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Optimization of ship's crew change schedule

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Abstract

Seaborne shipping must often cope with issues related to planning, ship scheduling, and arranging crews and optimal shipping routes between ports. Human resources departments typically plan ship crew shifts with regards to the seafarers' right to vacation days. It is difficult to harmonize all the requirements and to satisfy both the seafarers and the company. Ideally, arrangements are made for the crewmember to sign off upon completion of a contract, with the vessel being at a port convenient to change the crew at a minimum cost. The latter may vary greatly, depending on the size of the crew to be replaced, the distance of the port from the crew destination, and the available taking-over crew at a specific place and time, etc. In these situations, linear programming (LP) is frequently used as a mathematical method to determine the optimal results. This study suggests the use of a linear-binary programming model in LINGO software to arrange the ship's crew change schedule.

Introduction

Linear programming (LP) is a specific form of mathematical optimization that can be applied in various areas of science and research, as well as the transport, telecommunications, manufacturing, and energy production and distribution industries. The goals of LP include the optimization, exploitation maximization, or minimization of costs within given constraints. In seaborne shipping, LP is also used to address various optimization issues, e.g., the optimization of a ship's crew changes and arrangements (Reeb & Leavengood, 2002; Zenzerović & Bešlić, 2003; Guo, Wang & Zhou, 2015).

Linear programming analyses these problems where an objective function must be optimized, i.e., maximized or minimized, with regard to the conditions and constraints given in the form of equations and non-equations. The objective function consists of a number of structural variables x_1, x_2, …, x_n, which are interconnected via linear connections, i.e. the abovementioned constraints. Formulating a real-life problem using linear programming is very difficult and requires the well-coordinated teamwork of experts from different areas.

The simplex method using linear programming was first introduced by G.B. Dantzing in 1947 to determine how to arrange US Air Force pilots. Similarly, manning a number of shipping lines within a large company presents a problem for merchant shipping, and an objective function that optimizes the arrangement of crewmembers can be defined to efficiently address this issue. Possible optimal solutions are then defined by implementing the objective function using LINGO software, which is a computer-aided optimization software that solves linear, non-linear, and mixed integer linear and non-linear programs. It is developed by LINDO Systems Inc. (Schrage, 2002).

LINGO software solutions are used in:

- Optimized modelling (Cao et al., 2018),
- Optimizing models for input-output supply chains (Tan et al., 2019),
- Optimal cost locating (Gupta & Bari, 2017),

- Routing within various modes of transportation (Wang, Han & Wang, 2018),
- Defining container ship routes in internal fairways (Maras, 2008) and the rationalization of transport networks (Zelenika, Vukmirovic & Mujic, 2007).

This paper uses LINGO to construct a model to optimize crew distributions across shipping lines, and specifically to arrange three crews on eleven shipping lines.

Methodology

A real-life example has been used to design a mathematical model and a linear-binary program. The following sections include the interpretation of the solutions obtained using the software. A large shipping company must define a schedule for three crews whose home port is in Oakland, CA on the US West Coast. They must cover eleven shipping lines at a minimum cost. It is permitted that more than one crew be on board a ship – the additional crew-members travel as passengers but, according to their contract, they are paid just as if they were at work. The costs associated with the respective crews are assumed and shown in Table 1 (expressed as units x$1000, used as reference number; the company will define a real fixed cost as per their budget and current market situation). In the given example, the objective function is the minimization of the overall costs of all three crews that serve all required shipping lines.

Table 1 shows the potential distribution of the crews under the condition that each crew must return to their home port in Oakland. Each column represents a voyage schedule of one crew. The crew cost it is not a sum, and it is a result calculated using LINGO software. This number represents a mathematical model of a function objective as for x_j, and they are used to obtain minimal/optimal costs within the constraints. The objective function is mathematically shown as (Winston, 2004):

$$F = \underset{x_j}{\text{opt}} \left\{ f\left(x_1, x_2, \ldots, x_n\right) \right\} \tag{1}$$

The typical objective functions include maximization and minimization. Maximization refers to the profit, revenue, price difference, capacity exploitation, produced quantity, and flow (Hillier & Lieberman, 2001):

$$\text{Maximize } Z = c_1 x_1 + c_2 x_2 + \ldots + c_n x_n$$

With regard to the constraints:

$$a_{11} x_1 + a_{12} x_2 + \ldots + a_{1n} x_n \leq b_1 \tag{2}$$

$$a_{21} x_1 + a_{22} x_2 + \ldots + a_{2n} x_n \leq b_2 \tag{3}$$

$$a_{i1} x_1 + a_{i2} x_2 + \ldots + a_{in} x_n \leq b_i \tag{4}$$

where:

Z – value of overall measures of performance;
x_j – level of activity j (for $j = 1,\ldots,n$);
c_j – increase in Z that would result from each unit increase in level of activity j;
b_i – amount of resource i that is available for allocation to activities (for $i = 1,\ldots,m$);
a_{ij} – amount of resource i consumed by each unit of activity j.

Table 1. Crew distributions across individual shipping lines

Shipping lines	Possible crew distributions on individual lines											
	1	2	3	4	5	6	7	8	9	10	11	12
1. OAK – LA	1			1			1			1		
2. OAK – YOK		1			1			1			1	
3. OAK – MAN			1			1			1			1
4. LA – FMNTL				2			2		3	2		3
5. LA – OAK	2					3				5	5	
6. FMNTL – YOK				3	3				4			
7. FMNTL – MAN							3	3		3	3	4
8. YOK – OAK		2		4	4				5			
9. YOK – FMNTL					2			2			2	
10. MAN – OAK			2				4	4				5
11. MAN – LA						2			2	4	4	2
Crew costs	2	3	4	6	7	5	7	8	9	9	8	9

OAK (Oakland), LA (Los Angeles), YOK (Yokohama), MAN (Manila), FMNTL (Freemantle).

Minimization refers to the price, loss, production cost, transport cost, dimensions, deviation, and duration (Hillier & Lieberman, 2001).

$$\text{Minimize } Z = c_1 x_1 + c_2 x_2 + \ldots + c_n x_n$$

With regard to the constraints:

$$a_{i1} x_1 + a_{i2} x_2 + \ldots + a_{in} x_n \geq b_i \quad (5)$$
for some value of i

$$a_{i1} x_1 + a_{i2} x_2 + \ldots + a_{in} x_n = b_i \quad (6)$$
for some value of i

With reference to Table 1, the mathematical model for the objective function assumes the following form in LINGO:

$$\min = 2 \cdot X_1 + 3 \cdot X_2 + 4 \cdot X_3 + 6 \cdot X_4 + 7 \cdot X_5 + 5 \cdot X_6 + + 7 \cdot X_7 + 8 \cdot X_8 + 9 \cdot X_9 + 9 \cdot X_{10} + 8 \cdot X_{11} + 9 \cdot X_{12} \quad (7)$$

where the following constraints are used:

$$X_1 + X_4 + X_7 + X_{10} \geq 1 \quad (8)$$

$$X_2 + X_5 + X_8 + X_{11} \geq 1 \quad (9)$$

$$X_3 + X_6 + X_9 + X_{12} \geq 1 \quad (10)$$

$$X_4 + X_7 + X_9 + X_{10} + X_{12} \geq 1 \quad (11)$$

$$X_1 + X_6 + X_{10} + X_{11} \geq 1 \quad (12)$$

$$X_4 + X_5 + X_9 \geq 1 \quad (13)$$

$$X_7 + X_8 + X_{10} + X_{11} \geq 1 \quad (14)$$

$$X_2 + X_4 + X_5 + X_9 \geq 1 \quad (15)$$

$$X_5 + X_8 + X_{11} \geq 1 \quad (16)$$

$$X_3 + X_7 + X_8 + X_{12} \geq 1 \quad (17)$$

$$X_6 + X_9 + X_{10} + X_{11} + X_{12} \geq 1 \quad (18)$$

$$X_1 + X_2 + X_3 + X_4 + X_5 + X_6 + X_7 + + X_8 + X_9 + X_{10} + X_{11} + X_{12} = 3 \quad (19)$$

A *binary* integer variable – also called a 0/1 variable – is a special case of an integer variable that must be either zero or one. It is often used as a switch to model Yes/No decisions.

The syntax of the *@BIN* function is: @BIN (variable *name*);

Where *variable name* is the name of the desired binary variable.

The *@BIN* function may be used anywhere in a model in which you would normally enter a constraint. The *@BIN* function can be embedded in an *@FOR* statement to allow all, or selected, variables of an attribute to be set to binary integers.

$$@\text{BIN}(X_i), \quad i = 1,\ldots,12 \quad (20)$$

Results and discussion

The obtained software solution (LINGO) is presented in the tables below. Table 2 shows the optimal solution obtained at step eight, where the obtained minimal value of costs amounts to 18,000 dollar units.

Table 2. Presentation of the first part of the solution

Global optimal solution found at step:	8
Objective value:	18.000000
Branch count:	0

Table 3 presents optimal values with minimal costs obtained with crew No. 3, No. 4, and No. 11.

Table 3. Presentation of the second part of the solution

Variable	Value	Reduced Cost
X_1	0.00000	0.00000
X_2	0.00000	0.00000
X_3	1.00000	0.00000
X_4	1.00000	0.00000
X_5	0.00000	1.00000
X_6	0.00000	0.00000
X_7	0.00000	0.00000
X_8	0.00000	1.00000
X_9	0.00000	0.00000
X_{10}	0.00000	1.00000
X_{11}	1.00000	0.00000
X_{12}	0.00000	0.00000

Table 4 presents the optimal solution, i.e. minimal costs.

Table 4. Presentation of the third part of the solution

Row	Slack or Surplus	Dual Price
1	18.0000000	0.0000000
2	0.0000000	0.0000000
3	0.0000000	–2.0000000
4	0.0000000	–3.0000000
5	0.0000000	–5.0000000
6	0.0000000	–1.0000000
7	0.0000000	0.0000000
8	0.0000000	–1.0000000
9	0.0000000	0.0000000
10	0.0000000	–3.0000000
11	0.0000000	0.0000000
12	0.0000000	0.0000000
13	0.0000000	–1.0000000

Table 5. Optimal solution for crew scheduling on individual shipping lines

Shipping lines	Possible distribution of the crews on individual lines											
	1	2	3	4	5	6	7	8	9	10	11	12
1. OAK – LA	1			1			1			1		
2. OAK – YOK		1			1			1			1	
3. OAK – MAN			1			1			1			1
4. LA – FMNTL				2			2		3	2		3
5. LA – OAK	2					3				5	5	
6. FMNTL – YOK				3	3				4			
7. FMNTL – MAN							3	3		3	3	4
8. YOK – OAK		2		4	4				5			
9. YOK – FMNTL					2			2			2	
10. MAN – OAK			2				4	4				5
11. MAN – LA						2			2	4	4	2

OAK (Oakland), LA (Los Angeles), YOK (Yokohama), MAN (Manila), FMNTL (Freemantle).

The optimal solution, i.e. minimal costs of the three crews, amounting to 18,000 dollar units, was obtained by arranging crews 3, 4, and 11, which are represented by the changeable variables X_3, X_4, and X_{11} in the model. The optimal solution is presented in Table 5 in the marked areas. Given the number of variables, the solution would be impossible to obtain manually, but the LINGO program performed this task relatively fast.

Conclusions

This research shows that the suggested model, designed and tested in LINGO software, is suitable for solving problems associated with ship crew distributions. Namely, in complex distribution problems (e.g., the distribution of N crews on M shipping lines or the allocation of N vessels to M lines), it is recommended to apply methods which will be fast and accurate to obtain an optimal arrangement in terms of both efficiency and cost reductions. These methods are used and described in this research. Furthermore, it is suggested that further research should be performed to test this model in various shipping companies to provide inputs and possible guidelines for future developments. The research results provide boundary values of the presented model's efficiency, which will vary with the size of the shipping company, i.e. its tonnage and on-board staff.

An essential task of every shipper is to have a satisfied and professional crew. One of the key factors in ensuring this lies in the contract duration. Upon completion of the contract, it is important to replace the crew within the shortest possible interval of time. In practice, this is not always possible, and no one expects to be relieved of duty while the vessel is underway or in a port that is not convenient for crew change arrangements. However, due to poor planning, seafarers may extend their contracts for a month or even longer, which results in dissatisfaction on-board and with the company administration. It is therefore important for the shipping companies to address this issue and use all available means to achieve an optimal distribution of their crewmembers to ensure the satisfaction of all stakeholders in this process.

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