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Business process reengineering for health-care system using multicriteria mathematical programming

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Abstract

This paper presents an application of multicriteria mathematical programming (MCMP) as an aid to strategic planning for business process infrastructure development in an organization. The MCMP model is formulated and evaluated to address the strategic planning in business process infrastructure development. The goal levels are identified and prioritized using the analytic hierarchy process. The model result is analyzed and the solution implication is evaluated to improve the model applicability. The MCMP model application reinforces the strategic planning of the organization's business process infrastructure development and other production and operations planning settings. © 2002 Published by Elsevier Science B.V.

Keywords: Multicriteria mathematical programming; Goal programming; Health-care infrastructure; Business process reengineering

1. Introduction

Many health-care systems face extreme pressures to survive in an environment of rapidly changing expectations, increased financial demands, efficient operations, appropriate resource utilization, and global information needs. It is imperative that the health-care systems seeking business process reengineering (BPR) address the growing requirements for effective strategic planning for business process infrastructure development (Stoddard and Jarvenpaa, 1995; Sarker and Lee, 1999; Peppard, 1996).

However, health-care systems must also recognize that they have made significant information technology investments and progress. In fact, many of the challenges confronting to health-care systems are the result of institutional activity and growth. Clearly, the health-care systems have taking a proactive stance in the development of the infrastructure required to overcome the challenges of the information and knowledge age. Therefore, a systematic model development and evaluation of a strategic planning for developing a business process

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infrastructure is essential to address directions for BPR planning, frameworks for future business process infrastructure development, and actions for the goal attainments.

One of the important activities of the strategic planning for business process infrastructure development in a health-care system is the effective planning for scarce resource allocations. The numerous factors make decision-making process in the strategic planning difficult to plan and implement. Many tangible and intangible factors need to be involved in the decision-making process of a large-scale business process infrastructure development. When the decision-making involves a number of objectives to attain, the use of a multicriteria mathematical programming (MCMP) approach facilitates the decision-making process, such as in acquisition analysis (Schniederjans and Hoffman, 1992), business process infrastructure development (Gross and Talavage, 1979), information resource management (Bacon, 1992; van Grembergen and van Bell, 1999; Lee and Kwak, 1999), resource scheduling (Chen, 1988) and other production and operations planning environments (Khouja and Conrad, 1995; Winkofsky et al., 1981).

Recently, BPR has become an increasingly integral and important function in a health-care system. It is significant because the health-care system is aware of the vision for and commitment to BPR as a primary system infrastructure development for achieving its objectives.

The purpose of this paper is to develop an MCMP (specifically goal programming, GP) model which aids in supporting the BPR decision-making pertinent to strategic planning for business process infrastructure development. Therefore, the overall objective of this research is to design and evaluate a model for effective BPR planning in a health-care system.

This MCDM model is able to improve decision-making planning process and managerial policy in health-care BPR planning and similar planning settings. The MCDM model positions the health-care system to respond to innovation and new growth, while reinforcing ongoing BPR planning strategies to meet defined requirements of the health-care system.

2. Literature review

2.1. Business process reengineering

Business process reengineering (BPR) has become an increasingly significant and integral part of a health-care system as well as of any other organization (Caron et al., 1994; Kettinger et al., 1997). It is, therefore, important that health-care decision-makers be aware of the vision for and commitment to BPR as an essential aspect of strategic planning for the mission of health-care service and management. The goals surrounding BPR decisions are complex and conflicting since the goals are different in each subsystem and subprocess. It is very complicated and difficult to balance current requirements of multi-dimensional subsystems without a systematic approach to evaluate potential future BPR decisions. If it is overlooked in the evaluating and structuring of the BPR decision, the system may fail to meet the challenging demands of the market and satisfying stakeholders. In other words, if one goal is selected with little or no consideration for other goals, the decision can be costly both in terms of competitive advantages and long-term strategic planning.

BPR planning is considered as a particularly complicated multicriteria decision-making problem. It is complicated because many qualitative and quantitative factors have to be included in the BPR decision-making process. Since the content of the BPR problem has practical applications, many studies have applied diverse optimization algorithms and/or approximation algorithms to the real-world situations. In recent years, a plethora of information technology related BPR researches have appeared in the literature (Davenport and Short, 1990; Lucas and Baroudi, 1994; Ramani et al., 1995; Willcocks and Smith, 1995; Land, 1996; Teng et al., 1996, 1998; Fuglseth and Grohaug, 1997).

The use of MCDM in business process reengineering has generally been limited to the financial policies, rather than the technological considerations and other strategic policies of an organization. OR-based studies have been explored in such publications as Aldowaisan and Gaafar (1999) and Ackermann et al. (1999), in addition to somewhat, less application-oriented BPR in a health-care system (Short and Venkatraman, 1992).

2.2. Multicriteria mathematical programming

Multicriteria mathematical programming (MCMP) is a mathematical model for a decision-making process which allows a decision-maker to achieve multiple goals. One of the most widely used MCMP model is GP. GP model has been applied to many of studies, such as education area (Kwak and Lee, 1998), dynamic programming model (Sutardi et al., 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 et al., 1985), and transshipment model (Hemaida and Kwak, 1994).

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 the analytic hierarchy process (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 et al., 1988), and scaling or normalizing of goal constraint parameters (Gass, 1987).

3. Problem statement

3.1. Data background

An academic-based health-care system wants to avoid problems by consistently following a three-tier program of consolidation, integration, and networking. However, organizational effectiveness remains hampered by a multi-layered bureaucracy which prevents decisions from being made and actions carried out in a timely fashion.

Strategic issues in health-care system have been acknowledged. Strategic objective is to enhance organizational effectiveness by streamlining key decision-making processes, and developing an integrated information system. Therefore, strategy and actions are proposed as follows: (1) in order to streamline key decision-making processes, an initial step will include key process review and identification of dysfunctional process. Once problem processes have been identified and prioritized, process improvement initiatives will be implemented; (2) a parallel action will empower individuals within the health-care system to carry out decision-making at the lowest appropriate levels; and (3) development of an integrated information system linking key hospital, departmental and professional functions requires an experienced Chief Information Officer (CIO) to oversee and lead this process. The CIO is expected to identify information system requirements of key stakeholders, and develop an information systems strategic plan. Adequate resources (capital equipment, personnel, etc.) must be available to fund implementation of the information system strategic plan, which should proceed expeditiously. Even though the health center appeared to be doing fine, the center's strategy for success and the rational need to be reengineered and changes are necessary.

The health-care system in this study is a leading patient-centered, physician-guided provider of health-care services, located at St. Louis, MO, USA. The center's purpose is to support the institution by providing a setting for and financial support of health professions education and health services research. The center's goal is to provide the most caring, high quality and cost-effective health-care services while exemplifying the center's mission.

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. Group decision-makers (GDM) of the health-care system are involved in the strategic BPR planning development process. The goals and criteria are derived from the GDM who are a vice-president of the health-care system, a CIO, a Chief Financial Officer (CFO), a director of a medical group, and representatives of physicians, nurses and other medical staff. After necessary data templates related to the strategic BPR planning had been generated, GDM reviews the data set and provides the validation for the collected data. All the data were validated by GDM who are responsible for the health-care systems. Thus, the health-care systems' BPR planning strategies throughout the 1990s have been developed using the framework of Fig. 1.

3.2. Information management process

There are six projects to be considered.

Project 1. To provide an appropriate information infrastructure for technology development.

Project 2. To provide end-users with currently available technology for effective utilization.

Project 3. To use available technology resource to provide better services and to attract clients to the organization.

Project 4. To develop procedures for cost containment and improving cost effectiveness of technology expenditures.

Project 5. To expand shared computing resources and support services.

Project 6. To improve end-user services by expanding voice response technology or online access to support systems.

3.3. Financial budget process

Table 1 shows the ratios for six available project resources at each location in each year.

3.4. Operational process

Health-care management wants to reduce total percentage of variation up to 20% for seven operational performance matrices. Table 2 shows that each matrix has available operational performance along with its estimated budget and variation percent allowed.

3.5. Personnel process

Health-care management concerns assigning optimally its human resources as well as minimizing annual payment. The following data are employed: there are 83 personnel for three departments in shift 1; 45 personnel for three departments in shift 2; and 26 personnel for three departments in shift 3. Table 3 presents currently employed human resources at each department in each period.

Based on the above data, the goal priorities and the relevant information about resource allocation are established as follows: Priority 1 – financial budget process (G1); Priority 2 – information management process (G3); Priority 3 – operational process (G2); and Priority 4 – personnel process (G4).

4. Model development

4.1. Goal decomposition and prioritization

In the MCMP model development, the AHP has been utilized for establishing goal decomposition

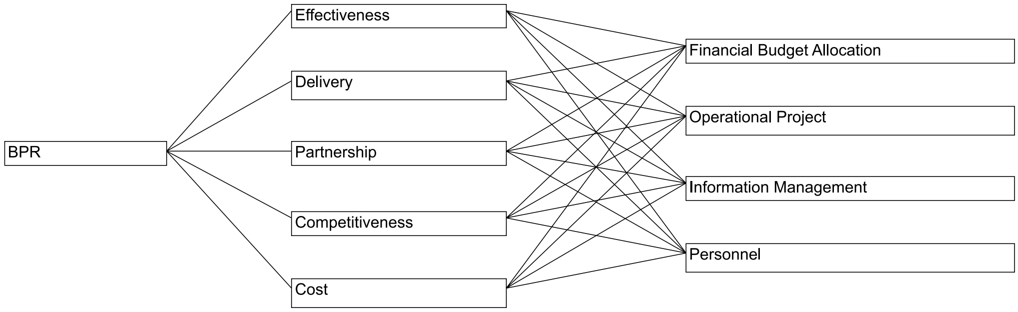

Fig. 1. Criteria and goals for strategic planning.

Table 1
Available resource and project

Time	Location	Available project resource (%)						
		1	2	3	4	5	6	Total
T1	L1	3.3	3.7	1.8	5.0	0.0	0.7	14.5
	L2	10.0	1.3	4.2	1.7	0.0	0.0	17.2
T2	L1	3.3	4.1	2.0	0.5	3.3	1.8	15.0
	L2	13.3	1.7	1.7	1.7	0.0	0.6	19.0
T3	L1	3.3	4.0	2.3	2.3	1.7	0.4	14.0
	L2	16.3	0.0	1.0	3.0	0.0	0.0	20.3
Total		49.5	14.8	13.0	14.2	5.0	3.5	100.0

T: time period, L: location.

Table 2
Available operational performance matrixes

	Estimated budget ($000)	Allowed % variation
Admissions	2885	4.4
Length of stay	6.28	3.3
Patient days	18,089	7.8
Occupancy rate	64.9	7.7
Total CMI	1.80	2.1
Cost/adjusted discharge	5912	0.2
Outpatient services	330,585	12.6

Table 3
Actual human resource at each department in each period

Time shift	Emergency department		Radiology department		Nuclear medicine department		Available human resource level
	Doctor	Nurse	Doctor	Technician	Doctor	Technician	
Shift 1	2	9	14	38	6	14	83
Shift 2	4	12	1	16	4	8	45
Shift 3	2	9	0	11	2	2	26
Annual wages ($000)	70	33	70	27	70	27	

Table 4
Relative importance (normalized eigenvectors)

	C_1	C_2	C_3	C_4	C_5	RP	Rank
G_1	0.563	0.393	0.101	0.520	0.566	0.466	1
G_2	0.108	0.139	0.262	0.058	0.113	0.131	3
G_3	0.267	0.418	0.592	0.124	0.046	0.315	2
G_4	0.062	0.050	0.045	0.298	0.275	0.088	4
CRP	0.497	0.246	0.116	0.048	0.093		

G_1: financial budget allocation; G_2: operational projects; G_3: information management; G_4: personnel; RP: relative priority; CRP: criteria relative priority; C_1: effectiveness criterion; C_2: care delivery criterion; C_3: partnership criterion; C_4: competitiveness criterion; C_5: cost criterion.

and prioritization. In order to obtain the overall relative importance of the four goals, synthesized priority is calculated for each goal using Expert Choice. Table 4 presents the relative importance with normalized eigenvectors. As this table illustrates, financial budget allocation goal (G_1) is the most important when considering organization effectiveness criterion (C_1). Information management goal (G_3) is the most important in terms of health-services delivery criterion (C_2). Information management goal (G_3) is the most important when considering the strategic partnership criterion (C_3). Financial budget allocation goal (G_1) is the most important goal in terms of competitive medical care environment criterion (C_4). Financial budget allocation goal (G_1) is the most important when considering cost effectiveness criterion (C_5).

Table 4 also illustrates the final overall prioritization for goals of strategic planning for health-care resource allocation. This table presents the relative priority (RP) and the order of prioritization. The synthesized prioritization of the overall goals for the resource allocation has been justified by the decision-makers in the health-care system under consideration.

4.2. MCMP model

Goal programming (GP) is a structured decision-making approach used to evaluate an satisfying solution based on the priorities or weighted ranking assigned to each goal. While GP provides no systematic method to prioritize or rank relative importance or weights of the goals, the AHP measures the relative importance of multiple goals with consistency. A systematic approach to rank elements (goals or alternatives) in AHP can be utilized in the replacement of a subjective judgment to prioritize each goal in GP. Khorramshahgol and Ignizio (1984) originally discussed an integration of GP and AHP concepts in the study of single and multiple decision-making in a multiple objective environment.

Since AHP is most widely accepted remedy to establish a relative importance among goals, the integrated model in this study utilizes AHP to determine the priorities used in the GP model development. Therefore, the model in this study requires the evaluation of elements (goals or alternatives) with respect to how much these elements affect the overall effectiveness of strategic planning for resource allocation in the health-care system. In many cases, no quantitative data exists for each alternative project/goal combination. Thus, for each goal, the decision-maker will make pairwise comparisons of each element with all others, using the AHP judgment scale.

The generalized MCMP model can be stated in the following form:

$$\text{minimize:}\quad Z = \sum_{g=1}^{G}\sum_{i=1}^{m} W_{gi}P_g(d_i^- + d_i^+)$$

$$\text{subject to:}\quad \sum_{j=1}^{n} a_{ij}X_j + d_i^- - d_i^+ = b_i,\quad i = 1,2,\ldots,m,$$

and

$$X_j = \begin{cases} 0 & \text{otherwise,} \\ 1 & \text{if the } j\text{th entity is selected,} \end{cases}\quad j = 1,2,\ldots,n,$$

$$d_i^-, d_i^+ = \text{nonnegative integers},$$

where Z is the sum of weighted deviational variables, W_{gi} the relative weight assigned to g priority level for the ith constraints, P_g the gth-level preemptive priority factor, a_{ij} the 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 ith-goal achievement), X_j the jth decision variable X, d_i^- and d_i^+ the deviational variables representing under- and over-achievement of the ith goal.

In this paper, an MCMP model was formulated based on the following information.

4.2.1. Decision variables

There are four different types of decision variables for this study.

X_j^C is the decision variable for six possible projects to which financial budget amounts can be allocated over three-year period ($j = 1, 2, \ldots, 6$);

X_j^I is the decision variable for different types of information projects to be selected ($j = 1, 2, \ldots, 18$);

$X_j^{\varnothing}$ is the decision variable for seven operational performance matrices which percentage variance of each budget category can be optimally established ($j = 1, 2, \ldots, 7$);

X_j^P is the decision variable for 18 different work sites of human resources to be allocated ($j = 1, \ldots, 18$),

where

$$X_j^C, X_j^{\varnothing} \geqslant 0,$$

$$X_j^I, X_j^P = \begin{cases} 0 & \text{otherwise}, \\ 1 & \text{if the } j\text{th entity is selected.} \end{cases}$$

4.2.2. Constraints

The GP model has 14 systems constraints and 36 goal constraints. Since the systems constraints do not have deviational variables, deviational variables will not appear in the objective function.

4.2.2.1. Systems constraints. Constraint 1. Assign certain projects to a given fiscal year.

$$X_1^I + X_7^I + X_{13}^I = 1, \tag{1}$$

$$X_2^I + X_8^I + X_{14}^I = 1, \tag{2}$$

$$X_3^I + X_9^I + X_{15}^I = 1, \tag{3}$$

$$X_4^I + X_{10}^I + X_{16}^I = 1, \tag{4}$$

$$X_5^I + X_{11}^I + X_{17}^I = 1, \tag{5}$$

$$X_6^I + X_{12}^I + X_{18}^I = 1. \tag{6}$$

Constraint 2. Balance human resources utilization.

$$X_1^P + X_2^P + X_3^P + X_4^P + X_5^P + X_6^P = 83, \tag{7}$$

$$X_7^P + X_8^P + X_9^P + X_{10}^P + X_{11}^P + X_{12}^P = 45, \tag{8}$$

$$X_{13}^P + X_{14}^P + X_{15}^P + X_{16}^P + X_{17}^P + X_{18}^P = 26, \tag{9}$$

$$X_1^P + X_3^P + X_5^P + X_7^P + X_9^P + X_{11}^P + X_{13}^P + X_{15}^P + X_{17}^P = 35, \tag{10}$$

$$X_4^P + X_6^P + X_{10}^P + X_{12}^P + X_{16}^P + X_{18}^P = 89, \tag{11}$$

$$\sum X_j^P = 154. \tag{12}$$

Constraint 3. Minimize the annual payroll utilization.

$$70X_1^P + 33X_2^P + 70X_3^P + 27X_4^P + 70X_5^P + 27X_6^P + 70X_7^P + 33X_8^P + 70X_9^P + 27X_{10}^P + 70X_{11}^P + 27X_{12}^P + 70X_{13}^P + 33X_{14}^P + 70X_{15}^P + 27X_{16}^P + 70X_{17}^P + 27X_{18}^P = 5633. \tag{13}$$

Constraint 4. Do not allow total percentage of budget variations by 20%.

$$X_1^{\varnothing} + X_2^{\varnothing} + X_3^{\varnothing} + X_4^{\varnothing} + X_5^{\varnothing} + X_6^{\varnothing} + X_7^{\varnothing} = 20. \tag{14}$$

4.2.2.2. Goal constraints. Four goals are ranked based on the AHP priority method in the following order: G1 (financial budget process), G3 (information management process), G2 (operational process), and G4 (personnel process). Goal constraints are developed with prioritized goal ranks.

Priority 1 (P_1: *Financial budget process* (*G*1)). Financial budget is allocated adequately, but not to exceed the entire budget, and not to exceed the available budget levels for each location in each year. Under-achievement of the budget allocation will be minimized to fully utilize the allocated budget. That is, invest as much as possible within the budget limit. That is:

$$X_j^C + d^- = B_t,$$

where B_t is an available budget limit in year t and X_j^C is the financial investment required for project j in year t.

Specifically,

$$49.5X_1^C + 14.8^C X_2 + 13.0X_3^C + 14.2X_4^C + 5.0X_5^C + 3.5X_6^C + d_1^- - d_1^+ = 100, \quad (15)$$

$$3.3X_1^C + 3.7^C X_2 + 1.8X_3^C + 5.0X_4^C + 0.7X_6^C + d_2^- - d_2^+ = 14.5, \quad (16)$$

$$10.0X_1^C + 1.3X_2^C + 4.2X_3^C + 1.7X_4^C + d_3^- - d_3^+ = 17.2, \quad (17)$$

$$3.3X_1^C + 4.1X_2^C + 2.0X_3^C + 0.5X_4^C + 3.3X_5^C + 1.8X_6^C + d_4^- - d_4^+ = 15.0, \quad (18)$$

$$13.3X_1^C + 1.7X_2^C + 1.7X_3^C + 1.7X_4^C + 0.6X_6^C + d_5^- - d_5^+ = 19.0, \quad (19)$$

$$3.3X_1^C + 4.0X_2^C + 2.3X_3^C + 2.3X_4^C + 1.7X_5^C + 0.4X_6^C + d_6^- - d_6^+ = 14.0, \quad (20)$$

$$16.3X_1^C + 1.0X_3^C + 3.0X_4^C + d_7^- - d_7^+ = 20.3. \quad (21)$$

Priority 2 (P$_2$: *Information management process* ($G3$)). There are six projects to be considered. Assign projects to a certain fiscal year, but not to exceed two projects to each fiscal year.

$$X_1^I + X_2^I + X_3^I + X_4^I + X_5^I + X_6^I + d_8^- - d_8^+ = 2, \quad (22)$$

$$X_7^I + X_8^I + X_9^I + X_{10}^I + X_{11}^I + X_{12}^I + d_9^- - d_9^+ = 2, \quad (23)$$

$$X_{13}^I + X_{14}^I + X_{15}^I + X_{16}^I + X_{17}^I + X_{18}^I + d_{10}^- - d_{10}^+ = 2, \quad (24)$$

$$X_j^I = \begin{cases} 0 & \text{otherwise,} \\ 1 & \text{if the } j\text{th project is selected in year } t. \end{cases}$$

Priority 3 (P$_3$: *Operational process* ($G2$)). There are seven operational matrices. They are:

$$X_1^{\varnothing} + d_{11}^- - d_{11}^+ = 4.4, \quad (25)$$

$$X_2^{\varnothing} + d_{12}^- - d_{12}^+ = 3.3, \quad (26)$$

$$X_3^{\varnothing} + d_{13}^- - d_{13}^+ = 7.8, \quad (27)$$

$$X_4^{\varnothing} + d_{14}^- - d_{14}^+ = 7.7, \quad (28)$$

$$X_5^{\varnothing} + d_{15}^- - d_{15}^+ = 2.1, \quad (29)$$

$$X_6^{\varnothing} + d_{16}^- - d_{16}^+ = 0.2, \quad (30)$$

$$X_7^{\varnothing} + d_{17}^- - d_{17}^+ = 12.6. \quad (31)$$

Priority 4 (P$_4$: *Personnel process* ($G4$)). Health-care system's efficiency can be measured by the efficient assignments of resources under the given systems constraints. The system wishes to optimize the current assignments along with minimizing annual payroll budget, as follows.

(a) Desired number of personnel for three departments in shift 1.

$$X_1^P - 2 + d_{18}^- - d_{18}^+ = 0, \quad (32)$$

$$X_2^P - 9 + d_{19}^- - d_{19}^+ = 0, \quad (33)$$

$$X_3^P - 14 + d_{20}^- - d_{20}^+ = 0, \quad (34)$$

$$X_4^P - 38 + d_{21}^- - d_{21}^+ = 0, \quad (35)$$

$$X_5^P - 6 + d_{22}^- - d_{22}^+ = 0, \quad (36)$$

$$X_6^P - 14 + d_{23}^- - d_{23}^+ = 0. \quad (37)$$

(b) Desired number of personnel for three departments in shift 2.

$$X_7^P - 4 + d_{24}^- - d_{24}^+ = 0, \quad (38)$$

$$X_8^P - 12 + d_{25}^- - d_{25}^+ = 0, \quad (39)$$

$$X_9^P - 1 + d_{26}^- - d_{26}^+ = 0, \quad (40)$$

$$X_{10}^P - 16 + d_{27}^- - d_{27}^+ = 0, \quad (41)$$

$$X_{11}^P - 4 + d_{28}^- - d_{28}^+ = 0, \quad (42)$$

$$X_{12}^P - 8 + d_{29}^- - d_{29}^+ = 0. \quad (43)$$

(c) Desired number of personnel for three departments in shift 3.

$$X_{13}^P - 2 + d_{30}^- - d_{30}^+ = 0, \quad (44)$$

$$X_{14}^P - 9 + d_{31}^- - d_{31}^+ = 0, \quad (45)$$

$$X_{15}^P + d_{32}^- - d_{32}^+ = 0, \quad (46)$$

$$X_{16}^P - 11 + d_{33}^- - d_{33}^+ = 0, \quad (47)$$

$$X_{17}^P - 2 + d_{34}^- - d_{34}^+ = 0, \quad (48)$$

$$X_{18}^P - 2 + d_{35}^- - d_{35}^+ = 0. \quad (49)$$

(d) Minimize the annual payroll utilization.

$$\begin{aligned} &70X_1^P + 33X_2^P + 70X_3^P + 27X_4^P + 70X_5^P \\ &\quad + 27X_6^P + 70X_7^P + 33X_8^P + 70X_9^P + 27X_{10}^P \\ &\quad + 70X_{11}^P + 27X_{12}^P + 70X_{13}^P + 33X_{14}^P + 70X_{15}^P \\ &\quad + 27X_{16}^P + 70X_{17}^P + 27X_{18}^P + d_{36}^- - d_{36}^+ = 5633. \end{aligned} \quad (50)$$

4.2.3. Objective function

Minimize $Z =$

$$P_1 \sum_{i=1}^{7} (d_i^+ + d_i^-) : \text{Financial budget process goal}$$

$$+ P_2 \sum_{i=8}^{10} (d_i^+ + d_i^-) : \text{Information management process goal}$$

$$+ P_3 \sum_{i=11}^{17} (d_i^+ + d_i^-) : \text{Operational process goal}$$

$$+ P_4 \sum_{i=18}^{36} (d_i^+ + d_i^-) : \text{Personnel process goal.}$$

Thus, the GP problem is to minimize the value of the objective function subject to goal constraints (15)–(50), satisfying the preemptive priority rules.

5. Model solution and analysis

5.1. Model solution

The MCMP model was solved using a software, Micro Manager. The solution was determined after 54 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

Table 5
Solution analysis

(a) Solution results

DV (X_j^C)	DV (X_j^I)	DV ($X_j^{\varnothing}$)	DV (X_j^P)
$X_1^C = 1$	$X_1^I = 0$	$X_1^{\varnothing} = 4.4$	$X_1^P = 2$
$X_2^C = 1$	$X_2^I = 0$	$X_2^{\varnothing} = 3.3$	$X_2^P = 9$
$X_3^C = 1$	$X_3^I = 0$	$X_3^{\varnothing} = 7.8$	$X_3^P = 14$
$X_4^C = 1$	$X_4^I = 0$	$X_4^{\varnothing} = 4.5$	$X_4^P = 38$
$X_5^C = 1$	$X_5^I = 1$	$X_5^{\varnothing} = 0$	$X_5^P = 6$
$X_6^C = 1$	$X_6^I = 1$	$X_6^{\varnothing} = 0$	$X_6^P = 14$
	$X_7^I = 0$	$X_7^{\varnothing} = 0$	$X_7^P = 4$
	$X_8^I = 0$	$d_{14}^- = 3.2$	$X_8^P = 12$
	$X_9^I = 1$	$d_{15}^- = 2.1$	$X_9^P = 1$
	$X_{10}^I = 1$	$d_{16}^- = 0.2$	$X_{10}^P = 16$
	$X_{11}^I = 0$	$d_{17}^- = 12.6$	$X_{11}^P = 4$
	$X_{12}^I = 0$		$X_{12}^P = 8$
	$X_{13}^I = 1$		$X_{13}^P = 2$
	$X_{14}^I = 1$		$X_{14}^P = 5$
	$X_{15}^I = 0$		$X_{15}^P = 0$
	$X_{16}^I = 0$		$X_{16}^P = 11$
	$X_{17}^I = 0$		$X_{17}^P = 2$
	$X_{18}^I = 0$		$X_{18}^P = 2$
			$d_{31}^- = 4$

(b) Solution implication

Goal priority	Ouput values	Goal achievement	Goal implication
P_1	0	Fully achieved	Financial budget: fully allocated
P_2	0	Fully achieved	Information projects: fully selected
P_3	18.1	Partially achieved	Operation variation: 20% reduced
P_4	4	Partially achieved	Human resources: 4 persons saved

All other deviational variables are zero.

Table 6
Predicted human resource assignment at each department in each period

Time shift	Emergency department		Radiology department		Nuclear medicine department	
	Doctor	Nurse	Doctor	Technician	Doctor	Technician
Shift 1	2	9	14	38	6	14
Shift 2	4	12	1	16	4	8
Shift 3	2	5	0	11	2	2

computer solution yields the following results as shown in Table 5.

Priority 1 is of financial budget allocation process. This priority is fully satisfied in terms of managerial concern ($P_1 = 0$). All deviational variables are zero ($d_1^+, d_1^- = 0$, $d_2^+, d_2^- = 0$, $d_3^+, d_3^- = 0$, $d_4^+, d_4^- = 0$, $d_5^+, d_5^- = 0$, and $d_6^+, d_6^- = 0$). This means that all financial budgets are allocated with respect to the estimated budget amounts.

Priority 2 is of information management process. Since all deviational variables for selecting two projects in each year are zero ($d_8^+, d_8^- = 0$, $d_9^+, d_9^- = 0$, $d_{10}^+, d_{10}^- = 0$), the Priority 2 is fully satisfied ($P_2 = 0$). There are 18 decision variables for selecting two projects in each year for three years (X_1^I to X_{18}^I). For the first year, the Projects 5 and 6 are selected for implementation ($X_5^I, X_6^I = 1$). For the second year, the Projects 3 and 4 are selected ($X_9^I, X_{10}^I = 1$). For the third year, the Projects 1 and 2 are selected ($X_{13}^I, X_{14}^I = 1$).

Priority 3 of allowing at most 20% in total variation for seven operational performance matrices is considered. Since $P_3 = 18.1$ and the original sum of variation is 38.1, this operational process goal is satisfied. Among seven operational performance matrices, all positive deviational variables are zero and four negative deviational variables are not zero ($d_{14}^- = 3.2$, $d_{15}^- = 2.1$, $d_{16}^- = 0.2$, $d_{17}^- = 12.6$).

One of the important goals for BPR in a health-care system is a personnel process goal (Priority 4). Since the original number of total human resources is 154, this goal is satisfied in terms of managerial perspective. All but one deviational variable ($d_{31}^- = 4$) are zero. $d_{31}^- = 4$ indicates that four less persons are assigned than the original personnel levels (i.e., a saving of four persons, $P_4 = 4$). Table 6 shows the optimally predicted assignment of human resources.

6. Concluding remarks

A multicriteria mathematical programming (MCMP) model was developed and analyzed to aid the organization's resource allocation in connection with strategic planning for business process infrastructure development in a health-care system. Currently, the organization reviews all these strategies as the possible alternative policies.

Demands and expectations for health-care system's BPR have never been greater within the organization. There is no singular solution, but most experts agree that progress depends upon institution-wide attention, new investments and finding strategies, resource reallocation, and greater co-operative efforts. The task groups will also work more closely with other service departments and support personnel to consolidate a successful health-care system's BPR planning.

The BPR planning is restructured and its role broadened to promote newly attempted services focusing on four overall goals: financial budget process goal, information management process goal, operational process goal, and personnel process goal. The proposed MCMP model reinforces the health-care system's ongoing strategic planning policy to position the health-care system to respond to new innovation and competitiveness, while meeting defined organizational constraints.

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