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Strategic Planning for Information Infrastructure Development Using a Multiple Objective Decision-Making Model

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Ⅰ. Introduction

Modern organizations in general have extreme pressures to survive in an environment of rapidly changing expectations, exploding global information needs and increased financial demands. Therefore, it is imperative that such organizations seeking information infrastructure development address the growing requirements for effective strategic planning for information infrastructure development.

However, organizations must also recognize that they have made significant information technology investments and progress. In fact, many of the challenges confronting to organizations are the result of institutional activity and growth. Clearly, the organizations now have been taking a proactive stance in the development of the infrastructure required to overcome the challenges of the technological age. Therefore, a systematic model development and evaluation of a strategic planning for developing an information infrastructure in an organization is essential to address directions for information technology, frameworks for future

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information infrastructure development, and actions for the goal attainments.

One of the important activities of the strategic planning for information infrastructure development in an organization is the effective planning for resource allocations. The numerous factors make decision-making process in the strategic planning difficult to plan and implement, since many tangible and intangible factors need to be involved in the decision-making process of a large-scale resource allocation (Bacon, 1992; Davies, 1994). However, a number of objectives to attain require the use of a multiple objective decision-making (MODM) approach for an information infrastructure development (Gross and Talavage, 1979) and other production and operations planning environments (Khouja and Conrad, 1995; Winkofsky, Baker, and Sweeney, 1981).

Information technology has become an increasingly integral and important function in an organization. Therefore, it is significant because the organization is aware of the vision for and commitment to information technology as a primary resource for achieving the organization's objectives.

The purpose of this paper is to develop an MODM model which aids in supporting the resources allocation decision-making pertinent to strategic planning for information infrastructure development. The proposed MODM model is developed, based on the data obtained from the organization being studied. The MODM model reinforces the organization's ongoing strategic planning policy to position the organization to respond to new innovation and competitiveness, while meeting defined organizational constraints.

II. Literature Review

Multiple objective decision-making (MODM) is a mathematical model for a decision-making process which allows a decision-maker to achieve multiple goals. One of the most widely used MODM model is goal programming (GP). GP model has been applied to many of studies, such as assignment model (Hemaida and Kwak, 1994), dynamic programming model (Sutardi, Bector, and Goulter, 1995), game theory model (Cook, 1976), heuristic model (Chun, 1996), Markov analysis model (Zanakis and Maret, 1981), network model (Premachandra, 1993), and simulation model (Rees, Clayton, and Taylor, 1985).

Despite its advantages, one major drawback of GP is that the decision-makers must specify their goals and priorities in advance. The concept of non-dominated (non-inferior) solutions for non-commensurable goals cannot make an improvement of one goal without degrading other conflicting goals. Cohon (1978) defined a non-dominated solution in the following manner: a feasible solution to a multiple objective programming problem is non-inferior, if no other feasible solutions yield an improvement in one objective, without making a trade-off of another objective. GP, regardless of the weighting structures and the goals (one-sided or two-sided), can lead to inferior (dominated or inefficient), sub-optimal solutions. These solutions are not necessarily the optimal ones available to the decision-maker. Therefore, it is called a satisfying solution.

Many of the methodological improvements used in weighted GP and preemptive GP models can be found in applications of these models. The preemptive version of GP has received harsh criticisms in numerous studies because of its ordinal weighting scheme in determining the relative importance of multiple goals. The main strength of preemptive GP is that the weighting scheme allows the decision-maker to prioritize goals on an ordinal-scale basis. In practice, it may be easier for the decision-maker to prioritize multiple objectives, rather than specifying numerical weights. However, inappropriate use of this prioritizing scheme may cause critical effects to the solution process.

The methods of improving GP model formulation include AHP for relative importance of goals(Saaty, 1980), conjoint analysis for determining relative weighting or goal constraint parameter estimation (Green and Srinivasan, 1990), input-output analysis for technical parameter estimation (Schniederjans and Markland, 1986), logarithmic transformations of goals (Singh, 1983), regression analysis for determining relative importance or weights (Charnes, Cooper, and Sueyoshi, 1988), and scaling or normalizing of goal constraint parameters (Gass, 1987).

The use of GP in resource allocation has generally been limited to the financial policies(Chen, 1988; and Schniederjans and Hoffman, 1992), rather than the technological considerations and other strategic policies of an organization.

III. Problem Statement

Since 1994, the organization being studied has spent $3.5 million to buy 1,700 microcomputers. A 3-year, $3 million information infrastructure initiative project is initiated to improve computing and network access. A $3.5 million organization-wide data mining project is approved and will soon provide access to an extensive on-line catalog and numerous data bases. Information technology services expanded its support for computing and data connectivity, including a new telecommunications system, an expanded organization-wide fiber optic backbone and Ethernet service, and an enhanced general-purpose computer system. In the last three years, the organization has invested $10 million in major technology enhancements and another $9 million in supporting services for that technology.

This special project for an integrated information infrastructure development is intended to address the dramatic growth in information technology use, to foster continued innovation and the adoption of new technologies, and to expand information technology foundation. Thus, the organization's information technology investment strategies throughout the 1990s have been developed.

Based on the above data, the goal priorities are presented below and the relevant information about resource allocation illustrated.

Priority 1: Allocate resources adequately, but, not to exceed the entire resources, and not to exceed the available resource levels for each location in each year

Priority 2: Provide an appropriate information infrastructure for technology develop -ment (project 1)

Priority 3: Provide end-users with currently available technology for effective utilization (project 2)

Priority 4: Use available technology resource to provide better and to attract clients to the organization (project 3)

Priority 5: Develop procedures for cost containment and improving cost effectiveness of technology expenditures(project 4)

Priority 6: Expand shared computing resources and support services (project 5)

Priority 7: Improve end-user services by expanding voice response technology or online access to support systems(project 6)

Priority 8: Select the optimal network design among four alternatives

IV. Model Development

4.1 MODM Model

The generalized MODM model can be stated in the following form.

Minimize:

$$Z = \sum_{g=1}^{G} \sum_{i=1}^{m} W_{gi} P_g (d^-_i - d^+_i)$$

subject to:

$$\sum_{j=1}^{n} a_{ij}\chi_j + d^-_i - d^+_i = b_i \ ; \ i = 1, 2, \cdots, m$$

and

$$\chi_j = \begin{cases} 0 \text{ otherwise} \\ 1 \text{ if selected} \end{cases} \ ; \ j = 1, 2, \cdots, n$$

$$d^-_i, d^+_i \geq 0$$

where

Z = the sum of weighted deviational variables

W_{gi}= the relative weight assigned to g priority level for the i^{th} constraints

P_g = the g^{th}-level preemptive priority factor

a_{ij} = coefficients of decision variable j in constraint i

b_i = the right-hand-side value for each goal i (i.e., required level of the i^{th}-goal achievement)

χ_i = the j^{th} decision variables χ

d^-_i, d^+_i = deviational variables representing under - and over-achievement of the i^{th} goal

In this paper, a specific MODM (particularly GP) model was formulated based on the following information. The model is presented below.

4.1.1 Decision Variables

There are two different types of decision variables for this paper.

ξ_j = decision variables for six possible projects to which available amounts can be allocated over three-year period, (j = 1, 2,...,6)

Ψ_j = decision variables for different types of network alternatives to be selected with various budgetary and resource constraints, (j = 1, 2, 3, 4) where

$$\xi_j,\ \Psi_j = \begin{cases} 0 & \text{otherwise} \\ 1 & \text{if the } j^{th} \text{ project is selected} \end{cases}$$

4.1.2 Constraints

The GP model has seven system constraints and seventeen goal constraints. Since system constraints do not have deviational variables, deviational variables will not be appeared in the objective function. Table 1 presents the necessary information for constructing the GP model constraints.

TABLE 1. Available Resource and Project

Time	Location	Available Project Resource (%)						
		1(ξ_1)	2(ξ_2)	3(ξ_3)	4(ξ_4)	5(ξ_5)	6(ξ_6)	
T_1	L_1	3.3	3.7	1.8	5.0	0.0	0.7	
	L_2	10.0	1.3	4.2	1.7	0.0	0.0	
T_2	L_1	3.3	4.1	2.0	0.5	3.3	1.8	
	L_2	13.3	1.7	1.7	1.7	0.0	0.6	
T_3	L_1	3.3	4.0	2.3	2.3	1.7	0.4	
	L_2	16.3	0.0	1.0	3.0	0.0	0.0	
	Total	49.5	14.8	13.0	14.2	5.0	3.5	100%

T: time period, L: location

System Constraint 1: Select one network design.

$$\Psi_1 + \Psi_2 + \Psi_3 + \Psi_4 = 1 \quad (1)$$

System Constraint 2: Select (j = 1) one project or not (j = 0)and select five projects.

$$\xi_1 = 1 \quad (2)$$
$$\xi_2 = 1 \quad (3)$$
$$\xi_3 = 1 \quad (4)$$
$$\xi_4 = 1 \quad (5)$$
$$\xi_5 = 1 \quad (6)$$
$$\xi_6 = 1 \quad (7)$$

Goal Constraints: there are total seventeen goal constraints

$$49.5\,\xi_1 + 14.8\,\xi_2 + 13.0\,\xi_3 + 14.2\,\xi_4 + 5.0\,\xi_5 + 3.5\,\xi_6 - d^+_1 = 100 \quad (8)$$
$$3.3\,\xi_1 + 3.7\,\xi_2 + 1.8\,\xi_3 + 5.0\,\xi_4 + 0.7\,\xi_6 - d^+_2 = 14.5 \quad (9)$$
$$10.0\,\xi_1 + 1.3\,\xi_2 + 4.2\,\xi_3 + 1.7\,\xi_4 - d^+_3 = 17.2 \quad (10)$$
$$3.3\,\xi_1 + 4.2\,\xi_2 + 1.7\,\xi_3 + 0.3\,\xi_4 + 3.3\,\xi_5 + 1.8\,\xi_6 - d^+_4 = 14.8 \quad (11)$$
$$13.3\,\xi_1 + 1.7\,\xi_2 + 1.7\,\xi_3 + 1.7\,\xi_4 + 0.5\,\xi_6 - d^+_5 = 14.0 \quad (12)$$
$$3.3\,\xi_1 + 4.0\,\xi_2 + 2.3\,\xi_3 + 2.3\,\xi_4 + 1.7\,\xi_5 + 0.3\,\xi_6 - d^+_6 = 14.0 \quad (13)$$
$$16.3\,\xi_1 + 1.0\,\xi_3 + 3.0\,\xi_4 - d^+_7 = 20.7 \quad (14)$$
$$\xi_1 + d^-_8 - d^+_8 = 1 \quad (15)$$
$$\xi_2 + d^-_9 - d^+_9 = 1 \quad (16)$$
$$\xi_3 + d^-_{10} - d^+_{10} = 1 \quad (17)$$
$$\xi_4 + d^-_{11} - d^+_{11} = 1 \quad (18)$$
$$\xi_5 + d^-_{12} - d^+_{12} = 1 \quad (19)$$
$$\xi_6 + d^-_{13} - d^+_{13} = 1 \quad (20)$$
$$\Psi_1 + d^-_{14} - d^+_{14} = 1 \quad (21)$$
$$\Psi_2 + d^-_{15} - d^+_{15} = 1 \quad (22)$$
$$\Psi_3 + d^-_{16} - d^+_{16} = 1 \quad (23)$$
$$\Psi_4 + d^-_{17} - d^+_{17} = 1 \quad (24)$$

and

$$\xi, \Psi = \begin{cases} 0 \text{ otherwise} \\ 1 \text{ if selected} \end{cases}$$

$$d^+, d^- \geq 0$$

4.1.3 Objective Function

$$\text{Minimize } Z = P_1 \left(\sum_{i=1}^{7} d^+_i \right) + P_2(d^-_8) + P_3(d^-_9) + P_4(d^-_{10})$$

$$+ P_5(d^-_{11}) + P_6(d^-_{12}) + P_7(d^-_{13}) + P_8 \left(\sum_{i=14}^{17} d^-_i \right)$$

Thus, the GP problem is to minimize the value of the objective function subject to goal constraints (8)-(24), satisfying the preemptive priority rules.

V. Model Solution and Sensitivity Analysis

5.1 Model Solution

The zero-one GP model was solved using a software, Micro Manager(Lee and Shim, 1992). The solution was determined after 11 iterations. The possible solutions are enumerated at the first goal priority level and reduced at each subsequent goal priority level until overall goal satisfaction is no longer possible. The computer solution yields the following results as shown in Table 2.

Priority 1 is of allocating resources adequately. This priority is fully satisfied, since $P_1 = 0$. The negative deviational variable is zero ($d^+_1 = 0$, $d^+_2 = 0$, $d^+_3 = 0$, $d^+_4 = 0$, $d^+_5 = 0$, $d^+_6 = 0$, and $d^+_7 = 0$,). But some negative deviational variables are not zero ($d^-_1 = 3.5$, $d^-_2 = 0.7$, $d^-_4 = 1.8$, $d^-_5 = 0.6$, and $d^-_6 = 0.4$). This means that (1) 3.5% of the overall resource allocation is saved; (2) 0.7% of total resource in the location 1 (L_1) in time period 1 (T_1) is saved; (3) 1.8% of total budget in the location 1 (L_1) in time period 2 (T_2) is saved; (4) 0.6% of total resource in the location 1 (L_1) in time period 2 (T_2) is saved; and (5) 0.4% total resource in the location 1 (L_1) in time period 3 (T_3) is saved.

TABLE 2. Solution Results

Decision Variable	Deviational* Variable	Goal Priority	Goal Achievement
ξ_1 = 1	d^-_1 = 3.5	P_1 = 0.000	Fully achieved
ξ_2 = 1	d^-_2 = 0.7	P_2 = 0.000	Fully achieved
ξ_3 = 1	d^-_4 = 1.8	P_3 = 0.000	Fully achieved
ξ_4 = 1	d^-_5 = 0.6	P_4 = 0.000	Fully achieved
ξ_5 = 1	d^-_6 = 0.4	P_5 = 0.000	Fully achieved
ξ_6 = 0	d^-_{13} = 1.0	P_6 = 0.000	Fully achieved
Ψ_1 = 1	d^-_{15} = 1.0	P_7 = 0.000	Fully achieved
Ψ_2 = 0	d^-_{16} = 1.0	P_8 = 0.000	Fully achieved
Ψ_3 = 0	d^-_{17} = 1.0		
Ψ_4 = 0			

* All other deviational variables are zero.

Priority 2 to Priority 7 are of either selecting a project or not. Since all goal priority levels from P_2 to P_7 are zero ($P_2 = 0$, $P_3 = 0$, $P_4 = 0$, $P_5 = 0$, $P_6 = 0$, and $P_7 = 0$), the priority 2 to priority 7 are fully satisfied. There are six decision variables for implementing projects (ξ_1 to ξ_6). Among them, project 1 to project 5 are selected to be implemented ($\xi_1 = 1$, $\xi_2 = 1$, $\xi_3 = 1$, $\xi_4 = 1$, and $\xi_5 = 1$). All related deviational variables are zero (d^+_8 to d^+_{12} are zero and d^-_8 to d^-_{12} are zero). However, project 6 is not selected ($\xi_6 = 0$), since the negative deviational variable of project 6 is not zero ($d^-_{12} = 1$).

Priority 8 of selecting the optimal network design among four alternatives is fully satisfied, since $P_8 = 0$. There are four decision variables for network design alternatives (Ψ_1 to Ψ_4). Alternative network connection 1 ($\Psi_1 = 1$) is selected as the best alternative for network connection of infrastructure development, and the related deviational variable is zero ($d^-_{14} = 0$). Network connections 2, 3, and 4 are not selected ($\Psi_1 = 0$, $\Psi_2 = 0$, $\Psi_3 = 0$, and $\Psi_4 = 0$), along with all related deviational variables being not zero ($d^-_{15} = 0$, $d^-_{16} = 0$, and $d^-_{17} = 0$).

5.2 Sensitivity Analysis

A sensitivity analysis will have a scenario using "what if" type processes about the change of the order in the goal priority which is originally identified by the organization's decision-makers. Sensitivity analysis was performed in terms of priority changes. Initial selection and goal level attainment are supported by the MODM results shown in Table 3.

TABLE 3. Solution Results for New Scenario

Decision Variable	Deviational* Variable	Goal Priority	Goal Achievement
$\xi_1 = 1$	$d^-_9 = 21.5$	$P_1 = 0.000$	Fully achieved
$\xi_2 = 1$	$d^-_{10} = 2.5$	$P_2 = 0.000$	Fully achieved
$\xi_3 = 0$	$d^-_{11} = 4.2$	$P_3 = 0.000$	Fully achieved
$\xi_4 = 1$	$d^-_{12} = 7.1$		
$\xi_5 = 0$	$d^-_{13} = 2.3$		
$\xi_6 = 0$	$d^-_{14} = 4.4$		
$\Psi_1 = 1$	$d^-_{15} = 1.0$		
$\Psi_2 = 0$	$d^-_{18} = 1.0$		
$\Psi_3 = 0$	$d^-_{20} = 1.0$		
$\Psi_4 = 0$	$d^-_{21} = 1.0$		
	$d^-_{23} = 1.0$		
	$d^-_{24} = 1.0$		
	$d^-_{25} = 1.0$		

* All other deviational variables are zero.

There are one possible scenario given the following priority changes. The original priority levels between project 1 and project 6 have been set differently. In new scenario, the original goal priority level from P_2 to P_7 has been changed. The original P1 remains as P_1 (that is, $P_1 \rightarrow P_1$). All six priority levels for project selection are changed as: $P_2 \rightarrow P_2$, $P_3 \rightarrow P_3$, $P_4 \rightarrow P_2$, $P_5 \rightarrow P_2$, $P_6 \rightarrow P_2$, and $P_7 \rightarrow P_2$. In addition, group decision-makers want to select three among six projects. Goal priority level of network designs has been changed as follows: $P_8 \rightarrow P_3$.

The prioritized goal achievements in the above scenario is presented in Table 3, along with their solution results. As shown in this table, there are six decision variables for implementing projects (ξ_1 to ξ_6). Among them, project 1, 2, and 4 are selected to be implemented (ξ_1 = 1, ξ_2 = 1, and ξ_4 = 1). All related deviational variables are zero (d^+_8, d^+_9, and d^+_{11} are zero and d^-_8, d^-_9, and d^-_{11} are zero). However, project 3, 5, and 6 are not selected (ξ_3 = 0, ξ_5 = 0, and ξ_6 = 0), since the negative deviational variable of projects 3, 5, and 6 are one (d^-_{10} = 1, d^-_{11} = 1, and d^-_{12} = 1).

VI. Concluding Remarks

A multiple objective decision-making (MODM) model, specifically goal programming (GP) model was developed and analyzed to aid the organization's resource allocation in connection with strategic planning for information infrastructure development. Currently, the organization is utilizing all these strategies.

Demands and expectations for information technology resources, support and services have never been greater within the organization. Moreover, there is no singular solution, but most experts agree progress depends upon institution-wide attention, new investments and finding strategies, resource reallocation and greater cooperative efforts. The task groups will also work more closely with other service departments and support personnel to consolidate telecommunications and information infrastructure network project planning.

The information technology services is restructured and its role broadened to promote new services in addition to infrastructure and basic computing tools. Several new units are formed to improve the technological support for the end-users who use computing, to provide more assistance to managers, and to establish partnerships within the organization to seek external alliances.

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< 국문초록 >

다목표 의사결정 모형을 이용한 전략적 정보 인프라 개발 계획

이 창 원

본 연구는 특정 조직의 정보 인프라 개발을 위한 전략적 계획을 수립하기 위해 의사결정 지원 도구로서 다수 목표 의사결정 모형 (Multiple Objective Decision-Making Model: MODM), 구체적으로는 목표 계획법 (Goal Programming: GP)의 응용을 제시하고 있다. 연구대상 조직은 3년 동안의 정보 인프라 개발 프로젝트를 추진하고 있다. 이러한 특별 프로젝트는 조직 전체에 궁극적인 통합 정보 기술 서어비스를 제공하기 위하여 최고 의사결정자의 전략적 계획 측면에서 추진되고 있다. 본 연구는 총 8개의 목표가 수립되었고 현 조직 환경하에서 이들 목표들에 대한 우선 순위가 설정되었다. Micro Manager가 본 연구 모형의 실행을 위하여 활용되었고 분석결과 6개의 정보 인프라 프로젝트 중 첫 5개가 실행되기 위하여 선택되어 졌으며 4개의 네트웍 대안 중에서 첫 번째 대안이 최적 대안으로 선택되었다. 초기 설정 목표들에 대한 우선 순위를 변경시킴으로써 연구 모형의 가변성을 검토하기 위해 민감도 분석이 실행되었다. 변경된 목표와 우선 순위하에서는 6개의 정보 인프라 프로젝트 중 3개만이 실행을 위하여 선택되었고 네트웍 대안은 첫번째 대안이 역시 최적 대안으로 선택되었다. 본 연구 모형은 다수의 서로 상충하는 목표를 가지는 조직 및 이와 유사한 경영환경에 직면해 있는 전략적 의사결정 수립에 효과적인 방안을 제시할 것이다.