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Decision-making support system for human resource allocation in product development projects

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Recent dismal economic conditions and a ruthlessly competitive environment have forced many companies to restructure, or reorganize their priorities. For such companies, the concentration of various resources upon their particular corporate strong points has become a central strategy. Consequently, there has been a rapid increase in the importance of (1) selecting profitable projects from a wealth of possible alternatives and (2) optimizing the allocation of current resources among the selected projects. This paper proposes an optimization system for project selection that not only yields the most beneficial project set, but also the optimum allocation of human resources for the selected projects. The optimization system consists of two algorithms, namely (1) a project selection algorithm for choosing the set of projects that maximizes the total estimated profit, and (2) a human resource allocation algorithm for optimally placing human resources among the selected projects, having considered the satisfaction level provided by each employee's skills, personal motivation and career goals.

Keywords: Human resource allocation; Project management; Production management; Decision-making support system; System engineering

1. Introduction

Recent developments in the capability of network technologies has enabled the globalization of corporate industrial environments and intensified competition concerning product qualities and value in the market place. Under such circumstances, each company seeks to maximize its competitiveness by the intelligent investment of financial and personnel resources in the direction of greatest engineering strength. That is, companies select which development projects to pursue from among a variety of candidate projects, and concentrate their resources upon the selected projects that best fit their circumstances.

In companies where a primary consideration is efficiency, great importance is placed on (1) the selection of development projects generating maximum profits utilizing company resources to the fullest and (2) suitable allocation of human

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resources among chosen development projects. The latter is particularly important, but is also a complex issue, since the personalities and abilities of people must be evaluated and taken into account. Methods for optimally allocating human recourses in dynamic corporations seeking to respond to a variety of needs have yet to be developed and utilized.

Human resource allocation decisions are usually made according to the experience and intuition of project managers. However, as the contents of the projects become more complex and the required abilities to carry them out more diversified, there in an increasing need for logical support systems to assist decision makers when seeking the best possible deployment of the human resources.

This paper proposes an optimization system that supports decision-making where the merits of diverse candidate development projects, taking into account the optimal allocation of human resources, are presented to a decision maker. In the proposed decision-making method, human resources are not treated as uniform entities; quite the opposite, their specific personalities and potential are considered as much as possible. Project management aims to supervise and support a variety of project activities, so that product requirements will be efficiently realized by the application of related knowledge and techniques. In development projects where certain aspects are changeable or in flux and where development periods must be as short as possible, human resource management is becoming an increasingly important aspect of project management.

In 1988, Pinto and Prescott reported that the success or failure of projects did not depend on worker factors, but Belout (1998) did not agree with this assessment. Matsuotani (2002) directed his attention to the fact that the performance seen during projects greatly depends on the work-related motivation of the people engaged in various tasks, and presented a motivational framework.

The management of project leaders also plays an important role in the overall management of successful projects. Cleland (1995) stressed the need for more comprehensive discussions. El-Sabaa (2001) clarified the differences between project managers and functional managers, based on investigations, and discussed the required skills for effective project leaders.

A typical research area concerning the optimization of human resource allocation deals with resource-constrained project scheduling (hereafter RCPS). RCPS, a type of optimization problem that integrates the optimization of scheduling and resource allocation, is the subject of intensive study. RCPS frameworks have been adapted to a wide variety of subjects, and various optimization methods have been proposed to address specific problems that arise when developing practical tools.

For example, Herroelen *et al.* (1998) reviewed papers concerning RCPS methods during the second half of the 1990s. Kara *et al.* (2001) proposed a heuristic approach for allocating human resources to so-called bottleneck tasks, Yan *et al.* (2002) optimized the number of human resources allocated to tasks forming a project, and Ghomi and Ashjari (2002) studied RCPS using simulation modelling under the probabilistic circumstances of multi-projects.

The principal purpose of project scheduling under RCPS is to construct an execution plan so that the completion time of plural tasks is minimized while satisfying the precedence relations among the tasks, with human resources usually considered as a constraint. Hence, the allocation results of human resources are given as the number of human resources allocated to each task. In such optimization, human resources are treated like uniform entities. Today, in response to evolving RCPS requirements, human resources are being included in decision variables of the optimization. However, even at this time, human resources are usually treated as uniform entities, and the particular characteristics of individual human resources, such as their motivation and career path, are ignored.

Furthermore, since project scheduling is the core purpose of RCPS, the actual selection of projects to be carried out from among plural candidate projects in multi-project environments is an additional problem, and one not easily solved. At present, many companies face a dauntingly large number of candidate development projects, due to the wide variety of market demands and the high speed of technological innovations. Yet companies are expected to select a precise set of projects that maximizes their chances of market place success. Under such circumstances, Wester *et al.* (1992) compared three kinds of order accept strategies in order-oriented production environments that have given set-up times and appointed delivery dates. Lewis and Slotnick (2002) proposed project selection methods considering simple profits, where the appointed delivery dates link profits and the future expected profits.

Few studies have addressed numerical or logical support issues concerning decision making for optimal allocation of human resources to product development projects. Nembhard (2001) introduced a heuristic approach to human resource allocation based on the subjects' personal learning abilities.

2. Description of human resource allocation problems

The purpose of this study is to construct a system that supports the decision-making required to implement a series of optimal human resource allocations across a set of development projects after selecting the most suitable set of projects from a collection of projects grouped together in different sets.

The numerical models used in this paper were arrived at based on enquiries during visits to a number of industrial companies and discussions with industry managers. When the method presented here is applied to a specific industrial problem, however, the modelling should be modified according to the specific characteristics of the companies being considered.

The human resource allocation problems dealt with in this study are described below.

2.1 *Company organization*

Here, company organizations such as that shown in figure 1 are considered. Each human resource individual belongs to a section that reflects his or her own area of expertise, and each is also placed in a project engaged in the development of a product.

Sections are generally called divisions or branches, and are comprised of human resources that are vertically categorized, based on skill levels within expert engineering field classes. Each section has a manager who directs the career path of each of the human resources belonging to the section. On the other hand, projects are entities where human resources actually work together for relatively short periods of time. When working on a project, human resources having a range of

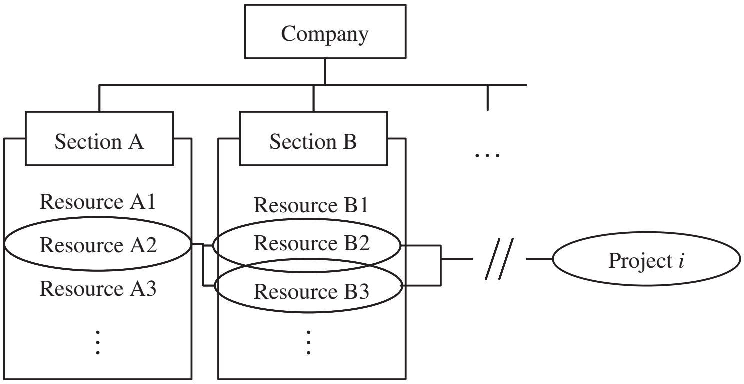


Figure 1. Concept of the company organization.

expert skills are gathered together from a number of sections. In contrast to the vertically oriented sections, the organization of most members within a project is horizontal, and depends on a mixture of experts widely drawn from the company's human resource pool.

2.2 *Handling of human resources*

It is obvious that human resources are people, but the specifics of their particular personalities and abilities are vitally important in cooperative projects, as described in many references. The quality and suitability of human resource management has a great influence on the success or failure of development projects (Belout 1998, Nembhard 2001), and personal motivation directly influences the performance of difficult tasks that depend on the skill and abilities of people (Matsuotani 2002). Companies often place specific demands upon their individual human resources, concerning work related tasks or study. The optimization system proposed here considers not only the feasibility of the projects at hand, but also the motivation and career path desires of the human resources that may be engaged in the various projects.

In practical companies, a single worker often participates in a number of development projects. In the method proposed here, the simultaneous allocation of human resources to two or more projects is allowed. The skills of human resources participating in two or more development projects are also shared among the allocated projects, as needed. The time allocation rates of human resources are here denoted x_{ji}, which expresses the fraction of the total working time applied by human resource j to development project i. For the purposes of this paper, and to reduce unwieldy complexity, the time allocation rates are considered to be equal to the skill allocation rates of human resource j for development project i, where the skill allocation rate is an evaluative measure of the set of skills that a human resource has as compared with those required for a given development project. The numerical range of x_{ji} is [0, 1]. For each worker, the sum of the x_{ji} rates for all development projects must be 1. Here, discrete variables are used in order to make application of the Genetic Algorithms easy. The range [0, 1] of x_{ji} is quantised into 10 steps, and x_{ji} is treated as a discrete variable with values of $\{0, 0.1, 0.2, \dots, 1\}$.

Simply allocating human resources having sufficient skills to various development projects does not guarantee successful results. A project leader (hereafter, PL) who has a global understanding of project details and skilfully manages the entirety of the project is required. Here, a PL is initially selected for a development project, and human resources are then allocated to it.

2.3 *Supporting on-demand type decision making*

Many companies are currently seeking to channel their management resources into areas in which they are strongest, while streamlining their management. Here, the most effective sets of projects, ones with the greatest potential benefit to the company, are first selected from among candidate sets of developments projects. The selection of projects and the human resource allocation determination are integrated in the system and conducted sequentially during the decision-making procedures. When significant changes occur concerning the human resources required for the projects, a human resource re-allocation process is conducted.

In the proposed method, if a situation arises where re-allocation of human resources is required, optimization of human resource allocations is re-conducted on demand. Examples of such projects are the completion of projects, starting new projects, and increased requirements for human resources in ongoing projects.

3. Optimization procedures to support project selection and human resource allocation decision-making

3.1 *Outline of the decision-making procedures*

The flow of the proposed optimization system for supporting decision-making is shown in figure 2. First of all, n candidate sets of projects having greater total profits are selected from n_0 candidate projects, using the project-selecting algorithm expressed as a single objective optimization problem. Next, for each of the candidate projects, a project leader (PL) is selected. Then, the optimum allocation of human resources is obtained via the human resource allocation algorithm. The decision maker determines the number n of candidate sets of projects that are simultaneously optimized, after careful consideration according to the scale of the problem.

The practical model constructed in this paper is a basic case used to explain the procedural details. The formulations constructed are simplified so that the fundamental procedures can be applied to general problems, and should be modified as necessary, according to the specific situations the contexts that pertain.

3.2 *Project selection algorithms*

Initially, n project sets are selected from among the pool of candidate development projects. This selection is conducted by solving the following single objective optimization problem, where y_i is a binary decision variable in which project i is selected when $y_i = 1$, but not selected when $y_i = 0$, and the set of y_i is denoted $\mathbf{y}$.

$$\begin{aligned} &\text{Maximize} \quad f_0(\mathbf{y}) \\ &\text{subject to} \quad g_0(\mathbf{y}) \leq 0, \quad y_i \in \{0,1\} \end{aligned} \tag{1}$$

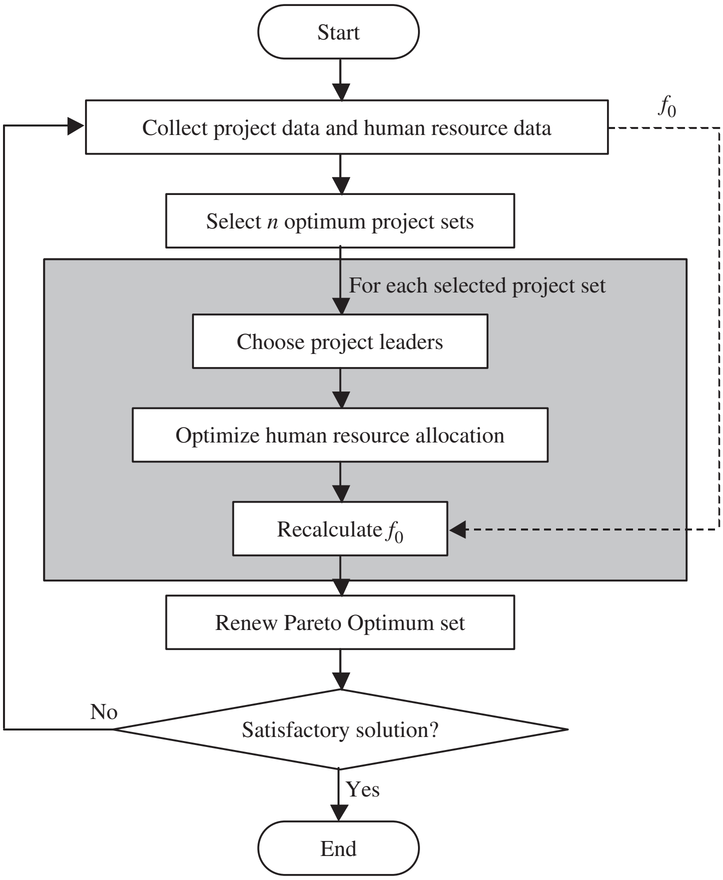


Figure 2. Flow chart of the optimization system.

Here, the value of development project i is formulated by summing the expected profit eprofit_i obtained after completion of the development project, and the strategic importance level importance_i that includes evaluation of the level of future promise offered by the project, as well as additional merits. Maximization of the development project value is pursued. The expected profit eprofit_i expresses a practical profit, while the strategic importance level importance_i index expressing the potential for future profit. When the total number of candidate development projects is n_0, from which the projects to be developed are to be selected, the objective function is expressed as follows:

$$f_0(\mathbf{y}) = \sum_{i}^{n_0} \left[\left(w_{01} \times \text{eprofit}_i + w_{02} \times \text{importance}_i \right) * y_i \right] \tag{2}$$

where w_{01} and w_{02} are weighting coefficients, given according to the importance levels for each evaluation factor. The $*$ is used as a multiplication symbol. In this study, a project's success or failure is evaluated by summing the skills provided by the human resources for each of the expert fields used in the project. In this paper,

Table 1. Definitions of the four levels of skill ability.

Class	Definition	Skill level
Novice	No Experience, no knowledge	0 (blank)
Informed	Has basic knowledge, but not enough experience	0.5
Experienced	Well informend, has certain amount of experience	1
Expert	Well experienced, able to teach others	2

Table 2. Human resource ability matrix.

	Skill 1	Skill 2	Skill 3	Skill 4	Skill 5	Skill 6	Skill 7	Skill 8	Skill 9	Skill 10	plpara
HR 1	2	1	0.5	0	0	0.5	0.5	2	1	1	0.97
HR 2	1	2	0.5	0	1	0.5	0.5	0	0	0.5	0.83
HR 3	0	1	2	0	1	0	2	0.5	1	0	0.61
HR 4	0.5	0	0.5	2	0	1	0.5	0	0	2	0.76
HR 5	0	1	1	0.5	0	0	0	0	1	0.5	0.29
HR 6	0	0.5	1	0.5	0	0.5	1	1	0	1	0.42
HR 7	0	1	0	0.5	1	1	2	0	0	0.5	0.39
HR 8	0	1	1	1	2	0	0	0	0.5	1	0.65
HR 9	1	1	0	0	0.5	1	0.5	0.5	0	0.5	0.28
HR 10	0	0	1	1	0	1	1	0	0	0.5	0.43
HR 11	0	0.5	1	1	0	1	0.5	0	0.5	1	0.45
HR 12	2	0	0.5	0	0.5	0	0.5	1	0.5	1	0.54
HR 13	0	0.5	1	1	0	0	2	0	0.5	2	0.77
HR 14	1	0.5	0.5	1	0.5	0	0	0	1	0	0.3
HR 15	0.5	2	0	0	1	0	0	1	0	0.5	0.55
Total	8	12	10.5	8.5	7.5	6.5	11	6	6	12	–

the skill ability of each human resource is categorized into four levels, as shown in table 1. The detailed skill abilities of each human resource used in the applied example are given as shown in table 2. The data are arbitrarily set.

If the sum of the skill requirements for a selected candidate project exceeds the sum of the skills available from the pool of existing human resources, there exists a clear shortage for at least one skill in the development project. The following constraints are then given for each skill so that the allocated human resources can satisfy the required amount of skills. The number of existing human resources (people) is denoted n_r, the required amount of skill k for developing project i is denoted pskill_{ij}, and the level of ability of human resource j for skill k is denoted rskill_{kj}.

$$\text{For each skill } k, \quad g_0(\mathbf{y}) = \sum_{i}^{n_0} \left[\text{pskill}_{ik} * y_i\right] - \sum_{j}^{n_r} \text{rskill}_{jk} \tag{3}$$

In this paper, the skills that human resources have are numerically modelled, and the following assumptions are in effect: when the summation of skills reaches the skills needed for completion of the project, the project is considered feasible. The propositions were obtained by interviews with managers in practical enterprises.

3.3 *Selection of project leaders*

A project leader is selected for each selected candidate project. Each leader is charged with managing the human resources for their project, establishing connections and negotiating with other project leaders and external organizations, and grasping the overall status of their project during development.

Project leaders (PL) must have ability at an expert level for an important skill, called a core skill. Each core skill has an identifying number, which for project i is denoted cskill_i, among the various skills needed for the development project. Project leaders must also satisfy the required suitability conditions and have a project leader ability parameter plpara value greater than a specific value. A plpara value is given for each human resource, and ranges from 0 to 1. The PL is chosen from the entire pool of human resources, must satisfy both the foregoing two conditions, and the individual whose skill ability is most suitable for the project is selected as the project leader.

3.4 *Algorithms for allocation of human resources*

After the selection of the PL, optimum allocations of human resources for the projects are obtained by solving the following multi-objective optimization problem. The allocation solutions are shown in the form of allocation rates x_{ji} for development project i using human resource j. The abilities offered by each human resource are allocated to the corresponding projects according to these allocation rates.

$$\begin{aligned} &\text{Maximize} \quad F(\mathbf{x}) = [f_1, f_2, f_3] \\ &\text{Subject to} \quad g_1(\mathbf{x}) \leq 0, \quad x_{ji} \in \{0, 0.1, \ldots, 1\}, \quad \sum_i x_{ji} = 1 \end{aligned} \tag{4}$$

Each of the three objective functions f_1, f_2 and f_3 was formulated based on the discussions with industry managers as described below.

3.4.1 Satisfaction levels of skills required for a development project. The skill satisfaction level function f_1, which is to be maximized, expresses the ratio of the sum of the skills available from the human resources when compared with the aggregate skills required for completion of the project under development.

When the relative priority among development projects is p_i, f_1 can be formulated as follows:

$$f_1(\mathbf{x}) = \sum_i^{\mathrm{n}} \left[\mathrm{p}_i * \frac{1}{n_s} \sum_k^{n_s} \sum_j^{n_{ri}} \frac{\mathrm{rskill}_{jk} * x_{ji}}{\mathrm{pskill}_{ik}} \right] + \min_{i,k} \left\{ \sum_j^{n_{ri}} \frac{\mathrm{rskill}_{jk} * x_{ji}}{\mathrm{pskill}_{ik}} \right\} \tag{5}$$

where n_s is the total number of skills. The first term of the right-hand side of equation (5) represents the increase in mean satisfaction level for all skills. The second term is used to improve the solution searching efficiency performed by the genetic algorithms. That is, the term regarding the project having the lowest skill satisfaction level is added to the first portion to increase the skill satisfaction levels of all development projects as equally as possible. The second term may be not necessary for cases other than use of the genetic algorithms.

The feasibility of each project depends most crucially on the set of the required skills and their detailed characteristics, and the skill satisfaction level function f_1 is considered the most important function among the three objective functions. Here, both a surplus of skills and insufficient skills are to be avoided as much as possible. The following constraint is applied to the optimization.

$$\text{For each } i \text{ and } k, \quad \text{if } \sum_{j}^{n_{ri}} \frac{\text{rskill}_{jk} * x_{ji}}{\text{pskill}_{ik}} \geq 1 \quad \text{then} \quad \sum_{j}^{n_{ri}} \frac{\text{rskill}_{jk} * x_{ji}}{\text{pskill}_{ik}} = 1 \tag{6}$$

3.4.2 Human resource career path satisfaction levels. The section managers may stipulate that each human resource follow specific career paths. These career paths are treated as 'meeting required skill conditions'. The career path satisfaction level function f_2, which is to be maximized, is expressed as the satisfaction level of the section managers. When the satisfaction level for human resource j allocated to project i is cplan_{ji}, f_2 is formulated as follows:

$$f_2(\mathbf{x}) = \frac{1}{n_r} \sum_{j}^{n_r} \sum_{i}^{n_0} \left[\text{cplan}_{ji} * x_{ji}\right] + \min_{i} \left\{ \sum_{i}^{n_0} \left[\text{cplan}_{ji} * x_{ji}\right] \right\} \tag{7}$$

The first term represents the increase in the mean satisfaction level for all human resources, while the second term represents the increase in the satisfaction level for the human resource having the lowest satisfaction level. The second term may only be necessary for cases using genetic algorithms.

3.4.3 Human resource motivation. A worker's motivation is here considered from two points of view: the requirement to meet the individual's aspiration (need for progress and advancement) and the requirement concerning the external working environment (compatibility among cohorts). Concerning the aspiration requirement, the characteristics of the projects to which particular human resources are allocated should necessarily satisfy each individual's needs as much as possible. As for the external working environment, compatibilities among the working partners are evaluated and play an important role in the selection of particular personnel for a given project. The summation of the satisfaction levels with respect to the foregoing two points of view is expressed as the motivation function f_3, which is to be maximized, where the first term represents the increase in the mean satisfaction level for all human resources, while the second term represents the increase in satisfaction level for the human resource having the lowest satisfaction level.

$$f_3(\mathbf{x}) = \frac{1}{n_r} \sum_{j}^{n_r} \text{mot}_j + \min_{j} \{\text{mot}_j\}$$

where

$$\text{mot}_j = \sum_{i}^{n_0} \left[\left(w_{31} * \text{rsat}_{ji} + w_{32} * \sum_{l \neq j}^{n_{ri}} \frac{\text{rcomp}_{jl}}{n_{ri} - 1} \right) * x_{ji} \right] \tag{8}$$

The second term of the right-hand side of equation (8) is used to improve the genetic algorithms' solution searching efficiency. That is, the term regarding the project having the lowest level is added to the first portion, to increase the satisfaction level for all human resources as equally as possible. $rsat_{ji}$ is the level of desire that human resource j has for working on project i (in terms of the fulfilment of future career benefit to the worker), and $rcomp_{jl}$ is the compatibility level of human resource j with human resource l. The compatibility level between personnel who haven't worked together before is set as a neutral value of 0.5. w_{31} and w_{32} are weighting coefficients. As above, the second term of equation (8) may only be necessary for cases using genetic algorithms.

3.4.4 Description of genetic algorithms. As shown in the formulations used in this study, the human resource allocation optimization problem is a nonlinear combinatorial optimization problem, in which discrete design variables such as x_{ji} are also included. This allows genetic algorithms (hereafter abbreviated as GAs) to be used during the optimization procedure. The optimization problem being regarded includes discrete variables and multiple objective functions and GAs are the most effective optimization tool in such circumstances. A two-stage heuristic optimization procedure is used, namely (1) selection of projects and (2) determination of human resource allocations. It is difficult to assure global optimality for the current problem but heuristically optimum solutions can be obtained using the proposed methods.

In GAs parameters at the searching point are expressed in an individual comprised of a sequence of genes. Genetic operations such as selection, crossover, and mutation are conducted for sets of individuals, and the results evolve toward optimal solutions. The efficiency of the search for optimum solutions largely depends on the suitability of the coding of decision variables into genotypes, and the adjustments of genetic operators.

Decision variables in the human resource allocation problem used in this paper are the time allocation rates x_{ji} for human resource j to development project i. As described in section 2.2, decision variables x_{ji} are discrete variables in which the range [0,1] is equally divided into 10 steps. The sum of x_{ji} for each human resource over the all allocated projects must be 1. Considering these points, decision variables x_{ji} are coded as a gene sequence, as shown in figure 3. In this gene sequence coding, a "0" represents a time allocation step of 0.1, i.e. 10% of the total time a worker devotes to all projects. The number 1 simply represents a partition, or

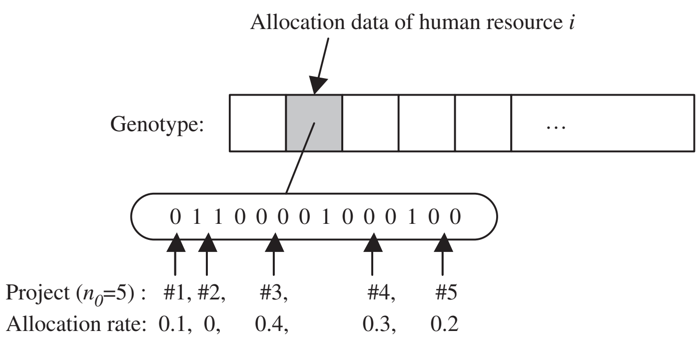


Figure 3. Genotype.

'separator' between adjacent development projects. In practice, the code expression for each human resource will have 10 zeros, representing the total allocation time distributed over n_0 projects, and $(n_0 - 1)$ number of 1s that partition n_0 development projects.

3.4.5 Pareto optimum solution sets including the total profit criterion. The skill satisfaction levels in development projects and the completion time of the projects directly influence the speed of project progress and the profit, respectively. The total profit f_0 when each non-inferior solution is adopted can be recalculated according to the following equation:

$$f_0(\mathbf{x}) = \sum_{i}^{n_0} \left[\frac{1}{n_s} \sum_{k}^{n_s} \sum_{j}^{n_{ri}} \frac{\text{rskill}_{jk} * x_{ji}}{\text{pskill}_{ik}} * (w_{01} * \text{eprofit}_i + w_{02} * \text{importance}_i) \right] \quad (9)$$

After adding the recalculated total profit f_0 to the non-inferior solutions forming the Pareto optimum solution set for the three objective functions $\{f_1, f_2, f_3\}$ of n candidate projects, a new Pareto optimum solution set for the four objective function $\{f_0, f_1, f_2, f_3\}$ is formed. The improved non-inferior solutions are then shown to the decision maker. When there are an excessive number of non-inferior solutions, a process to reduce the number to a manageable quantity is necessary.

4. Applied numerical example

4.1 *Problem descriptions*

The proposed decision-making supporting optimization system was applied to hypothetical numerical problems composed of 15 human resource individuals, 10 skills, and 12 candidate development projects. Table 2 lists the individual's skills, while table 3 shows information concerning the candidate development projects. Comparison of the two tables reveals that the total number and quality of skills that are required for all the candidate projects is insufficient. Thus, selection of development projects that can be successfully adopted is required.

4.2 *Results*

The result obtained by completing the project selection algorithm, using the two data matrices given, is shown in table 4. GAs were used for the optimization. The number of project sets, n, that the optimization procedure is applied to, is 4. In table 4, the value of the cells in the columns under the project heading shows whether or not project i is adopted in group p of the project sets. 1 (one) means that the project is adopted, while 0 (zero) means that it is not adopted.

In order to decrease the computation time, optimization for each group of the project sets can be processed using parallel computation techniques.

In order to clarify the flow of the proposed decision making supporting system in detail, the results for project set $p = 1$ are explained below. The adaptability of human resources with respect to the project leader of each project, and the selected project leaders, are shown in table 5. The numerical values in the cells of table 5

Table 3. Project data matrix.

	Skill 1	Skill 2	Skill 3	Skill 4	Skill 5	Skill 6	Skill 7	Skill 8	Skill 9	Skill 10	eprofit	Importance	Core skill No.
Project 1	5	4	3	0	2	0	0	4	3	4	1	0.2	1
Project 2	3	5	0	0	3	3	2	2	0	2	0.5	0.8	2
Project 3	0	3	5	3	2	0	4	0	3	2	0.7	0.3	3
Project 4	0	0	2	5	0	3	4	0	0	4	0.3	0.6	4
Project 5	3	0	0	2	4	0	5	0	4	0	0.3	0.5	7
Project 6	5	3	2	3	2	0	0	0	3	2	0.5	0.9	1
Project 7	2	4	3	0	0	4	2	4	0	5	0.9	0.4	10
Project 8	2	0	4	0	5	2	0	2	2	0	0.2	0.6	5
Project 9	0	0	2	2	0	3	4	3	0	5	0.4	0.5	10
Project 10	0	0	3	3	2	4	5	3	0	4	0.9	0.3	7
Project 11	0	5	2	2	0	4	0	3	3	0	0.4	0.7	2
Project 12	4	5	0	3	2	0	3	2	2	0	0.6	0.4	2
Total	24	29	26	23	22	23	29	23	20	28	6.7	6.2	–

Table 4. Result of project selection algorithm.

	Project												
p	1	2	3	4	5	6	7	8	9	10	11	12	f_0
1	0	1	1	0	0	1	0	0	1	0	0	0	2.3
2	1	1	1	1	0	0	0	0	0	0	0	0	2.2
3	0	0	1	0	0	1	1	0	0	0	0	0	1.8
4	0	1	1	0	0	1	0	0	0	0	0	0	1.8

Table 5. Result of choosing project leaders ($p = 1$).

	Project 2	Project 3	Project 6	Project 9
HR 1			5.5 (3)	
HR 2	5.5 (0.5)			
HR 3		7 (0.5)		
HR 4				6 (0.5)
HR 5				
HR 6				
HR 7				
HR 8				
HR 9				
HR 10				
HR 11				
HR 12			4.5 (1.5)	
HR 13				6 (1)
HR 14				
HR 15	5 (0)			
PL	HR 2	HR 3	HR 12	HR 4

indicate that a particular human resource is a potential project leader for the project being considered. Larger cell values imply an improved potential to act as the project leader. The values in parentheses indicate a value concerning skills that are not needed for the given project, and smaller values are preferable. The numerical values outside the parentheses indicate the sum of the levels for skills that are needed for developing the project, so larger values are preferable and the human resource with the largest value is dominant for selection as leader of a particular project. When human resources have the same values outside the parentheses, the human resource having the smaller parenthetical value is selected, since human resources having larger values for skills not needed for the particular project have a greater potential for being selected to participate in other projects. The empty cells imply that the adaptability levels were too low for meaningful consideration.

The human resource allocation problem constructed in this paper is a multi-objective optimization problem having four objective functions. In such multi-objective optimization problems, specific constraints or conditions are difficult to establish when the optimization formulation is defined. Candidate optimum solutions that are initially obtained should be expressed as a Pareto optimum solution set, which contains a number of solutions. The Pareto optimum solution set express the conflicting relationships between the objective functions. To select the optimum

Table 6. Four peculiar allocation from Pareto optimal solution set ($p = 1$).

	f_1	f_2	f_3	Average
f_1-max	1.421	0.536	1.116	1.024
f_2-max	0.885	1.423	1.002	1.103
f_3-max	1.071	1.164	1.443	1.226
Average-max	1.292	1.286	1.340	1.306

Table 7. Five peculiar allocation from renewed Pareto optimal solution set.

	f_0	f_1	f_2	f_3	Average	p
f_0-max	2.003	1.421	0.536	1.116	1.269	1
f_1-max	1.793	1.849	1.154	1.111	1.477	4
f_2-max	1.548	1.162	1.608	1.034	1.338	3
f_3-max	1.773	1.071	1.164	1.443	1.362	1
Average-max	1.821	1.328	1.286	1.442	1.520	2

solution from a group of candidate solutions, decision-supporting procedures are followed, in which unsuitable Pareto optimum solutions are gradually discarded according to the desired features of the solutions being sought. Details concerning the process for discarding unsuitable solutions are specified based on observations of the solution results.

Table 6 shows the figures for four allocation solutions and the maximum values of f_1, f_2, f_3, as well as the mean for f_1, f_2, and f_3, as examples of distinctive characteristics of the non-inferior solutions.

Concerning the selected project set, $p = 1$, the human resource allocation algorithm was applied using GAs. The resulting Pareto optimum solution set consists of 183 non-inferior solutions.

The total number of non-inferior solutions in the Pareto optimum solution set for the four project sets was 604. The total profit f_0 according to equation (9) was calculated for each of the 604 allocation solutions. A Pareto optimum solution set for the four objectives $\{f_0, f_1, f_3, f_4\}$ (the three objectives $\{f_1, f_2, f_3\}$ plus f_0) was then obtained. This resulted in a reduction in the number of non-inferior solutions, to 340.

In a similar fashion as for table 6 and 7 shows five distinctive characteristics of the non-inferior solutions, including the solution having the maximum value of f_0.

The fact that many non-inferior solutions were obtained means that diverse solutions can be shown to the decision maker. That this can be done is preferable, but a detailed examination of all the solutions is impossible. Therefore, the group of candidate solutions was further reduced.

The first step to implement a further reduction in the number of candidate solutions was to set a condition that the satisfaction levels for the core skills and the satisfaction levels for the other required skills must be greater than 0.7 and 0.5, respectively, to increase the feasibility of each development. The number of non-inferior solutions was thus reduced from 340 to 149, but since this number was still too large, the following procedure was conducted.

Table 8. Final alternatives for decision-making.

		f_0			f_1			f_2			f_3	
	p	Potential	Expected		Minimum	Average		Minimum	Average		Minimum	Average
60	2	2.2	1.868	1.432	0.583	0.849	1.355	0.55	0.805	1.213	0.527	0.686
64	2	2.2	1.864	1.447	0.600	0.847	1.364	0.55	0.814	1.209	0.527	0.682
106	4	1.85	1.788	1.716	0.750	0.966	0.796	0.1	0.696	1.233	0.543	0.690
130	4	1.85	1.772	1.698	0.740	0.958	0.888	0.1	0.788	1.263	0.574	0.690
137	4	1.85	1.766	1.715	0.760	0.955	1.350	0.5	0.850	1.223	0.558	0.665
139	4	1.85	1.762	1.732	0.780	0.952	1.304	0.5	0.804	1.215	0.553	0.662
142	4	1.85	1.758	1.690	0.740	0.950	0.850	0.1	0.750	1.264	0.572	0.692
149	4	1.85	1.751	1.646	0.700	0.946	1.208	0.4	0.808	1.259	0.565	0.693
150	4	1.85	1.750	1.713	0.767	0.946	1.188	0.4	0.788	1.229	0.542	0.687

The second step set a lower limit constraint for the total profit f_0, the most important criterion for companies, so that obtaining the required profit was more likely. That is, the total profit f_0 returned by equation (9) must be greater than 1.75. The number of non-inferior solutions was reduced to 50, which is still too large, so the number of candidate solutions was reduced by a third step.

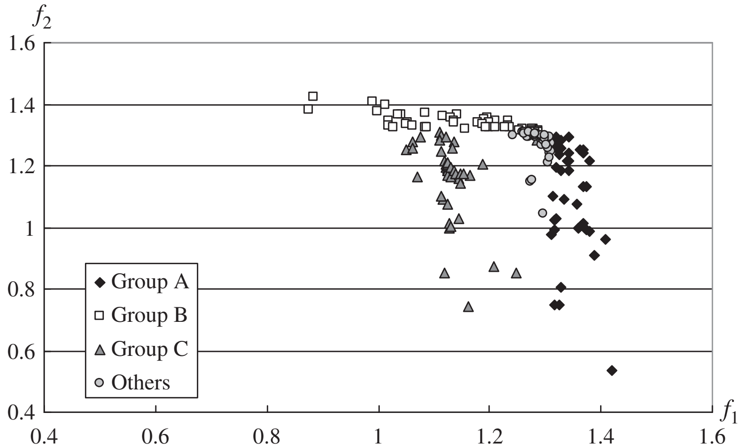
The third step set a lower limit of 1.2 for the motivation function f_3, to improve selecting allocation results that better satisfy human resource motivations.

Using the foregoing three-step candidate solution reduction procedure, the number of non-inferior solutions was reduced to nine, as shown in table 8. The decision maker then conducted comparative investigations for six non-inferior solutions, having excluded three solutions (solutions 106, 130 and 142) that had extremely low career path satisfaction levels where the minimum value was less than 0.2, and finally was able to select the best solution. In this example, the career path satisfaction level was an important factor promoting future job-related activity, so solution 137, which had the greatest average career path satisfaction level of 0.850, was selected as the final solution. This paper described the process for discarding unsuitable solutions; however, the selection of the very final solution depends on the specifics of the company in question and/or the decision makers' particular preferences.

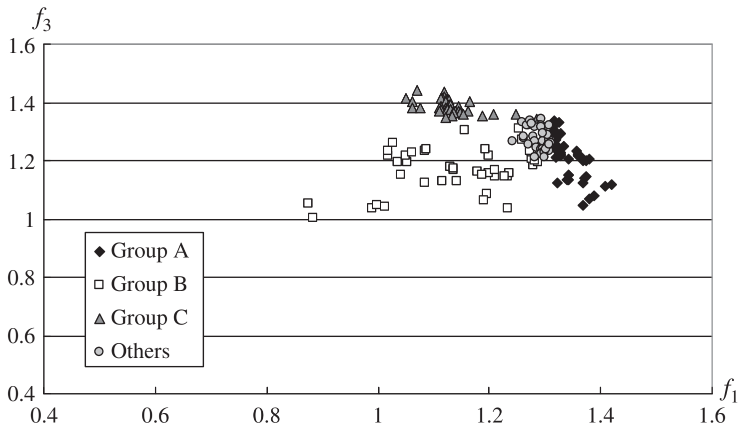
5. Discussion

In order to verify the effectiveness of the proposed method, the human resource allocation problems were considered not only from the standpoint of the feasibility of the projects but also with respect to the satisfaction levels concerning the career path and motivation of the participating personnel. The human resource allocation results were investigated for the selected $p = 1$ project set.

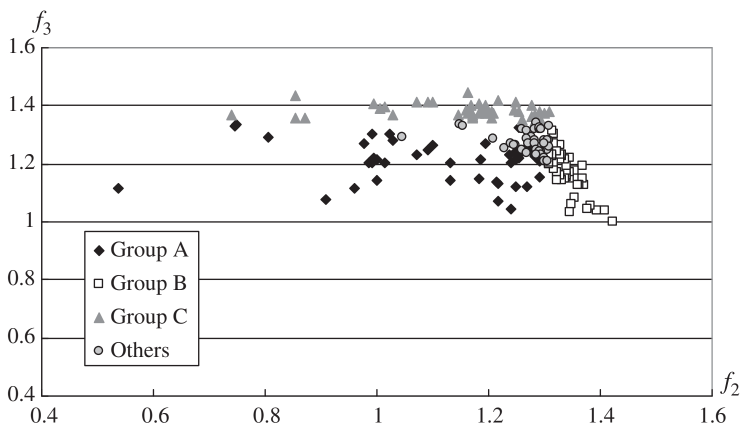
The Pareto optimum solution set results for f_1, f_2, and f_3 were cut along three planes in two-dimensional space, namely f_1 and f_2, f_1 and f_3, and f_2 and f_3, as shown in figure 4. For comparison of the results, the non-inferior Pareto solutions were categorized into four groups, A, B, C, and one group including all others. Groups A, B, and C each represent the selected best 25% of non-inferior solutions from the company-wide pool of human resources, i.e. individuals having better values



(a) $f_1 - f_2$ cross section



(b) $f_1 - f_3$ cross section



(c) $f_2 - f_3$ cross section

Figure 4. Cross sections of Pareto optimal solution set ($p = 1$).

from the standpoint of the skill satisfaction function f_1 (group A), the career satisfaction level function f_2 (group B), and the motivation function f_3 (group C). In this example, each non-inferior solution happened to belong to only one of the groups, i.e. after optimization, no human resource wound up present in more than a single group.

When skill levels are the single consideration when evaluating the feasibility of each development project in terms of human resource allocation, effectively all allocation solutions will belong to group A alone. However, such solutions are inferior to those of the other groups from the standpoints of the career path and/or motivation of the participating personnel.

It can be understood that human resource allocation based solely on the evaluation of the skill satisfaction levels will be unable to provide allocation results that also address career path advancement and motivational concerns. Similar difficulties were seen from the results based on the use of groups B and C in isolation. Thus, an integrated method, such as proposed in this paper, which concurrently evaluates the three functions pertaining to the human resources (skills, career path, and motivation), is required for the optimal allocation of personnel to development projects.

6. Concluding remarks

This paper constructed an optimization system supporting a bilateral decision-making processes enabling (1) the selection of suitable development projects, and (2) the optimum allocation of human resources. This study can be summarized as follows:

1. The constructed optimal allocation decision-making algorithm balances the participation of individual human resources in multiple projects by using time allocation rates expressed as decision variables.
2. The human resources were treated here as human beings having particular personalities and abilities. Selection of project leaders was carried out prior to the allocation of human resources. The career path and motivation/satisfaction levels for individual workers were included in the formulation of the human resource allocation problem integrated in the feasibility evaluation for each of the several development projects included in the selected project set.
3. Possible project sets are simultaneously evaluated and selected, and for each of the project sets the optimum allocation candidate solutions concerning human resources are obtained as global views of the Pareto optimum solution sets, in which the more preferable solutions are included.
4. The proposed optimum human resource allocation method was applied to numerical examples, and the effectiveness of the method was discussed.

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