Work-Scheduling Model for an Open Cast Coal Mine in Turkey with Integer Programming

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Abstract: Tunçbilek Open Cast Coal Mine of Garp Lignite Enterprise (GLI) is located in Kütahya, Turkey and the overburden removal operations are carried out by using Truck/Shovel Systems which is faced with the problem of changing number of trucks due to equipment breakdowns. The maintenance of failed trucks are planned to occur at fixed scheduling days. It is required to determine the operating number of truck drivers for each operating shifts in a weekly planning horizon. A simple Integer Programming model is developed using LINGO software to determine the optimum number of truck drivers required to satisfy the variable number of trucks for each operating shift. The developed model schedules the trucks drivers optimally for each operating shift in a weekly scheduling period.

Introduction

Cyclic staff scheduling problems arise in a variety of service delivery systems including nurses in hospitals, baggage handlers in airlines, operators in telephone companies, etc. Many such systems operate 24 hours a day, seven days a week with demand for services varying in some daily or weekly pattern over each hour of the week. Full-time employees in these service organizations are often assigned to a prescribed 40-hour work schedule (eight hours per day, five consecutive days) each week Staff scheduling or rostering is the process of constructing work timetables for its staff so that an organization can satisfy the demand for its goods or services. It involves a number of hierarchical sub problems including demand modeling, shift design, days-off scheduling, lines of work construction and staff assignment. The first part of this process involves in determining the number of staff, with particular skills, needed to meet the service demand. Individual staff members are allocated to shifts so as to meet the required staffing levels at different times and duties are assigned to individuals for each shift. All industrial regulations associated with relevant workplace agreements must be observed during the process. Days-off scheduling has been extensively discussed in literature in a variety of planning context, including many contributions from the area of nurse scheduling. (Alfares et al., 2007), (Ernst et al., 2004), (Morris, J.G. and. Showalter**,** M. J, 1983), and Baker, (1974) are some of the research papers in this staff scheduling or rostering problems in various fields of applications.

This study is concerned with scheduling the daily truck drivers for a weekly scheduling period at GLI open cast coal mine truck/shovel systems operations in Kütahya, Turkey. In this system, the daily required number of truck driver changes frequently for each working day since the maintenance of trucks and shovels are scheduled for regular inspection days in a weekly planning horizon. It is required to schedule the truck drivers for each operating shift in a weekly planning horizon.

Problem and Background

Tunçbilek Lignite Reserve which is operated by Garp Lignite Enterprise (GLI) is located in Kütahya, Turkey and is one of the most important lignite deposits being in production since 1940's. The overburden removal operations are carried out by using truck/shovel systems with 85-ton and 100-ton trucks and 10 and 20 cu-yd capacity shovels. The open cast coal mine is faced with the problem of changing number of trucks due to regular machinery maintenance. The maintenance of truck and shovel resources are planned to occur at fixed scheduling days. It is required to determine the operating number of truck drivers for each operating shift in a week period. The problem considered in this paper focuses on the days-off scheduling phase of the rostering process, and has been dealt with in the context of open cast coal mine truck/shovels systems. The main concern in days-off scheduling is to determine the off-work days for each staff member over the rostering planning horizon. The constraints refer to the individual days of the planning horizon and are concerned with satisfying the required daily staffing levels for each shift. In this paper, it is assumed that the required shifts and their staffing levels for each day have been determined prior to the days-off scheduling phase and hypothetical data for a case study are given in (Tab. 1). Each truck driver is scheduled to work for six successive day shifts and is off-work for the following single day. It is also assumed that the scheduling model is developed for a single shift in a day for week duration.

Days-off Patterns x_j		**Required Daily Number of Truck Drivers,** r_i	
Monday	x1	17	r1
Tuesday	x2	13	r2
Wednesday	x3	15	r3
Thursday	x4	19	r4
Friday	x5	14	r5
Saturday	x6	16	r6
Sunday	x7	11	r7

Table 1. Hypothetical Data for Daily Number of Truck Drivers Demanded

Models and Scheduling

Shift and days-off scheduling problems have received much attention in the literature of integer programming approaches to workforce scheduling. A typical managerial use would be to schedule full-time employees to minimize the number of labor hours while satisfying variable workforce requirements of a service delivery system. To satisfy the daily demand for truck drivers shown in (Tab. 1) most efficiently with minimum cost, the optimum number and schedule of truck driver needs to be determined for the open cast coal mine at GLI which currently employs a (6,7) work schedule. The (6,7) work schedule assigns workers to seven day-off patterns with one-single day off per week. The (6,7) days-off scheduling problem can be represented as an integer linear programming model as follows:

$$\text{Minimize} \qquad W = \sum xj \qquad (1)$$

Subject to

$$\left(\sum_{j=1}^{7} xj \right) - x_{i+1} \geq r_i \qquad \text{for} \qquad i = 1, 2, 3 \ldots 7 \qquad (2)$$

$$x_j \geq 0 \quad \text{and an integer,} \qquad \text{for} \qquad j = 1, 2, 3 \ldots 7 \qquad (3)$$

x_j = number of workers assigned to a days-off pattern j ,
(i.e. number of workers off on just day j+1)
r_i = minimum number of workers required on day i,
W = workforce size, (i.e. total number of workers assigned to all days-off patterns)

During the planning stage of operations in open cast coal mining at GLI, a mathematical model is established with Integer Programming method and is used to find answers to truck drivers scheduling and reduce costs. The above formulated days-off scheduling model for determining the optimum number of truck drivers in GLI open cast coal mine truck/shovel systems operations is developed with Integer Programming using LINGO software package very easily and is given in (Fig. 1). (Fig. 2) gives the generated LINGO display of the developed model. (Fig. 3) gives the LINGO model formulation report for scheduling truck drivers.

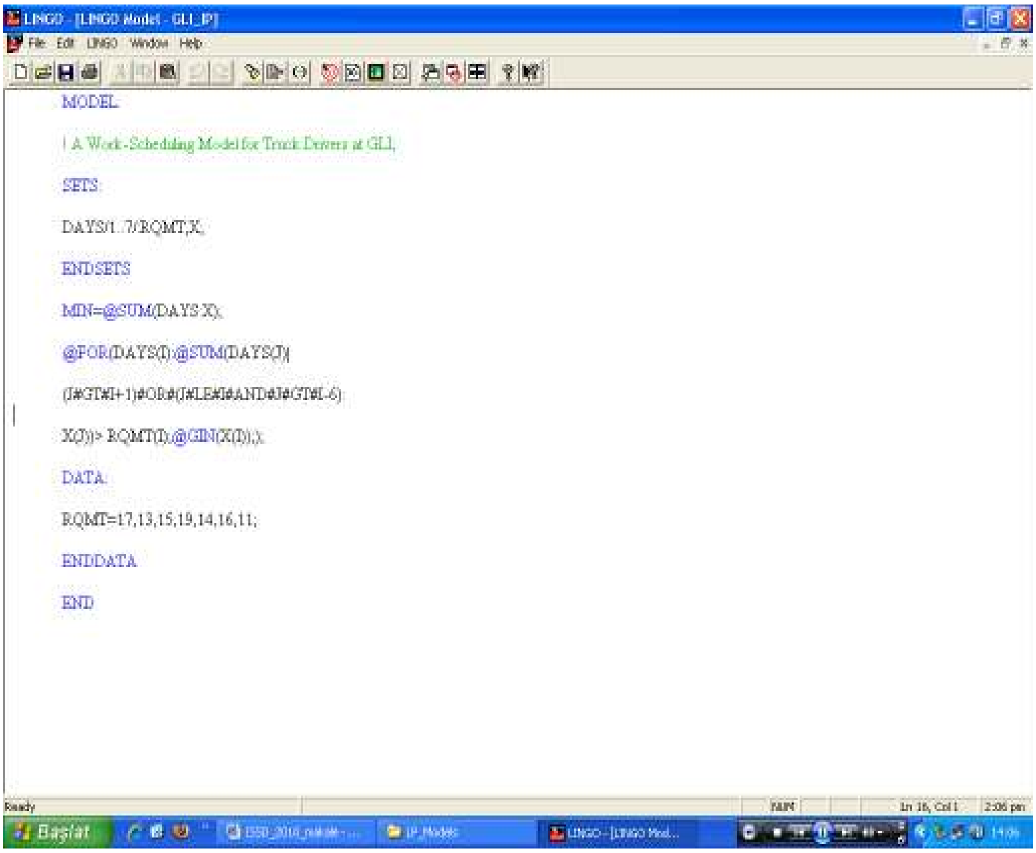

Figure 1: LINGO Model Program for Scheduling Truck Drivers at GLI

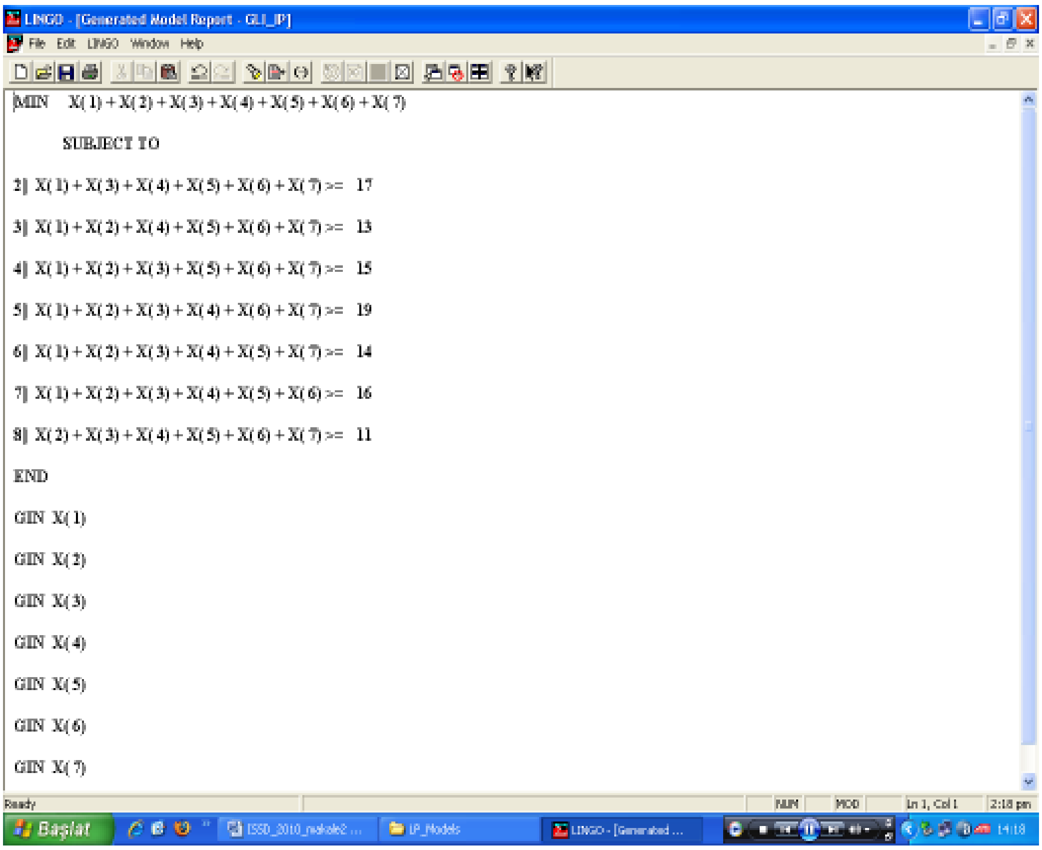

Figure 2: LINGO Generated Model Display for Scheduling Truck Drivers at GLI

LINGO Model Statements

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1]      MODEL:
2]      ! A Work-Scheduling Model for Truck Drivers at GLI;
3]      SETS:
4]      DAYS/1..7/:RQMT,X;
5]      ENDSETS
6]       MIN=@SUM(DAYS:X);
7]      @FOR(DAYS(I):@SUM(DAYS(J)|
8]      (J#GT#I+1)#OR#(J#LE#I#AND#J#GT#I-6):
9]      X(J))> RQMT(I);@GIN(X(I)););
10]     DATA:
11]     RQMT=17,13,15,19,14,16,11;
12]     ENDDATA
13]     END
14]
        END
```

Figure 3: LINGO Model Formulation Report

As shown in (Fig. 3), Line 3 defines the sets needed to solve the problem. Line 4 defines the days of the week (Monday, Tuesday… Sunday) and associates each with two quantities: the number of truck drivers needed (RQMT) and the number of truck drivers that will begin work on that day of the week (X). Line 5 ends the definitions of the sets. In line 6, an objective function is created by summing the number of truck drivers starting work on each day of the week. Lines 7-9 create for each day of the week the constraint that ensures the number of truck drivers working on that day is at least as large as the day's requirement. For DAY (I), lines 7 and 8 sum the number of truck drivers starting work over the values of J satisfying $J > I + 1$ or $J \leq I$ and $J > I - 6$. For instance, for $I = 1$, this generates the sum

X(1) + X(3) + X(4) + X(5) + X(6) + X(7)

which is indeed the number of truck drivers working on DAY 1 (Monday). Line 9 (in concert with lines 7 and 8) ensures that the number of truck drivers working on Day I is at least as large as the number needed on Day I [RQMT (I)]. Line 10 begins the DATA section of the program. In line 11, the input requirement for each day of the week is inputted.

The Open cast coal mine must ensure that sufficient number of truck drivers is working on each day of the week. For example, to ensure that at least 17 truck drivers are working on Monday, it is required that the constraint [2] in (Fig. 2).

X(1) + X(3) + X(4) + X(5) + X(6) + X(7) ≥ 17

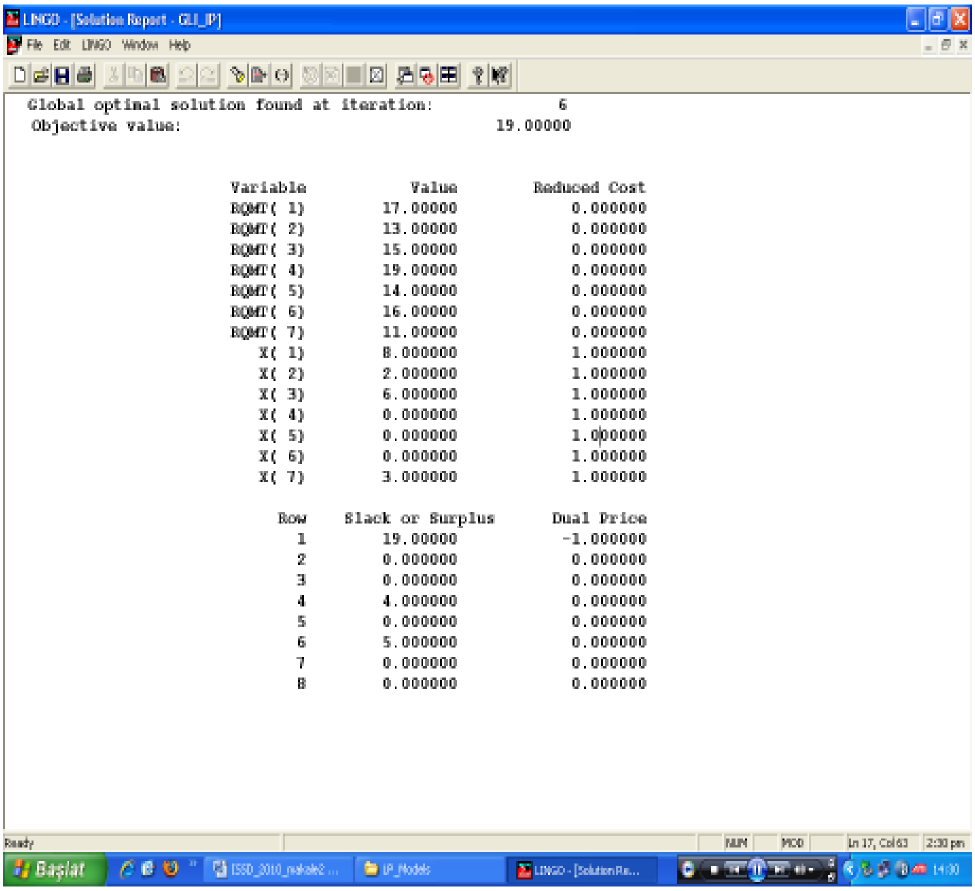
must be satisfied which does not include X(2) term since it is the number of truck drivers who begin work on Tuesday and they will be off-work on Monday. The constraints [3- 8] must be added to the model for the remaining six days in a similar way to complete the whole off-day patterns. GIN X(I) statements are needed for i = 1,2,…,7 to make all decision variables as integer values since number of truck drivers starting work on any day can be positive-valued integers only.

Results and Conclusions

The objective of this paper is to determine the optimum number of truck drivers workforce for (6, 7) work schedule that satisfies each daily demand with minimum cost. The results of days-off assignments for optimum number of truck drivers determined from LINGO Solution Report are given in (Fig. 4). As it can seen from the LINGO Solution Report, the optimum total number of truck drivers is determined as 19 truck drivers and the number of truck drivers beginning work on each days-off work pattern are as follows:

x1 = 8, x2 = 2, x3 = 6, x4 = 0, x5 = 0, x6 = 0, x7 = 3

An Integer Programming model is developed using LINGO software for determining the optimum number of truck drivers for truck/shovel systems operations to meet the daily work schedule demand at GLI open cast coal mine in Kütahya, Turkey. If there is a future change in daily required number of truck drivers as the mine progresses over time, the LINGO program can easily be modified to determine the required size of truck drivers and the days-off assignments to satisfy the new demands. The developed model is site–specific and can only be used for the given specific mine conditions that prevail. The developed model assumes deterministic equipment breakdowns, which is not realistic for actual operating mines. Stochastic models will be needed to provide more accurate systems performance measures. It is hoped that the developed model to the GLI's open cast truck driver's days-off scheduling problem will provide convenient timetables to improve the efficiency of operations.



Variable	Value	Reduced Cost
RQMT(1)	17.00000	0.000000
RQMT(2)	13.00000	0.000000
RQMT(3)	15.00000	0.000000
RQMT(4)	19.00000	0.000000
RQMT(5)	14.00000	0.000000
RQMT(6)	16.00000	0.000000
RQMT(7)	11.00000	0.000000
X(1)	8.000000	1.000000
X(2)	2.000000	1.000000
X(3)	6.000000	1.000000
X(4)	0.000000	1.000000
X(5)	0.000000	1.000000
X(6)	0.000000	1.000000
X(7)	3.000000	1.000000

Row	Slack or Surplus	Dual Price
1	19.00000	-1.000000
2	0.000000	0.000000
3	0.000000	0.000000
4	4.000000	0.000000
5	0.000000	0.000000
6	5.000000	0.000000
7	0.000000	0.000000
8	0.000000	0.000000

Figure 4: LINGO Solution Report for Scheduling Truck Drivers at GLI

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