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Applications of Google OR-Tools in solving construction management linear optimization problems

Ứng dụng công cụ Google OR-Tools trong giải các bài toán tối ưu hóa tuyến tính trong quản lý dự án xây dựng

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Abstract

Construction projects often require large investment costs. They usually entail complex technical requirements and construction schedule. Therefore, optimizing the project planning and execution is a practical need of construction companies. Linear optimization problems are widely encountered in construction project management. This study demonstrates the application of Google OR-Tools as a powerful, easy-to-use, and open source software suite in tackling linear programs. Herein, this open source tool has been integrated with Visual C# programming and the optimization models are formulated in Microsoft Visual Studio. Two optimization case studies are used in this study to illustrate the implementation of the Google OR-Tools.

Keywords: Construction management; Linear programming; Mathematical modeling; Google OR-Tools; Visual studio.

Tóm tắt

Các công trình xây dựng thường đòi hỏi chi phí đầu tư lớn. Chúng thường có những yêu cầu kỹ thuật và tiến độ thi công phức tạp. Vì vậy, tối ưu hóa việc lập kế hoạch và thực hiện dự án là một nhu cầu cấp thiết của các công ty xây dựng. Các bài toán tối ưu hóa tuyến tính thường gặp nhiều trong quản lý dự án xây dựng. Nghiên cứu này ứng dụng công cụ OR-Tools của Google như một bộ phận mềm mở, mạnh mẽ, và dễ sử dụng trong việc giải quyết các bài toán tối ưu hóa tuyến tính. Công cụ mã nguồn mở này đã được tích hợp với lập trình Visual C # và các mô hình tối ưu hóa được xây dựng trong Microsoft Visual Studio. Hai bài toán cơ bản về tối ưu hóa tuyến tính đã được sử dụng trong nghiên cứu này để minh họa việc triển khai OR-Tools.

Từ khóa: Quản lý xây dựng; Lập trình tuyến tính; Mô hình toán học; Google OR-Tools; Visual Studio.

1. Introduction

The success of construction companies in an increasingly competitive market condition largely depends on their effectiveness of planning and managing resources [1-4]. Ineffective planning and resource utilization

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often increases construction cost and extends construction schedule [5-9]. To avoid such unwanted scenarios, construction companies need to optimize their operational processes [10-16]. Various problems encountered during the project planning and executing can be formulated as linear optimization problems or linear programming. Linear programming refers to mathematical modeling method in which a linear objective function is either minimized or maximized when subjected to a set of linear constraints [17].

The general form of a linear program is expressed as follows:

$$\text{Max. or Min. } f(x) = c^{T}x \quad (1)$$

$$\text{Subject to } \quad Ax \leq b$$

$$LB \leq x \leq UB$$

where x is a vector of decision variables. c, A, b are problem parameters. LB and UB denote the lower and upper boundaries of the decision variables.

The mathematical modeling technique of interest has been proven to be helpful for assisting quantitative decisions in business planning in various disciplines including construction and industrial engineering [18, 19]. This study applies the Google OR-Tools [20] as a powerful and open source software suite for solving linear optimization problems. We also integrate this open source software suite into the Microsoft Visual Studio with C# programming language. The optimization capability of Visual C# based OR-Tools in modeling and solving decision-making problems in construction management is demonstrated via two simple applications.

2. The OR-Tools applications

The first application involves the determination of a set of trucks used for dumping construction waste. Herein, a contractor needs to dump 160 tons of construction waste. It has two types of truck: A and B. Truck A's capability is 5 tons / trip. Truck B's capability is 3 tons / trip. The cost of truck A and B is 180,000 and 100,000 per trip, respectively. The total number of trips must not exceed 35. Find the optimal number of trips for each type of truck. Herein, we employ OR-Tools with Solving Constraint Integer Programs (SCIP) backend provided by the OR-Tools for finding integer variables (refer to **Fig. 1**). The optimization results are shown in **Fig. 2**. It is noted that to display the objective function value, the following code is used: *solver.Objective().Value()*. In addition, the decision variables are converted to real values as follows: *double x_sol = x.SolutionValue()* and *double y_sol = y.SolutionValue()*. Từ kết quả của bài toán, số lần chạy tối ưu của xe loại A là 29 và của xe loại B là 5.

```
Variable x = solver.MakeIntVar(0, 35, "x");
Variable y = solver.MakeIntVar(0, 35, "y");
// Set the constraints
solver.Add(x + y <= 35);
solver.Add(5 * x + 3 * y >= 160);
Console.WriteLine("Number of constraints = " + solver.NumConstraints());
// Set objective function
solver.Minimize(180 * x + 100 * y);
solver.Solve();
```

Fig. 1 Problem definition for the 1st application

```
C:\Users\Asus\source\repos\ConsoleVS_Study\ConsoleVS_Study\bin\x64\Debug\ConsoleVS_Study.exe
Number of constraints = 2
Solution:
Objective value = 5720
x = 29.
y = 5.
Constraint 0:
x + y = 34 <= 35.
Constraint 1:
5x + 3y = 160 >= 160.
Execution time = 586 (ms).
```

Fig. 2 Optimization results of the 1st application

In the 2nd application, a simplified project selection optimization problem is considered. Herein, a company considers the investments of six potential construction projects, the profits (VND billion), the required capital (VND billion), and the required manpower for each project are shown in **Table 1**. Provided that the capital capacity of the company is 250 billion, the number of available engineers and workers are 60 and 550, the company wishes to find an optimal set of invested projects that maximizes that total profits. The problem formulation is shown in **Fig. 3** and the optimization outcomes are reported in **Fig. 4**. Herein, the decision variables are formulated as binary variables with the value of 1 means the decision of investing and the value of 0 corresponds to the decision of not investing. Từ kết quả của bài toán, các dự án 1, 3, 4, và 6 đã được lựa chọn.

Table 1. Project information

Project	1	2	3	4	5	6
Cost	40	20	45	55	67	90
Engineers	12	8	5	17	8	18
Workers	100	120	110	200	150	80
Profit	2.5	1.1	1.8	1.3	0.7	3.2

```
Solver solver = Solver.CreateSolver("SCIP");
// Create the variables x and y.
Variable x0 = solver.MakeBoolVar("x0"); Variable x1 = solver.MakeBoolVar("x1");
Variable x2 = solver.MakeBoolVar("x2"); Variable x3 = solver.MakeBoolVar("x3");
Variable x4 = solver.MakeBoolVar("x4"); Variable x5 = solver.MakeBoolVar("x5");
// Set the constraints
solver.Add(40 * x0 + 20 * x1 + 45 * x2 + 55 * x3 + 67 * x4 + 90 * x5 <= 250);
solver.Add(12 * x0 + 8 * x1 + 5 * x2 + 17 * x3 + 8 * x4 + 18 * x5 <= 60);
solver.Add(100 * x0 + 120 * x1 + 110 * x2 + 200 * x3 + 150 * x4 + 80 * x5 <= 550);
// Set objective function
solver.Maximize(2.5 * x0 + 1.1 * x1 + 1.8 * x2 + 1.3 * x3 + 0.7 * x4 + 3.2 * x5);
solver.Solve();
double x0_sol = x0.SolutionValue(); double x1_sol = x1.SolutionValue();
double x2_sol = x2.SolutionValue(); double x3_sol = x3.SolutionValue();
double x4_sol = x4.SolutionValue(); double x5_sol = x5.SolutionValue();

Console.WriteLine("Solution:");
Console.WriteLine("Objective value = " + solver.Objective().Value());
Console.WriteLine("x0 = {0}.", x0_sol); Console.WriteLine("x1 = {0}.", x1_sol);
Console.WriteLine("x2 = {0}.", x2_sol); Console.WriteLine("x3 = {0}.", x3_sol);
Console.WriteLine("x4 = {0}.", x4_sol);  Console.WriteLine("x5 = {0}.", x5_sol);
```

Fig. 3 Problem definition for the 2nd application

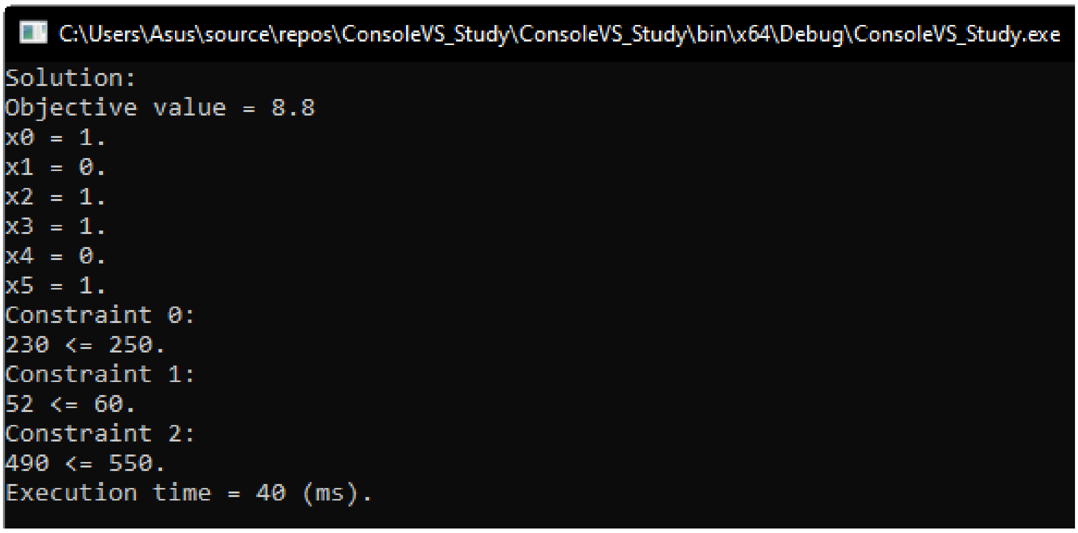

Fig. 4 Optimization results of the 2nd application

3. Concluding remarks

Linear programming is widely encountered in construction project planning and execution. This study demonstrates the application of the Google OR-Tools as a powerful and open source software suite for solving linear optimization tasks. The Google OR-Tools is used with Visual C# in Microsoft Visual Studio. Two basic applications demonstrate the usefulness of the Google OR-Tools in developing software programs to assist the decision-making processes during various phases of construction projects.

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