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A METHOD FOR SELECTING THE OPTIMAL PORTFOLIO OF PERFORMANCE IMPROVEMENT PROJECTS IN A MANUFACTURING SYSTEM

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This paper proposes a method for selecting the optimal portfolio of performance improvement projects in a manufacturing system. The proposed method consists of evaluation process and selection process for selecting the optimal portfolio. In the evaluation process, the strategic value of a project portfolio is evaluated by considering both the strategy and the performance improvement of a system. In the selection process, the objective is to maximize the strategic value of a project portfolio without violating constraints and a genetic algorithm is used to select the optimal project portfolio. The strategic value of a project portfolio obtained in the project portfolio evaluation process is used as the fitness function of the genetic algorithm. An example of a project portfolio selection in a manufacturing system is discussed in order to illustrate the proposed project portfolio selection method.

Significance: This paper introduces a method for selecting the optimal project portfolio based on system performance improvement.

Keywords: Project portfolio selection, Project portfolio evaluation, Performance measurement, Genetic algorithm

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1. INTRODUCTION

A project portfolio is a group of projects that are carried out under the sponsorship and/or management of a particular organization. These projects must compete for scarce resources (people, finances, time, etc.) that are available from the sponsor, since there are usually not enough resources to carry out every proposed project. Project portfolio selection is the periodic activity involved in selecting a portfolio from available project proposals and projects currently underway that meets the organization's objectives in a desirable manner without exceeding available resources or violating other constraints (Archer and Ghasemzadeh, 1999).

Due to the importance of project portfolio selection, many portfolio selection methods have been developed (Archer and Ghasemzadeh, 1999; Dickinson *et al.*, 2001). The metrics used to select projects range from quantitative (e.g., return on investment) to qualitative (e.g., alignment with company strategy) measures. Different portfolio management tools have been developed to maximize different metrics. Mathematical and scoring models are used where quantitative metrics are available. Graphics and charting are used to evaluate qualitative metrics.

In previous studies, the formulation of the project portfolio selection problem assumes that the values of individual projects are independent and that the value of the portfolio is additive (i.e., the value of the overall portfolio is the sum of the projects' values) (Klastorin, 2004). However, the value of a project portfolio is not necessarily the sum of the values, since the value obtained by a project depends quite often on the level of improvement of the other projects. And this makes it very difficult to evaluate the value of an individual project in a manufacturing system independently. So the approach for evaluating a project portfolio must consider a project portfolio as a system design alternative, and evaluate the value of a project portfolio as system performance improvement from the system design perspective. Also, a project portfolio evaluation needs to assist the three goals of project portfolio management: (1) linking with strategy, (2) maximizing portfolio value, and (3) seeking the right balance of projects. Therefore, project portfolio evaluation needs to consider both the strategy and the performance of a system. In order to meet these needs, it requires that (1) performance measures are aligned to the organization's strategic objectives and (2) alternative portfolios are evaluated by considering both these objectives and the improvement of performance measures.

Cochran *et al.* (2000b) suggested that performance measures in a manufacturing system must be derived from the functional requirements of the manufacturing system design decomposition and the design of the manufacturing system decomposition must be based on the manufacturing strategy. Duta (2000) showed the usefulness of the axiomatic design decomposition approach for the development of an effective set of performance measures in a manufacturing system.

The objective of this study is to develop a method for selecting the optimal portfolio of performance improvement projects in a manufacturing system. The proposed method consists of evaluation process and selection process for selecting the optimal portfolio. In the project portfolio evaluation process, this paper presents a performance measurement model, performance evaluation of a project portfolio, and strategic evaluation of a project portfolio. The performance measurement model considers both a decomposition model of a manufacturing system and performance measures that are derived from manufacturing system design decomposition. The value of a project portfolio is evaluated by relating system performance improvement by a project portfolio to the target values of the performance measures and the requirements of a manufacturing system. Then, as a means to evaluate the strategic value of a project portfolio that considers both the strategy and the value of a project portfolio, matrices are formed to express the relationships among strategic objectives, performance measures, and the performance improvement of a project portfolio. A combination of these matrices results in the generation of a strategic performance matrix that is used to evaluate the strategic value of a project portfolio. In the project portfolio selection process, a genetic algorithm is used to select the optimal project portfolio among alternative portfolios. In the genetic algorithm, the strategic value of a project portfolio obtained in the project portfolio evaluation process is used as the fitness function. An example in a manufacturing system is discussed to illustrate the proposed project portfolio selection method.

2. PROJECT PORTFOLIO EVALUATION PROCESS

In this paper, the project portfolio evaluation process consists of three phases: (1) prioritization of performance measures, (2) performance evaluation of a project portfolio, and (3) strategic evaluation of a project portfolio. Figure 1 shows the project portfolio evaluation process. The following explains the phases of the process in details.

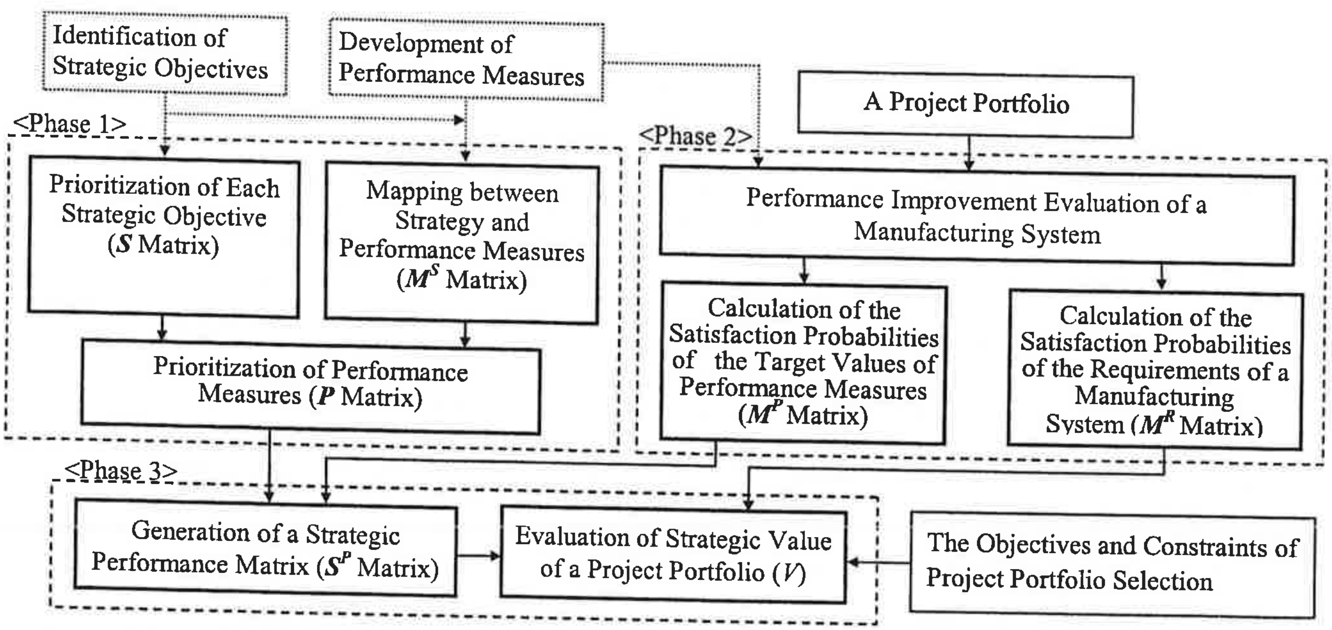

Figure 1. Project Portfolio Evaluation Process

2.1 Prioritization of Performance Measures

This process determines the relative importance of each performance measure with respect to the strategic objectives of a manufacturing system, and consists of three steps: (1) prioritization of each strategic objective, (2) mapping between strategy and performance measures, and (3) prioritization of performance measures (Duta, 2000).

2.1.1 Prioritization of Each Strategic Objective

In order to reflect the priority or relative importance of each aspect of strategy, an $s \times s$ priority matrix, S, is defined, where s is the number of relevant strategic objectives. Each diagonal element of the matrix, S_{ij}, represents the relative importance of strategic objective i to strategic objective j, using a scale range from 0 to 1. For simplicity of description, this process for determining the values of each diagonal element of S matrix is not described in this paper. For details, refer to Satty (1980) and Duta (2000).

2.1.2 Mapping between Strategy and Performance Measures

In order to map strategy to performance measures, an $s \times l$ mapping matrix, M^S, is used, where s is the number of relevant strategic objectives, and l is the number of performance measures. Each element of this matrix, M_{ij}^{s}, contains information describing the extent to which performance measure j impacts on the system performance with respect to the strategic objective i.

2.1.3 Prioritization of Performance Measures

Multiplication of the priority matrix S by the mapping matrix M^S yields another priority matrix, P (of size $s \times l$), as shown in Equation (1).

$$P = S \times M^S \tag{1}$$

This matrix indicates the relative importance of each performance measure with respect to the strategic objectives of a manufacturing system.

2.2 Performance Evaluation of a Project Portfolio

This process calculates the satisfaction probabilities of the target values of the performance measures and the requirements of a manufacturing system. In order to ensure global optimization of a manufacturing system, this paper proposes a performance measurement model that considers a decomposition model of a manufacturing system and performance measures that are derived from manufacturing system design decomposition. The value of a project portfolio is evaluated by relating system performance to the target values of the performance measures and the requirements of a manufacturing system.

2.2.1 Performance Measurement of a Manufacturing System

(1) Decomposition Model of a Manufacturing System

A decomposition model of a manufacturing system that consists of production units and several supporting units is shown in Figure 2. Each production unit is decomposed into sub-production units. In this model, a production unit unifies direct functions (operational/manufacturing processes) and decentralized indirect functions (informational processes) such as quality control, maintenance, production planning and control, R&D, product planning, shipping, service, and others (Cochran *et al.*, 2000a).

(2) Performance Measurement Model of a Manufacturing System

In order to ensure global optimization of a manufacturing system, a performance measurement model needs to synthesize the performance measurements of sub-production units. Therefore, this paper proposes a performance measurement model considering a decomposition model of a manufacturing system and the values of performance measures of sub-production units. This performance measurement model consists of value functions for each performance measure of a manufacturing system.

Due to the complexity of the model, value functions need to be reasonably simplified. In this paper, the following assumptions are considered.

- The structure of performance measures is the same across the sub-production units in the decomposition model of a manufacturing system.
- The production units (or sub-production units) can be modeled as a linked system.
- The value of a performance measure of a production unit is determined by the values of the corresponding performance measures of the sub-production units.

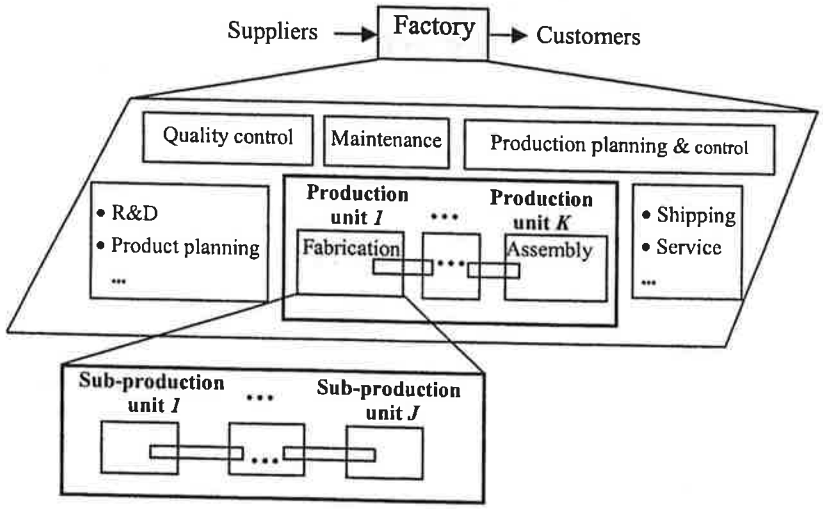

Figure 2. Decomposition Model of a Manufacturing System

The proposed value function for performance measure *i* of production unit *k* (*k*=1, ..., *K*) is shown in Equation (2)

$$Y_i^k = min\ \{X_i^{k1}, X_i^{k2}, ..., X_i^{kj}, ..., X_i^{kJ}\} \quad (2)$$

where

Y_i^k is the value of performance measure *i* (*i*=1, ..., *I*) of production unit *k* (*k*=1, ..., *K*),

X_i^{kj} is the value of performance measure *i* of sub-production unit *j* (*j*=1, ..., *J*) that is decomposed from production unit *k*,

I is the total number of performance measures,

J is the total number of sub-production units, and

K is the total number of production units.

Equation (2) shows that the value of performance measure *i* of production unit *k* is the lowest value of the corresponding performance measures of the sub-production units.

2.2.2 Performance Evaluation of a Project Portfolio

In performance evaluation of a project portfolio, the following assumptions are considered.

1. The improvement values of the performance measures expected at the sub-production units by individual project proposals are given. In determining the values of individual project proposals at the sub-production units, the interaction among projects is not considered.
2. All of the project proposals have the same funding cycle.

Performance evaluation of a project portfolio proceeds as follows.

<Step 1: Performance Improvement Evaluation of a Manufacturing System>

Once a project portfolio and the current values of the performance measures of a manufacturing system are identified, the values of the performance measures are determined using the performance measurement model, as shown in Equation (2).

<Step 2: Calculation of the Satisfaction Probabilities of the Target Values of Performance Measures>

A mapping matrix, M^P, can be formed to describe how well a particular project portfolio satisfies the target values of the performance measures of a manufacturing system. The value of each element of the matrix, $M^P{}_i$, is the possibility of the satisfaction (P_s=A_{cr}) of the target value of performance measure *i*, as shown in Figure 3.

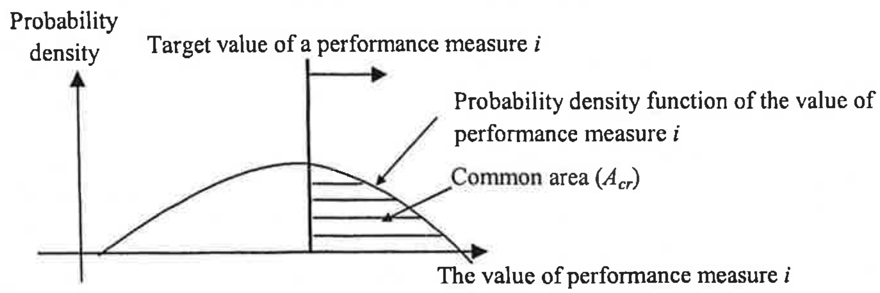

Figure 3. System Parameters for Defining Satisfaction Possibility (Suh, 2001)

<Step 3: Calculation of the Satisfaction Probabilities of the Requirements of a Manufacturing System>

A requirement matrix, M^R, can be formed to describe whether a project portfolio satisfies the requirements of a manufacturing system. Each element of the matrix, M^R_i, has a value 0 or 1, depending on the possibility of the satisfaction of requirements. In this paper, the requirements is defined as the minimum values of the performance measures of a production unit, and the value of each element of the matrix, M^R_i, is determined as follows: If the satisfaction possibility of the minimum value of performance measure *i* is 100%, the value of M^R_i is 1. Otherwise the value is 0.

2.3 Strategic Evaluation of a Project Portfolio

In order to evaluate the strategic value of a project portfolio that considers both the strategy and the value of a project portfolio, the following steps are proposed.

<Step 1: Generation of Strategic Performance Matrix>

Once the information on the prioritization of performance measures and the performance evaluation of a project portfolio are obtained in matrix form, a strategic performance matrix, S^P, can be generated as shown in Equation (3).

$$S^P = P \times M^P \tag{3}$$

Each element, S^P_i, provides information regarding how much a project portfolio can meet the strategic objective *i*.

<Step 2: Strategic Project Portfolio Evaluation>

The strategic value of a project portfolio, *V*, is defined as shown in Equation (4).

$$V = \begin{cases} \sum_{i=1}^{s} S_i^P & \text{if } \forall M_i^R \text{ are satisfied} \\ 0 & \text{otherwise} \end{cases} \tag{4}$$

As shown in Equation (4), the evaluation defines that the strategic value of a project portfolio is the sum of the each element of strategic performance matrix (S^P_i) and assumes that if any requirement is not satisfied, the performance of the system does not improve.

3. PROJECT PORTFOLIO SELECTION PROCESS BASED ON GENETIC ALGORITHM

Genetic Algorithm (GA) is one of the stochastic search algorithms based on the mechanism of natural selection and natural genetics (Goldberg, 1989). GA has received considerable attention regarding their potential as a novel optimization technique. There are three major advantages when applying GA to optimization problems: (1) *Adaptability*: GA does not have much mathematical requirements about the optimization problems. Due to the evolutionary nature, GA will search for solutions without regard to the specific inner workings of the problem. GA can handle any kind of objective functions and any kind of constraints, i.e., linear or non-linear, defined on discrete, continuous or mixed search spaces. (2) *Robustness*: The use of evolution operators makes GA very effective in performing global search (in probability), while most of conventional heuristics usually perform local search. It has been proved by many studies that GA is more efficient and more robust in locating optimal solutions and reducing computational effort than other conventional heuristics. (3) *Flexibility*: GA provides us a great flexibility to hybridize with domain-dependent heuristics to make an efficient implementation for a specific problem (Gen and Cheng, 1997).

Project portfolio selection matches the advantages of GA. Project portfolio selection is a constrained optimization problem and a mathematical formulation of an optimization model is very difficult when considering the interactions among projects such as benefit interactions, technical interactions, and resource interactions (For details about the interactions, refer to Schimidt (1994)). Therefore, in this paper, GA is used as a solution method for selecting the optimal portfolio of projects. In order to apply the GA to the project portfolio selection problem, the GAlib, genetic algorithm package (Wall, 2004), is used. The following describes the chromosome representation and fitness function in the GA application.

3.1 Chromosome Representation

In the project portfolio selection problem, each gene of a chromosome represents each project proposal. The length of the chromosome represents the number of project proposals. Let the number of project proposals be N; a chromosome can then be represented as follows:

$$S_j = [P_1 \; P_2 \; P_3 \ldots P_k \ldots P_N]$$

where S_j is the j^{th} chromosome and P_k is the k^{th} gene.

Since the project portfolio selection problem is modeled as (0, 1) variables, the value of each gene is mapped to 0 or 1. If the value of the k^{th} gene is 1, project proposal i is selected to the portfolio. Otherwise, vise versa.

3.2 Fitness Function

The objective of project portfolio selection is to maximize the strategic value of a project portfolio without violating constraints. Therefore, the proposed fitness function of the GA consists of the strategic value (V) of a project portfolio and a penalty function as shown in Equation (5).

$$f\,(x) = g(x) + \sum_{i=1}^{m} C_i \delta_i \qquad (5)$$

where

$f(x)$ is the fitness function,

$g(x)$ is the project portfolio evaluation function that calculates the strategic value (V)of a project portfolio,

C_i is a penalty value imposed for violation of constraint i $(i=1,..,m)$,

δ_i is a zero-one value whether constraint i is violated or not, and

m is the total number of constraints in project portfolio selection.

In this study, the penalty values were determined so as to make the fitness function zero if any constraint is violated. The constraints in selecting a project portfolio are available resource amount, inter-dependence of project proposals (e.g., (1) project proposal 1 and 7 do not selected together, (2) project proposal 1 and 9 are selected together, etc.), resource allocation balance between sub-system areas, periods, project types, etc. In case of the available resource amount, it is checked whether the total resource amount required in a selected project portfolio exceeds the available resource amount or not. In case of inter-dependence of project proposals, constraints regarding mutual exclusiveness and/or simultaneous selection are defined, and then it is checked whether a selected project portfolio satisfies the constraints or not. In case of resource allocation balance, the range of numbers of projects to be allocated for each sub-system according to the project types is defined and then it is checked whether a selected project portfolio satisfies the range of numbers of projects or not.

4. AN EXAMPLE IN A MANUFACTURING SYSTEM

This example considers the following situations. "A manufacturing manager of a car manufacturer needs to choose how to prioritize 20 projects available to him. He has to balance their impact on strategy and their likelihood of improving current performance; but has limited resources." This example considers a production unit of a manufacturing system that consists of three sub-production units. The following describes the inputs for project portfolio selection and the experimental results of project portfolio selection in the manufacturing system.

4.1 Inputs for Project Portfolio Selection

(1) The Current and Target Values of the Performance Measures and the Requirements of the Manufacturing System

The performance measures (PMs) used in this example were derived from the axiomatic design decomposition of a car manufacturing system, which was developed by the authors based on Manufacturing System Design Decomposition (Cho, 2003). The current and target values of the performance measures and the requirements are shown in Table 1 and considered as qualitative ratings (e.g., 5- very good; 4-good; 3-moderate; 2-bad; 1-very bad). For example, in case of PM-Q11 "Number of defects caused by machine errors", the current values of the performance measures of sub-productions unit 1, 2, and 3 are 3(moderate), 4 (good), and 5 (very good), respectively. And the requirement and target value of the performance measure of production unit is 3 (the moderate) and 4 (good), respectively.

Table 1. The Current and Target Values of the Performance Measures (PMs) and the Requirements

Index of PMs	Description of PMs	Current Values of the PMs of Sub-Production Units			Requirements of the PMs of Production Unit	Target Values of the PMs of Production Unit
		1	2	3		
1	PM-Q11 Number of defects caused by machine errors	3	4	5	3	4
2	PM-Q12 Process capability of the method used	4	4	3	4	5
3	PM-Q131 Operator training	4	3	4	3	4
4	PM-Q132 The ability of operators to follow standard work methods	4	4	3	3	4
5	PM-Q133 Number of defects caused by human error`	4	3	4	3	4
6	PM-Q14 Number of defective parts received	4	3	4	3	4
7	PM-Q3 Process capability improvement over time	3	3	4	3	4
8	PM-P1 Mean time to failure, unplanned line downtime	3	5	4	3	4
9	PM-R11 Mean time to recognize disruptions	3	4	4	3	4
10	PM-R12 Mean number of people contacted to solve disruptions	3	4	4	3	4
11	PM-R13 Average time to solve problems	4	3	4	3	4
12	PM-T1 Run size	4	5	3	3	4
13	PM-T2 % of subsystems operating at customer takt time	5	3	4	3	4
14	PM-T3 Transportation lot size	3	4	4	3	4
15	PM-T4 Total transportation distance	4	4	3	3	4
16	PM-T5 Amount of production shortfall due to interference	3	5	4	4	5
17	PM-C1 % of value-adding work time of direct labor	4	5	3	3	4
18	PM-C2 % of support time of indirect labor	4	4	3	3	4
19	PM-C3 Floor space consumed	4	4	3	3	4

(2) Priority Matrix of Each Strategic Objective (S)

The strategic objectives pursued in this example are as follows:

S1: Cost
S2: Quality
S3: Delivery Performance-Throughput Time
S4: Volume Flexibility-Upwards.

An 4 × 4 priority matrix, S, used in this study is as follows:

$$S = \begin{matrix} S1 \\ S2 \\ S3 \\ S4 \end{matrix}\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0.65 & 0 & 0 \\ 0 & 0 & 0.37 & 0 \\ 0 & 0 & 0 & 0.13 \end{bmatrix}.$$

In the priority matrix, each diagonal element of the matrix, S_{ij}, represents the relative importance of the corresponding aspects of strategy. The priority matrix shows that the cost and quality continues to be the dominant factors in making decision, but the result also show that other strategic aspects of performance are of significant importance as well.

(3) Mapping Matrix between Strategy and Performance Measures ($\mathbf{M}^s$)

Table 2 shows a mapping matrix ($\mathbf{M}^s$) between strategy and performance measures. Each element of this matrix, M^s_{ij}, describes the extent to which performance measure *j* impacts on system performance with respect to the strategic objective *i* (e.g., 1-strong relationship; 1/3-moderate relationship; 1/9-weak relationship; 0-no relationship). For example, M^s_{11} show that there is moderate relationship between PM-Q11 "Number of defects caused by machine errors" (PM_1) and achieving a low cost system (S1).

Table 2. Mapping Matrix between Strategy and Performance Measures ($\mathbf{M}^s$)

Index	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
S \ PM-	Q11	Q12	Q131	Q132	Q133	Q14	Q3	P1	R11	R12	R13	T1	T2	T3	T4	T5	C1	C2	C3
S1	1/3	1/3	1/3	1/3	1/3	1/3	1/3	1/3	1/3	1/3	1/3	1/3	1/3	1/3	1/3	1/3	1	1	1
S2	1	1	1	1	1	1	1/3	1/3	1/3	1/3	1/3	1/3	1/3	1/3	1/3	1/3	1/3	1/3	1/3
S3	1/3	1/3	1/3	1/3	1/3	1/3	1/3	1/3	1/3	1/3	1/3	1	1	1	1	1	0	0	0
S4	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	0	0	0

(4) Project Proposals

In this paper, the information of a project proposal consists of expected performance improvement value of performance measure *i* $(i=1,\ldots,I)$ of sub-production unit *j* $(j=1,\ldots,J)$ and the required resource amount. The information of project proposals used in this study is shown in Table 3. For example, project 1 is proposed to improve the value of PM-R11 "Mean time to recognize disruptions" at sub-production unit 1. The improvement values is expected as uniform distribution u~(1,2) and the required resource amount is 20 units.

Table 3. Information on Project Proposals

	The Expected Improvement Values of the Performance Measures			Required Resource Amount (Units)
	Sub-production unit 1	Sub-production unit 2	Sub-production unit 3	
Project 1	PM-R11→ Δu ~(1,2)			20
Project 2		PM-Q131→ Δu~(0.5,1.5) PM-R13→ Δu ~(0.5,1.5)		15
Project 3			PM-Q132→ Δu~(0.5,1.5)	20
Project 4		PM-T2→ Δu~(1,2)		10
Project 5			PM-Q12→ Δu ~(1,2)	20
Project 6	PM-R12→ Δu ~(1,2)			20
Project 7		PM-Q14→ Δu ~(1,2)	PM-C3→ Δu ~(1,2)	20
Project 8	PM-P1→ Δu ~(0.5,1.5)			10
Project 9			PM-C1→ Δu ~ (0.5,1.5)	15
Project 10			PM-T1→ Δu (0.5,1.5)	20
Project 11	PM-Q3→ Δu ~ (0.5,1.5)	PM-Q3→ Δu ~ (0.5,1.5)		20
Project 12		PM-C2→ Δu ~(1,2)		15
Project 13	PM-Q11→ Δu ~(1,2)			20
Project 14	PM-T3→ Δu ~(1,2)	PM-Q14→ Δu ~(1,2)		15
Project 15			PM-T3→ Δu ~(1,2)	20
Project 16		PM-Q133→ Δu ~(1,2)		15
Project 17			PM-T4→ Δu ~(1,2)	30
Project 18			PM-T2→ Δu ~(1,2)	20
Project 19	PM-T5→ Δu ~(1,2)	PM-Q14→ Δu ~(0.5,1.5)		30
Project 20			PM-C2→ Δu ~(0.5,1.5)	20

* Δ: performance improvement, u: uniform distribution

4.2 Experimental Results

The conditions for the GA experiments were as follows: Population Size =50, Generation Number = 1000, Crossover rate=0.9, Mutation rate=0.01. The experiment conditions for the minimum and maximum values of available resource amount are 50 and 375 units, respectively.

Table 4. The Relationship between Selected Project Portfolio and Available Resource Amount

Available Resource Amount (Units)	Index of Project Proposals																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
50					O														O	
100				O	O		O							O					O	
120				O	O		O	O						O		O			O	
160		O		O	O		O	O					O	O		O			O	
200	O	O		O	O		O						O	O		O	O		O	
240	O	O		O	O	O	O				O		O	O		O	O		O	
280	O	O	O	O	O	O	O	O	O		O		O	O		O	O		O	
320	O	O	O	O	O	O	O	O	O	O	O		O	O		O	O		O	O
375	O	O	O	O	O	O	O	O	O	O	O		O	O		O	O		O	O

* O: selected project proposal for the portfolio

Table 4 shows the selected project portfolio as the available resource amount increases. For example, when the given available resource amount is 100 units, the project portfolio is a set of project proposals {4, 5, 7, 14, 19}. In this example, project proposals {12, 15, and 18} have no impact on performance improvement. In Table 4, the results of project portfolio selection show that the optimal project portfolio should be selected by evaluating the collective effectiveness of individual projects.

5. DISCUSSION

This paper is basically an attempt to design the optimal portfolio selection method for performance improvement projects in a manufacturing system. This should reflect the performance improvement of the system. It is characterized that performance improvement of the system is not the results of the sum of the performance improvement of individual projects but of a portfolio of projects. However, few previous studies have considered the characteristics of the system performance improvement in a manufacturing system. Therefore, as a mean to develop a method for project portfolio selection, this paper proposes evaluation and selection process for selecting the optimal portfolio.

In the project portfolio evaluation process, this paper presents a performance measurement model, performance evaluation of a project portfolio, and strategic evaluation of a project portfolio.

(1) Performance measurement model: It is based on the decomposition model and performance measures of a manufacturing system. And the value of each performance measure of a production unit is determined by synthesizing the values of performance measures of sub-production units so as to ensure global optimization of a manufacturing system. Since this paper assumes that the system can be modeled as a linked system, the value of each performance measure of production unit is determined by the lowest value of the corresponding performance measures of the sub-production units. The approach for performance measurement is based on the analogy of system performance in the Theory of Constraints, that is, "Like a chain, a system's performance is limited by the performance of its weakest link." But when considering other system configuration models, this approach should be changed. Also, when it does not consider the decomposition model of the system due to the simplicity of the system, the performance measures of a production unit are used for evaluating performance improvement.

(2) Performance evaluation of a project portfolio: It evaluates how well expected performance improvement by a project portfolio satisfies the requirements and target values of performance measures of the system. Since the value of the project portfolio is determined by the satisfaction probabilities of requirements and target values of performance measures, it is critical to set right target values and requirements of a manufacturing system.

(3) Strategic evaluation of a project portfolio: Due to the need to consider both the strategy and the value of a project portfolio, the approach for evaluating the strategic value of a project portfolio is based on the strategic performance

matrix. This approach is considered to be applicable as a simple way, but future research needs to develop a more sophisticated approach.

The result of the discussion with experts in project management in a car manufacturer indicates that the proposed method is a useful approach for the optimal portfolio selection. But for the real application, many open issues remain. It includes the developments of user-friendly interface design of the system, assisting tool to set up right numbers in the matrices, and a sensitivity analysis tool for project portfolio selection. Also, further research is needed how to apply the proposed method to various manufacturing settings, and also how to expand the proposed method for product development projects and other types of projects.

6. CONCLUSIONS

Industry traditionally lacks a mechanism to select the optimal portfolio in achieving a stable and efficient manufacturing system. Thus it struggles to achieve the goals of the system by blindly throwing resources into successive waves of improvement projects. As an attempt to design a new method for the optimal portfolio selection of performance improvement projects in a manufacturing system, this paper proposes a new evaluation process and selection process for selecting the optimal project portfolio on the theoretical aspects. This paper emphasizes on project portfolio evaluation based on system performance improvement and shows the usefulness of the genetic algorithm for optimal selection of portfolio. An example is used to illustrate the proposed project portfolio selection method. Even though many open issues remain for real applications, we expect that this approach will play a role in enhancing the thinking on design of project portfolio selection method and implementation for real applications.

7. ACKNOWLEDGEMENT

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