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SELECTION OF PROJECTS UNDER BUDGET CONSTRAINT USING SIMULATED ANNEALING AND RESOURCE MANAGEMENT FOR SELECTED CONCURRENT PROJECTS USING CRITICAL CHAIN TECHNIQUE

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Abstract

Although project selection has been a popular research topic since 1960s, scheduling and resource management issues have rarely been considered. This paper presents a heuristic algorithm based Simulated Annealing (SA) to solve the project selection problem (PSP) under budget constraint. It also presents a solution based on Critical Chain technique, which is the application of the Theory of Constraints (TOC) to project scheduling, for the resource management problem.

Keywords: Project selection; Simulated Annealing; Theory of constraints; Critical chain; Resource scheduling; Decision-making;

1. Introduction

The selection of projects from feasible candidates is an organizational decision-making task commonly found in organizations to achieve its objective. It is hard and complicated task because it is very difficult to predict the future success and impacts of the candidate projects. So, decision support systems have been developed in real application, which integrate decision models and methods with computer-based supports together [1-3].

In the literature, a number of decision models and methods like mathematical programming and optimization, decision analysis and economic models which have been developed to help organizations make better decisions in project selection [4-5].

In practice, most projects are limited to the number of resources and they schedule activities according to resource constraints. Many algorithms have been developed to solve the problem of resource-constrained project scheduling since the advent of the CPM/PERT techniques [6-8].

In this paper, a new algorithm for the problem of project selection under budget constraint is presented, which is a hybridization of the simulated annealing (SA). Furthermore, this paper presents that Critical Chain technique used to manage resources shared by a number of concurrent projects.

The paper is organized as follows: In next section, after project selection problem (PSP) is generally described, proposed SA based algorithm for the PSP will be detailed, and then results of experiments are given. Theory of constraints and resource management for selected concurrent projects are examined in section 3.

2. Project Selection Problem

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A number of methods exist to evaluate project proposals. These methods may be grouped as economic and financial, multifactor techniques, mathematical programming and expert systems. Cabrol-Cardosa and Payne surveyed research and development decision makers on 152 simples in the United Kingdom about their use of formal selection methods in project selection decisions [9].

Economic and financial analyses include payback and cost/benefit analysis. Cost/benefit analysis seeks to identify accurate measures of benefits and costs, and uses the ratio of benefits to costs. Net present value (NPV) and internal rate of return (IRR) extend cost/benefit analysis to consider the time value. NPV method suggests that the project with the highest net present value should be selected. IRR method chooses the project with the largest internal rate of return that is higher than the firm's expected rate of return. The payback period, on the other hand, searches the project with the shortest payback period.

Checklist describes criteria of importance and their minimum acceptable levels of requirements. Project profile is to display how the project proposal compares with standards. Scoring and rating models are obtained on each criterion of importance and then combined in some fashion. Multi-criteria decision models measure how each project meets the criteria well, and combine the results into some value that can be used for ranking.

Mathematical programming provides optimal solutions for a portfolio of projects under constraints such as budget limits. Expert systems are usually sets of rules and provide near-optimal solutions.

In this paper, a new algorithm based on SA is presented while several projects with known cost (c) and profit (p) are to be selected under a budget constraint to maximize the total profit. The proposed algorithm uses “net profit” (p - c) as the decision criterion.

Table 1 shows the most commonly mentioned methods.

Table 1. Common used methods in project selection

Method	Percentage of Users
Economic and Financial	
Payback analysis	68
Cost/benefit analysis	63
NPV/IRR	40
Multifactor Techniques	
Checklist	38
Project profile	26
Scoring rating models	26
Multicriteria models	11
Mathematical Programming	
Goal programming	18
Expert Systems	6

2. 1 Problem Definition

Project selection problem (PSP) under one constraint is simple, but it is already NP-complete. In other words, it takes O(2n) computation time to decide the optimal solution in the worst case.
Mathematically, the PSP under budget constraint can be stated as follows:

Objective function:

$$\max \sum x_k \left(p_k - c_k\right) \tag{1}$$

Subject to:

$$\sum x_k c_k \le B \tag{2}$$

Notations:

$$x_k \begin{cases} 1, & \text{if project k is selected} \\ 0, & \text{if project k is not selected} \end{cases}$$

c_k : cost of each projects
p_k : profit of each projects

B : budget constraint
In this formula, decision criterion is "net profit" (p_k - c_k).

2.2 Application for PSP

The proposed algorithm for the problem of project selection is developed, which provides near-optimal solutions for the problems of size larger than 40. The proposed algorithm has two main steps: Initialization and solution manipulation.

2.2.1 Initialization

First, the value of (pk - ck) for each project is determined all values of (p_k-c_k) to obtain minimum number of projects (N) are arranged in non-increasing order when all values of (p_k-c_k) to obtain minimum number of projects (M) are arranged in non-decreasing order. Each unit between M and N is given a randomly chosen initial solution.

2.2.2 Solution Manipulation: Simulated Annealing

Initial solutions obtained are optimized by using SA. The base of SA method is an analogy with thermodynamics, specifically with the way that liquids freeze and crystallize, or metals cool and anneal. At high temperatures, the molecules of a liquid move freely with respect to one another. If the liquid is slowly cooled, thermal mobility is lost. The atoms are often able to line themselves up and form a pure crystal that is completely ordered over a distance up to billions of times the size of an individual atom in all directions. This crystal is the state of minimum energy for this system. This process gives inspiration to solve optimization problems. The relation between simulated annealing and combinatorial optimization can be explained as follows:

Table 2. The relation between simulated annealing and combinatorial optimization

Simulated Annealing	**Combinatorial Optimization**
States of System	Suitable Solutions
Energy	Objective Function
Change of State	Neighborhood Solution
Temperature	Control Parameters
Freezing State	Heuristic Solution

The efficiency of the algorithm depends on the number of iterations (K), the initial temperature (T_0), the last temperature (T_s), the temperature of iteration c (T_c) and the neighborhood mechanism. The cooling proportion (r) and temperature of subsequent iteration (T_{c+1}) based on the cooling proportion (r) are formulated as follows (see Equations (3) and (4)) [12]:

$$r = \left[(T_0 - T_s)/(K-1)T_0 T_c\right] \tag{3}$$

$$T_{c+1} = T_c/(1 + rT_c) \tag{4}$$

The proposed algorithm is presented into details Fig.ure 1 .

Design of experiment (DOE) is utilized to determine number of iterations (K), the initial temperature (To) and the last temperature (T_s). This work indicates that proposed algorithm gives very good results when parameters K, T_0 and T_s are set to K=500, T_0=100 and T_s=10.

The neighborhood of a permutation has been obtained according to one of two different randomly chosen mechanisms.

Initialization

Determine the value of (pk – ck) of each project
Sort (pk - ck) by the no increasing order to obtain N when

$$\sum_{k=1}^{N} c_k \le B$$

Sort (pk - ck) by no decreasing order to obtain M when

$$\sum_{k=1}^{M} c_k \le B$$

Solution manipulation

c=0; {c is a counter}
Determine the initial solution (s), a initial temperature (T_0), a last temperature (T_s), a cooling proportion (r);
Repeat

Create new solution (S_j) from current solution (S_i) by using selected neighbourhood mechanism;

$$\Delta = f(s_j) - f(s_i)$$

If $\Delta > 0$ **Then**

$s_i := s_j$

Else If random (0.1) < exp(- Δ /T) **Then**

$s_i := s_j$

$T_{c+1} = T_c / (1 + r \times T_c)$; {$T_c$ is a temperature of iteration}

Figure 1. A new method based on SA for project selection problem

Swap Mechanism

In this mechanism, two different randomly chosen elements from the current solution are swapped. For example;

current solution	chosen elements	new solution
2-3-4-1-5	2 and 4	4-3-2-1-5

Optimal Swap-Greedy Mechanism

A randomly chosen element from the current solution is swapped with elements into different positions. Optimal swap for objective function is selected.

For example;

current solution	randomly chosen element	chosen element	new solution
2-3-4-1-5	4	2	4-3-2-1-5
		3	2-4-3-1-5
		5	2-3-5-1-4

2.2.3 Experimental Results

The proposed algorithm provides near-optimal solutions for problems of size larger than 40. The performance of the algorithm has been tested with seven case studies and compared with linear programming [LP] solutions.

Case Study 1

This case includes that 15 projects are to be selected within the 1500 budget constraint [11]. Table 3 shows cost and profit of each project. Using initialization stage of the algorithm, the feasible range can be obtained as [N=l, M=2]. In other words, only one or two projects should be selected. The optimal solution of the problem is found as {8, 12} with 7581$ in 0,002 second of CPU-Time by using solution manipulation stage of the algorithm.

Case Study 2

In this case, 17 projects are to be selected within the 2130 budget constraint [12]. Table 4 shows cost and profit of each project for this case. The difference of the case 2 from case 1 is its feasible range. The feasible range can be obtained as [N=l, M=5] by using initialization stage.

Table 3. Cost and profit of each project for Case Study 1

Project k	Project cost ck ($)	Project profit pk ($)	pk-ck ($)
1	518	3219	2701
2	689	3749	3060
3	1133	2721	1588
4	705	2607	1902
5	1121	2940	1819
6	1115	2674	1559
7	1826	3600	1774
8	643	3676	3033
9	1997	3358	1361
10	1100	2646	1546
11	740	1576	1836
12	832	3905	3073
13	1097	1642	1545
14	541	2936	2395
15	1062	4016	2954

Table 4. Cost and profit of each project for Case Study 2

Project k	Projectcost ck ($)	Project profit pk ($)	pk-ck ($)
A01	230	250	20
A02	370	400	30
A03	180	200	20
A04	90	100	10
A05	570	640	70
B06	750	860	110
B07	370	410	40
BOS	250	270	20
B09	190	200	10
BIO	200	210	10
Cll	310	330	20
C12	430	440	10
C13	680	780	100
C14	550	600	50
D15	290	330	40
D16	200	220	20
D17	150	160	10

Table 5. Solution quality of the proposed algorithm and LP

Case	Size	Feasible Range [N,M]	Proposed Algorithm CPU	LP CPU Time(s)
1	15	[0,2]	0,002	0,256
2	17	[1,5]	0,062	0,425
3	20	[4,8]	0,078	0,396
4	30	[14,14]	0,069	0,426
5	40	[21,27]	0,214	0,724
6	50	[16,16]	0,107	-
7	60	[29,36]	1,259	-

In other words, 1, 2, 3, 4 or 5 projects should be selected. The optimal solution of the problem is found as {2, 5, 6, 13} with 310$ in 0,062 second of CPU Time by using solution manipulation stage of the algorithm. This shows that the more feasible range is large, the more problem is hard.

The experiments were performed on a Pentium IV CPU 2.56 GHz with 256 Mb of RAM and the algorithm that is coded by C++ programming language.

Comparison with LP

As shown in Table 5, the proposed algorithm found optimal solutions faster than LP for problems of size smaller than 40, which also obtained optimal solutions for problems of size larger than 40. As a result, the efficiency of the algorithm depends on feasible range and size of problem.

3. Resource Management For Selected Concurrent Projects

Resource management for multiple projects is as important as selection of projects. The problem of allocating resources to concurrent projects is fundamentally the same as the problem of job shop scheduling. Most researchers have studied on this subject up to now. Eli Goldratt demonstrates the application of his Theory of Constraints (TOC) to Project Management, Critical Chain [13]. In chapter 24 of the novel, Goldratt gives some indication about allocation resources. Firstly, TOC was applied to the scheduling of a single project by Steyn [14] who was inspired the Critical Chain. Second application of Critical Chain is allocation of resources that are shared by concurrent projects.

3.1 Theory of Constraints

The Theory of Constraints (TOC) is an overall management philosophy that has its basis in the manufacturing environment. TOC firstly applied the principles to operations management [15]. A factor that limits a company's ability to achieve more of its goal is referred to as a "constraint." Businesses need to identify and manage constraints. TOC is a management philosophy that focuses the organizations scarce resources on improving the performance of the true constraint, Goldratt uses a chain analogy to help illustrate why this is an effective way to get immediate results. A manufacturing company can be thought of as a chain of dependent events that are linked together like a chain. The activities that go on in one "link" are dependent upon the activities that occur in the preceding "link." TOC says that management needs to find the weak link in the chain since "a chain is only as strong as its weakest link." Thus, a company should focus on "chain strength" by working to strengthen the weakest link - the constraint. TOC is based on five steps [16].

1. Identify: In order to manage a constraint, firstly, it is necessary to identify it.
2. Exploit: Focus on how to get more production within the existing capacity limitations.
3. Subordinate: Prevent the materials needed next from waiting in a queue at a non-constraint resource.
4. Elevate: If, after fully exploiting this process, it still cannot produce enough products to meet market demand, find other ways to increase capacity.
5. Go back to Step 1.

This process is accepted as Goldratt's process of on-going improvement.

3.2 The Second Application of the Critical Chain: Application of TOC Principles to Managing Resources in Concurrent Project Environments

Critical chain is actually a set of interdependent tasks. The completion of each of them at the right time is important for the completion of the project as per schedule. To protect against uncertainty in a project schedule, the commitment date should be protected by identifying tasks that if delayed, would make the project longer. Those tasks should be considered most important and be protected.

In the application of five-step TOC approach to managing resources in concurrent project environments, step 1 is that the resource constraining the capacity identifies. To identity the resource constraining the capacity, managers should select resource with the highest workload. In step 2, the sequence of work performed by Capacity Constraining Resource (CCR) has to be scheduled. Then, the scheduling of other resources should be subordinated to this schedule (Step 3). Traditionally, the schedule is protected by padding individual tasks. In the critical chain approach, the project completion date is protected rather than individual tasks. This is done by adding scheduled blocks of time, called buffers. These buffers have to be put at the appropriate place. Buffers are inserted in the schedules to reduce the impacts of the shocks, which prevent CCR from having to wait when a preceding activity has been delayed. Fig. 2 explains using of buffers.

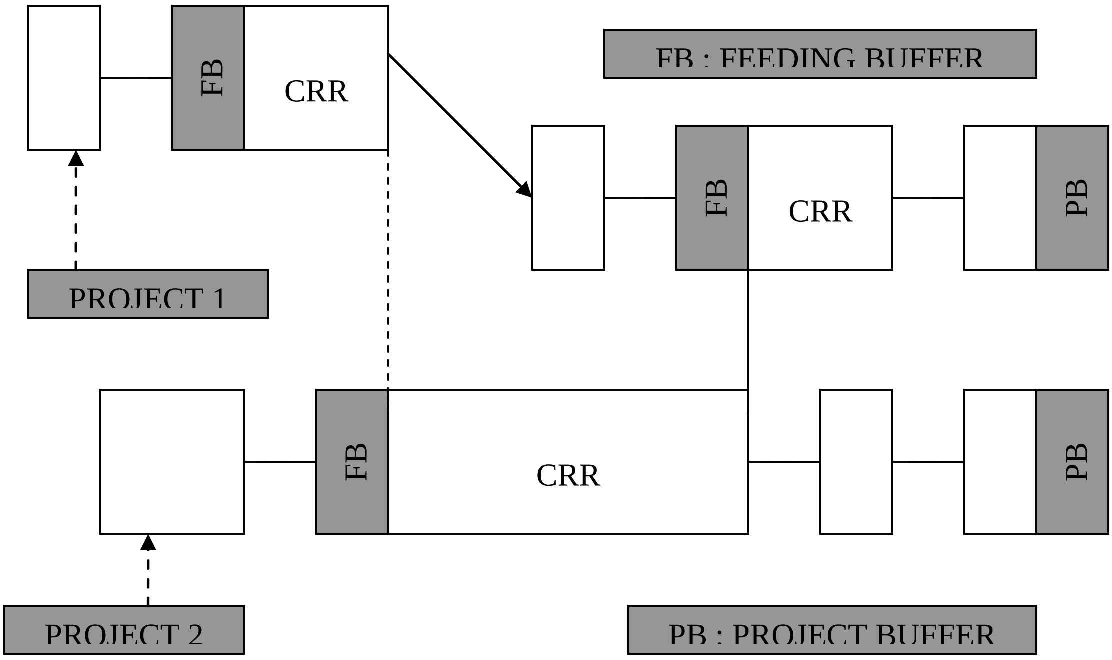

Figure 2. Feeding and project buffers inserted to prevent delays [17]

Money is invested to acquire additional resources (Step 4). Thus, the best possible use of existing capacity is obtained. In step 5, the manager should go back to Step 1 to identify the current constraint.

4. Conclusion

The selection of projects is a considerable task for organizations to achieve its objective, but it is NP-complete. So, an efficient heuristic algorithm based SA for solving the project selection problem under budget constraint has been presented in this paper. This algorithm found optimal solutions faster than LP for problems of size smaller than 40, which also obtained optimal solutions for problems of size larger than 40.

Not only optimal selection of projects is sufficient, but also an efficient resource management for concurrent projects selected is required. This paper proposes Critical Chain technique to allocate resources to multiple projects.

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