice," *The Engineering Economist,* Vol. 30, pp. 19-46, 1984.

[21] Hamalainen, R., "Facts or Values - How do Parliamentarians and Experts See Nuclear Power," *Energy Policy*, pp. 464-472, 1991.

[22] Hamalainen, R. P., and T. Seppalainen, "The Analytic Network Process in Energy Policy Planning," *Socio-economic Planning Sciences,* Vol. 20, pp. 399-405, 1986.

[23] Harker, P. T., and I. Miller, "Global Effective Questioning in the Analytic Hierarchy Process," *European Journal of Operations Research,* Vol. 48, pp. 88-97, 1990.

[24] Huber, R. F., "Justification: Barrier to Competitive Manufacturing," *Production*, pp. 46-51, 1985.

[25] Imber, S. E. Wasil, Jr., B. Golden and C. Stagg, "Selecting a Survey Design to Monitor Recreational Angling for Striped Bass in the Chespeake Bay," *Socio-economic Planning Science,* Vol. 25, pp. 113-121, 1991.

[26] Jensen, R. E., "International Investment Risk Analysis: extensions for Multinational Corporation Capital Budgeting Models," *Mathematical Modeling International Journal,* Vol. 9, pp. 265-284, 1987.

[27] Kamath, R. R., and S. Z. Khaksari, "Real estate Investment: An Application of the Analytic Hierarchy Process," *The Journal of Financial and Strategic Decisions,* Vol. 4, pp. 73-100, 1991.

[28] Klammer, T., B. Koch, and N. Wilner, "Capital Budgeting Practices-A Survey of Corporate Use," *Journal of Management Accounting Research*, pp. 113-130, 1991.

[29] Korhonen, P., and S. Wallenius, "Using Qualitative Data in Multiobjective Linear Programming," *European Journal of Operations Research*, Vol. 48, pp. 81-87, 1990.

[30] Leung, L. C., W. A. Miller, and G. Okogboa, "Evaluation of Manufacturing Expert Systems, Framework and Model," *The Engineering Economist*, Vol. 37, pp. 293-311, 1992

[31] Liberatore, M. J., T. F. Monahan, and D. E. Stout, "A Framework for Integrating Capital Budgeting Analysis with Strategy," *The Engineering Economist,* Vol. 38, pp. 31-43, 1992.

[32] Lim, K. H., and S. R. Swenseth, "An Interactive Procedure for Reducing Problem Size in Large-Scale AHP Problems," *European Journal of Operations Research*, Vol. 67, pp. 64-74, 1993.

[33] Mensah, Y. M., and P. J. Miranti, "Capital Investment Analysis and Automated Manufacturing Systems: A Review and Synthesis," *Journal of Accounting Literature*, Vol. 8, pp. 181-207, 1989.

[34] Mukherjee, T. K., and G. U. Henderson, "The Capital Budgeting Process: Theory and Practice," *Interfaces*, Vol. 17, pp. 87-90, 1987.

[35] Noble, J. L., "A New Approach for Justifying Computer-Integrated Manufacturing," *The Journal of Cost Management*, pp. 14-19, 1990.

[36] Primrose, P. L., and R. Leonard, "Evaluating the Intangible Benefits of FMS by Use of Discounted Cash Flow Algorithms within a Comprehensive Computer Program," *Flexible Manufacturing Systems: Current Issues and Models*, Industrial Engineering and Management Press, Atlanta, 1986.

[37] Proctor, M. D., and J. R. Canada, "Past and Present Methods of Manufacturing Investment Evaluation: A Review of the Empirical and Theoretical Literature,"

The Engineering Economist, Vol. 38, pp. 45-58, 1992.

[38] Ridgley, M., "Selection of Water-Supply Projects under Drought," *J. Environ. Syst.*, Vol. 21, pp. 207-221, 1992.

[39] Ridgley, M. A., and F. R. Rijsberman, "Multicriterion Analysis and the Evaluation of Restoration Policies for a Rhine Estuary," *Socio-economic Planning Science,* Vol. 28, pp. 19-32, 1994.

[40] Saaty, T. L., and L. G. Vargas, The Logic of Priorities, Kluwer Nijhoff Publishing, Massachusetts, 1982.

[41] Saaty, T. L., "Axiomatic Foundation of the AHP," *Management Science,* Vol. 32, pp. 841-855, 1986.

[42] Saaty, T. L., "Concepts, Theory and Techniques: Rank Generation, Preservation and Reversal in the AHP," *Decision Sciences,* Vol. 18, pp. 157-177, 1987.

[43] Saaty, T. L. Decision Making for Leaders, Lifetime Learning Publications, Belmont, California, 1986.

[44] Saaty, T. L., "Exploring Optimization Through Hierarchies and Ratio Scales," *Socio-economic Planning Sciences,* Vol. 20, pp. 355-360, 1986.

[45] Saaty, T. L., "Homogeneity and Clustering in AHP Ensures the Validity of the Scale," *European Journal of Operations Research,* Vol. 72, pp. 598-601, 1994.

[46] Saaty, T. L., "How to make a decision: The Analytic Hierarchy Process," *European Journal of Operations Research,* Vol. 48, pp. 9-26, 1990.

[47] Shim, J. P., "Bibliographical Research on the Analytic Hierarchy Process," *Socio-economic Planning Sciences,* Vol. 23, pp. 161-167, 1989.

[48] Stewart, W. R., and E. R. Horowitz, "Environmental Factor Weighting at the Federal Energy Regulatory Commission," *Socio-economic Planning Sciences,* Vol. 25, pp. 123-132, 1991.

[49] Stout, D. E., M. J. Liberatore, and T. E. Monahan, "Decision Support Software for Capital Budgeting," *Management Accounting,* pp. 50-53, 1991.

[50] Sullivan, A. C., and K. V. Smith, "Capital Budgeting Practices for Factory Automation Projects," Working Paper No. 90-11-1, Center for the Management of Manufacturing Enterprises, The Krannert School of Management, Purdue, 1990.

[51] Sullivan, N. G., "Models IEs Can Use to Include Strategic, Non-monetary Factors in Automation Decision," *Industrial Engineering,* pp. 42-50, 1986.

[52] Sutardi, C. R. Bector, I. Goulter, and T. C. E. Cheng, "Multiobjective Water Resources Investment Planning under Budgetary and Socioeconomic Uncertainties," *IEEE Transactions on Engineering Management,* Vol. 41, pp. 50-68, 1994.

[53] Tarimcilar, M., and S. Z. Khaksari, "Capital Budgeting in Hospital Management Using the Analytic Hierarchy Process," *Socio-economic Planning Sciences,* Vol. 25, pp. 27-34, 1991.

[54] Tashfeen M. A., and L. C. Leung, "Multiattribute Product Life-Cycle Approach to Replacement Decisions: An Application of Saaty's System-With-Feedback Method," *The Engineering Economist,* Vol. 38, pp. 321-344, 1993.

[55] Thurston, D. L., "Multiattribute Utility Analysis in Design Management," *IEEE Trans. Eng. Management,* Vol. 37, pp. 297-301, 1990.

[56] Thurston, D. L., J. V. Carnahan, and T. Liu, "Optimization of Design Utility," Conference on Proc. ASME Design Theory and methodology, Vol. 31, pp. 173-180, 1991.

[57] Thurston, D. L., "A Formal Method for Subjective Design Evaluation with Multiple Attributes," *Research Engineering Design,* Vol. 3, No. 2, 1991.

[58] Thurston, D. L., and J. V. Carnahan, "Fuzzy Ratings and Utility Analysis in Preliminary Design Evaluation of Multiple Attributes," *ASME J. Mechanical Design,* Vol. 114, pp. 648-658, 1992.

[59] Thurston, D. L., "Concurrent Engineering in an Expert System," *IEEE Trans. Eng. Management,* Vol. 40, pp. 124-135, 1993.

[60] Vargas, L. G., "An Overview of the Analytic Hierarchy Process," *European Journal of Operations Research,* Vol. 48, pp. 2-8, 1990.

[61] Varney, M. S., W. G. Sullivan and J. K. Cochran, "Justification of Flexible Manufacturing Systems with the Analytic Hierarchy Process," *Proceedings of 1985 IIE Spring Conference,* Norcross, GA, 1985.

[62] Wabalickis, R. N., "Justification of FMS with the AHP," *Journal of Manufacturing Systems,* Vol. 7, pp. 175-182, 1987.

[63] Weber, S. F., "A Modified AHP for Automated Manufacturing Decisions," *Interfaces,* Vol. 23, No. 4, 1993.

[64] Willet, K., and R. Sharda, "Using the Analytic Hierarchy Process in Water Resources Planning: Selection of Flood Control Projects," *Socio-economic Planning Sciences,* Vol. 25, pp. 103-112, 1991.

[65] Wilner, N., B. Koch, and T. Klammer, "Justification of High Technology Capital Investments," *The Engineering Economist,* Vol. 37, No. 4, pp. 341-354, 1991.

[66] Zahedi, F., "A Simulation Study of Estimation Methods in the AHP," *Socio-economic Planning Sciences,* Vol. 20, pp. 347-354, 1986.

[67] Zahedi, F., "The Analytic Hierarchy Process-A Survey of the Method and Its Applications," *Interfaces,* Vol. 16, pp. 96-108, 1986.

[68] Zahir, M. S., "Incorporating the Uncertainty of Decision Judgements in the AHP," *European Journal of Operations Research,* Vol. 53, pp. 206-216, 1991.

APPENDIX

TABLE 1. Cash flow requirements (million $ measured in 1991 figures).

Project Duration in Years	Project								
	K1	K2	K3	K4	K5	S1	S2	S3	S4
1	16.25	6.09	20.15	21.25	26.32	6.03	2.77	14.43	6.76
2	36.85	25.96	94.81	90.59	154.81	11.80	5.43	27.80	39.77
3	8.13	13.83	127.04	48.26	150.55	1.36	0.63	80.62	38.67
4	22.12	9.94	80.88	4.61	47.22	0.00	0.00	91.41	12.13
5	80.13	50.71	16.94	0.00	8.13	0.00	0.00	74.67	2.09
6	38.37	49.32	5.45	0.00	0.00	0.00	0.00	39.83	0.00
7	3.55	15.47	0.00	0.00	0.00	0.00	0.00	17.66	0.00
8	0.00	2.66	0.00	0.00	0.00	0.00	0.00	16.73	0.00
9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.93	0.00
10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.68	0.00
11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.99	0.00
12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.65	0.00
13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.65	0.00
14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.65	0.00
15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.65	0.00

TABLE 2. Collectable revenue profiles (Million $ measured in 1991 figures).

Project Progress in Years	Project			
	S1	S2	S3	S4
1	0.00	0.00	0.00	0.00
2	0.00	28.43	1.56	0.00
3	0.00	68.02	3.12	0.00
4	187.10	84.60	4.68	0.00
5	187.10	84.60	7.61	0.00
6	187.10	84.60	10.48	0.00
7	187.10	84.60	13.41	0.00
8	187.10	84.60	16.34	0.00
9	187.10	84.60	19.21	0.00
10	187.10	84.60	22.14	0.00
11	187.10	84.60	25.07	0.00
12	187.10	84.60	27.04	0.00
13	187.10	84.60	28.07	0.00
14	187.10	84.60	29.13	0.00
15	187.10	84.60	30.15	0.00

TABLE 3. The AHP comparison matrices.

Main Mission

	Economical	Social	Political
Economical	1.00	0.25	0.33
Social	4.00	1.00	3.00
Political	3.00	0.33	1.00

Inconsistency ratio: 0.063

Economical Objectives

	NPV	Time to Com.	Size	Cus. Type
NPV	1.00	6.00	5.00	9.00
Time to Com.	0.17	1.00	2.00	3.00
Size	0.20	0.50	1.00	5.00
Cus. Type	0.11	0.33	0.20	1.00

Inconsistency ratio: 0.088

Social Objectives

	Env./Health	Time to Com.	Size	Cus. Type
Env./Health	1.00	7.00	9.90	3.00
Time to Com.	0.14	1.00	4.00	0.25
Size	0.10	0.25	1.00	0.17
Cus. Type	0.33	4.00	6.00	1.00

Inconsistency ratio: 0.063

TABLE 3. (Cont.)

Political Objectives

	NPV	Env./Health	Man. Pref.	Time to Com.	Size	Cus. Type
NPV	1.00	0.20	2.00	0.17	0.14	1.00
Env./Health	5.00	1.00	8.00	5.00	3.00	5.00
Man. Pref.	0.50	0.13	1.00	0.14	0.13	0.25
Time to Com.	6.00	0.20	7.00	1.00	0.25	2.00
Size	7.00	0.33	8.00	4.00	1.00	7.00
Cus. Type	1.00	0.20	4.00	0.50	0.14	1.00

Inconsistency ratio: 0.093

Customer Type-Economical Objectives

	Households	Industry	Pub. Organ.
Households	1.00	0.10	0.14
Industry	9.90	1.00	4.00
Pub. Organ.	7.00	0.25	1.00

Inconsistency ratio: 0.105

Customer Type-Social Objectives

	Households	Industry	Pub. Organ.
Households	1.00	7.00	8.00
Industry	0.14	1.00	0.50
Pub. Organ.	0.13	2.00	1.00

Inconsistency ratio: 0.066

Customer Type-Political Objectives

	Households	Industry	Pub. Organ.
Households	1.00	8.00	9.90
Industry	0.13	1.00	2.00
Pub. Organ.	0.10	0.50	1.00

Inconsistency ratio: 0.022

TABLE 3. (Cont.)

NPV Economical

	K1	K2	K3	K4	K5	S1	S2	S3	S4	eigenvector
K1	1.00	4.00	4.00	6.00	1.62	0.50	5.71	1.42	9.90	0.1952
K2	0.25	1.00	0.25	1.87	0.36	0.10	0.45	0.14	1.24	0.0313
K3	0.25	4.00	1.00	5.00	1.35	0.20	2.26	0.65	5.66	0.0989
K4	0.17	0.54	0.20	1.00	0.30	0.10	0.33	0.10	1.60	0.0242
K5	0.62	2.75	0.74	3.33	1.00	0.50	1.50	0.50	6.00	0.0982
S1	2.00	9.90	5.00	9.90	2.00	1.00	6.00	4.00	9.99	0.3157
S2	0.18	2.22	0.44	3.03	0.67	0.17	1.00	0.20	1.22	0.0482
S3	0.70	7.14	1.54	9.90	2.00	0.25	5.00	1.00	6.00	0.1658
S4	0.10	0.81	0.18	0.63	0.17	0.10	0.82	0.17	1.00	0.0227

Inconsistency Ratio = 0.11

NPV Political

	K1	K2	K3	K4	K5	S1	S2	S3	S4	eigenvector
K1	1.00	1.00	1.00	1.75	0.21	0.36	0.71	4.00	3.00	0.0837
K2	1.00	1.00	0.33	0.44	0.10	0.19	0.24	1.00	1.20	0.0365
K3	1.00	3.00	1.00	0.88	0.21	0.21	0.71	2.00	5.50	0.0772
K4	0.57	2.28	1.14	1.00	0.24	0.57	0.81	2.28	7.50	0.0881
K5	4.76	9.90	4.76	4.18	1.00	2.00	3.50	9.52	9.99	0.3379
S1	2.78	5.26	4.76	1.75	0.50	1.00	1.37	4.00	9.99	0.1908
S2	1.41	4.23	1.41	1.24	0.29	0.73	1.00	2.82	7.76	0.1174
S3	0.25	1.00	0.50	0.44	0.17	0.25	0.35	1.00	6.00	0.0469
S4	0.33	0.83	0.18	0.13	0.10	0.10	0.33	0.17	1.00	0.0216

Inconsistency Ratio = 0.11

TABLE 3. (Cont.)

Time to Commission

	K1	K2	K3	K4	K5	S1	S2	S3	S4	eigenvector
K1	1.00	1.00	1.00	0.14	0.15	0.15	0.33	8.00	1.40	0.0488
K2	1.00	1.00	0.33	0.13	0.10	0.12	0.25	4.00	0.91	0.0321
K3	1.00	3.00	1.00	0.25	0.20	0.26	0.50	9.80	1.95	0.0699
K4	7.00	8.00	4.00	1.00	1.60	1.00	2.16	9.90	9.00	0.2518
K5	6.67	5.00	3.00	0.63	1.00	1.50	0.75	9.90	6.51	0.1926
S1	6.67	8.33	3.85	1.00	0.67	1.00	3.00	9.00	4.00	0.2203
S2	3.00	4.00	2.00	0.46	1.33	0.33	1.00	7.00	3.00	0.1264
S3	0.13	0.25	0.10	0.10	0.10	0.11	0.14	1.00	0.13	0.0138
S4	0.71	1.10	0.51	0.11	0.15	0.25	0.33	8.00	1.00	0.0444

Inconsistency Ratio = 0.11

Customer Type - Households

	K1	K2	K3	K4	K5	S1	S2	S3	S4	eigenvector
K1	1.00	0.75	0.55	5.00	4.00	2.29	5.66	1.55	9.90	0.1724
K2	1.33	1.00	0.55	4.00	5.00	0.60	5.00	1.00	9.90	0.1529
K3	1.82	1.82	1.00	9.00	9.00	1.00	9.00	1.80	9.90	0.2578
K4	0.20	0.25	0.11	1.00	0.95	0.60	1.00	0.30	5.00	0.0431
K5	0.25	0.20	0.11	1.05	1.00	1.20	1.60	0.40	4.50	0.0531
S1	0.44	1.67	1.00	1.67	0.83	1.00	5.00	0.33	9.00	0.1218
S2	0.18	0.20	0.11	1.00	0.63	0.20	1.00	0.20	5.00	0.0343
S3	0.65	1.00	0.56	3.33	2.50	3.00	5.00	1.00	9.00	0.1510
S4	0.10	0.10	0.10	0.20	0.22	0.11	0.20	0.11	1.00	0.0136

Inconsistency Ratio = 0.11

TABLE 3. (Cont.)

Customer Type - Public/Private Industry Sector

	K1	K2	K3	K4	K5	S1	S2	S3	S4	eigenvector
K1	1.00	0.20	0.75	2.38	1.50	1.50	3.33	0.55	1.60	0.0913
K2	5.00	1.00	5.00	7.00	4.00	5.00	9.90	1.65	6.00	0.3465
K3	1.33	0.20	1.00	4.00	2.00	1.50	6.00	1.96	2.00	0.1417
K4	0.42	0.14	0.25	1.00	0.50	1.00	2.00	0.40	2.00	0.0543
K5	0.67	0.25	0.50	2.00	1.00	2.70	4.20	1.20	0.70	0.0934
S1	0.67	0.20	0.67	1.00	0.37	1.00	2.00	0.50	0.33	0.0525
S2	0.30	0.10	0.17	0.50	0.24	0.50	1.00	0.25	0.50	0.0268
S3	1.83	0.61	0.51	2.50	0.83	2.00	4.00	1.00	2.00	0.1206
S4	0.63	0.17	0.50	0.50	1.43	3.00	2.00	0.50	1.00	0.0729

Inconsistency Ratio = 0.11

Customer Type - Public Organizations

	K1	K2	K3	K4	K5	S1	S2	S3	S4	eigenvector
K1	1.00	2.50	6.67	3.00	6.25	0.90	3.46	1.83	9.99	0.2412
K2	0.40	1.00	5.00	1.72	3.57	0.36	1.24	1.79	7.69	0.1379
K3	0.15	0.20	1.00	0.45	0.33	0.14	0.38	0.36	1.54	0.0313
K4	0.33	0.58	2.22	1.00	4.00	0.61	1.15	0.61	9.00	0.1075
K5	0.16	0.28	3.00	0.25	1.00	0.85	0.40	0.35	1.59	0.0570
S1	1.11	2.78	7.14	1.64	1.18	1.00	5.00	1.27	5.00	0.2045
S2	0.29	0.81	2.63	0.87	2.50	0.20	1.00	0.73	5.00	0.0833
S3	0.55	0.56	2.78	1.64	2.86	0.79	1.37	1.00	4.93	0.1171
S4	0.10	0.13	0.65	0.11	0.63	0.11	0.20	0.20	1.00	0.0202

Inconsistency Ratio = 0.10

Environmental/ Health Benefits

	K1	K2	K3	K4	K5	S1	S2	S3	S4	eigenvector
K1	1.00	0.40	0.37	2.00	0.28	1.50	3.79	3.73	1.12	0.0811
K2	2.50	1.00	1.12	5.00	0.75	2.00	9.99	9.99	3.38	0.2045
K3	2.73	0.89	1.00	7.00	0.81	2.00	6.67	8.07	2.92	0.1959
K4	0.50	0.20	0.14	1.00	0.14	0.66	4.00	2.50	0.87	0.0479
K5	3.52	1.33	1.23	7.00	1.00	3.50	9.90	9.90	2.50	0.2418
S1	0.67	0.50	0.50	1.52	0.29	1.00	5.00	3.00	0.20	0.0703
S2	0.26	0.10	0.15	0.25	0.10	0.20	1.00	0.25	0.13	0.0173
S3	0.27	0.10	0.12	0.40	0.10	0.33	4.00	1.00	0.17	0.0269
S4	0.89	0.30	0.34	1.15	0.40	5.00	8.00	6.00	1.00	0.1143

Inconsistency Ratio = 0.11

TABLE 3. (Cont.)

Project Size

	K1	K2	K3	K4	K5	S1	S2	S3	S4	eigenvector
K1	1.00	1.50	4.00	8.00	1.11	1.40	9.90	0.93	2.27	0.1854
K2	0.67	1.00	1.19	4.00	0.56	0.45	2.21	0.35	0.65	0.0798
K3	0.25	0.84	1.00	1.84	0.28	0.15	2.47	0.32	0.57	0.0491
K4	0.13	0.25	0.54	1.00	0.20	0.20	4.95	0.25	1.33	0.0440
K5	0.90	1.79	3.60	5.00	1.00	2.50	9.90	2.50	5.50	0.2338
S1	0.71	2.22	6.67	5.00	0.40	1.00	5.16	0.38	1.42	0.1378
S2	0.10	0.45	0.40	0.20	0.10	0.19	1.00	0.10	0.31	0.0202
S3	1.08	2.86	3.13	4.00	0.40	2.63	9.90	1.00	2.84	0.1813
S4	0.44	1.54	1.75	0.75	0.18	0.70	3.23	0.35	1.00	0.0685

Inconsistency Ratio = 0.11

Managerial Preferences

	K1	K2	K3	K4	K5	S1	S2	S3	S4	eigenvector
K1	1.00	0.40	0.36	0.98	1.36	1.62	0.97	0.60	1.23	0.0875
K2	2.50	1.00	0.80	1.87	2.00	0.90	5.00	1.78	1.81	0.1859
K3	2.81	1.25	1.00	2.75	1.72	1.00	1.22	1.28	0.65	0.1500
K4	1.02	0.53	0.36	1.00	1.39	1.65	0.99	0.61	1.26	0.0916
K5	0.73	0.50	0.58	0.72	1.00	2.00	1.00	1.00	1.00	0.0899
S1	0.62	1.11	1.00	0.61	0.50	1.00	0.33	0.79	0.49	0.0783
S2	1.03	0.20	0.82	1.01	1.00	3.00	1.00	1.00	1.00	0.1014
S3	1.67	0.56	0.78	1.64	1.00	1.27	1.00	1.00	1.63	0.1130
S4	0.81	0.55	1.54	0.79	1.00	2.04	1.00	0.61	1.00	0.1024

Inconsistency Ratio = 0.11

TABLE 4. Results of the LP model.

	CR	P	O	I	E	COM
1991	9.17	0.00	9.17	0.37	18.24	3.20
1992	40.10	0.00	49.27	2.34	42.92	3.00
1993	51.07	0.00	100.33	5.98	24.76	2.75
1994	42.88	0.00	143.21	9.74	-4.17	2.53
1995	68.70	0.71	211.20	14.18	54.40	2.19
1996	65.10	3.79	272.52	19.35	58.80	1.86
1997	37.23	7.72	302.03	22.98	6.30	1.68
1998	37.60	11.02	328.62	25.23	13.01	1.49
1999	53.12	16.30	365.44	27.76	60.77	1.23
2000	38.85	21.31	382.98	29.94	31.98	1.03
2001	25.38	24.17	384.19	30.69	-2.17	0.90
2002	28.57	27.07	385.70	30.80	8.97	0.76
2003	38.24	31.15	392.79	31.14	42.93	0.57
2004	16.41	34.14	375.06	30.71	-26.51	0.49
2005	1.42	36.09	340.39	28.62	-82.19	0.48

TABLE 5. Cost outlay of the solution given in Table 4.

Years	Project								
	K1	K2	K3	K4	K5	S1	S2	S3	S4
1991	0.00	0.00	20.15	0.00	0.00	0.00	2.77	0.00	0.00
1992	0.00	0.00	94.81	0.00	0.00	0.00	5.43	0.00	0.00
1993	0.00	0.00	127.04	0.00	0.00	0.00	0.63	0.00	0.00
1994	0.00	0.00	80.88	0.00	26.32	0.00	0.00	0.00	0.00
1995	0.00	0.00	16.94	0.00	154.81	0.00	0.00	0.00	0.00
1996	0.00	0.00	5.45	0.00	150.55	0.00	0.00	0.00	6.76
1997	0.00	6.09	0.00	0.00	47.22	0.00	0.00	0.00	39.77
1998	0.00	25.96	0.00	21.25	8.13	0.00	0.00	0.00	38.67
1999	16.25	13.83	0.00	90.59	0.00	0.00	0.00	0.00	12.13
2000	36.85	9.94	0.00	48.26	0.00	0.00	0.00	0.00	2.09
2001	8.13	50.71	0.00	4.61	0.00	0.00	0.00	0.00	0.00
2002	22.12	49.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2003	80.13	15.47	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2004	38.37	2.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	3.55	0.00	0.00	2.09	0.00	0.00	0.00	0.00	0.00

TABLE 6. Revenue outlay of the solution given in Table 4.

Years	Project			
	S1	S2	S3	S4
1991	0.00	0.00	0.00	0.00
1992	0.00	28.43	0.00	0.00
1993	0.00	68.02	0.00	0.00
1994	0.00	84.60	0.00	0.00
1995	0.00	84.60	0.00	0.00
1996	0.00	84.60	0.00	0.00
1997	0.00	84.60	0.00	0.00
1998	0.00	84.60	0.00	0.00
1999	0.00	84.60	0.00	0.00
2000	0.00	84.60	0.00	0.00
2001	0.00	84.60	0.00	0.00
2002	0.00	84.60	0.00	0.00
2003	0.00	84.60	0.00	0.00
2004	0.00	84.60	0.00	0.00
2005	0.00	84.60	0.00	0.00

BIOGRAPHICAL SKETCHES

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