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Maintenance Staff Scheduling at Afam Power Station

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Abstract. This paper describes the optimization of maintenance workforce scheduling at Afam power station in Nigeria. The objective is to determine the optimum schedule to satisfy growing maintenance labour requirements with minimum cost and highest efficiency. Three alternative maintenance workforce schedules are compared. The first alternative is to continue with the traditional five-day workweek schedule currently being practiced by Afam power station maintenance line. The second alternative is to switch to a seven-day workweek schedule for the morning shift only. The third alternative is to use a seven-day workweek schedule for all three work shifts. The third alternative is chosen, as it is expected to save 11% of the maintenance labour cost.

Keywords: Power Station, Maintenance, Optimization, Labour Scheduling.

1. INTRODUCTION

In the electric power Industry, an increasingly competitive environment has raised important questions concerning maintenance in plant systems. The present emphasis on deregulation in Nigeria power sector is likely to result in increased competition among the country's power producers. To survive the competition, suppliers have to reduce maintenance cost, i.e., handle maintenance more efficiently. One way to reduce maintenance cost is to optimize the utilization of maintenance resources. A key function that influences utilization of maintenance resources is the scheduling of the maintenance system (Duffuaa and Al-Sultan, 1999).

Maintenance requires three resources: manpower, materials and equipment. Manpower is usually the most important and expensive resource of any organisation. Hence, manpower scheduling is a crucial component of maintenance management and is the focus of this paper. Specifically, the aim of this paper is to present a model for maintenance worker scheduling at Afam power station in Nigeria. The objective is to determine the optimum maintenance workforce schedule to satisfy growing labour requirements with minimum cost and highest efficiency.

Afam power station has been generating far below maximum capacity due to maintenance problems. This has affected the availability and reliability of the power plant. In order to reduce these maintenance problems there is a need for effective maintenance workforce scheduling to handle ever-increasing plant maintenance load. The plant line maintenance has been operating on a five-day (Monday-to-Friday) schedule for all three daily shifts. Workers are assigned to the weekend work on overtime basis. The plant maintenance has been experiencing excessive overtime cost during the weekends.

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This has resulted in high maintenance labour cost and a consistent increase in overall plant maintenance cost. It was desired to determine the best schedule of maintenance personnel to respond to these challenges.

A recommendation was made to switch to a seven-day workweek for all three work shifts at Afam Power Station maintenance line. The recommendation was based on analysis of labour demand, overtime statistics, and current schedules to mention but a few. Switching to the proposed schedule is expected to yield an estimated savings of 11 percent of the maintenance labour cost.

2. LITERATURE REVIEW

The accelerating growth of the industry and increasing cost of labour have led to continuing interest in personnel scheduling. There have been numerous studies aimed at optimizing the workforce in light of a variety of considerations. These include non-homogenous workforce in terms of skill, cost and efficiency measures, various labour requirements such as maximum work stretches, break definitions, days off and weekends off policies (Bard *et al.*, 2003). Labour scheduling problems are traditionally classified into three types: (1) shift, or time-of-day, scheduling, (2) days-off, or days-of- week, scheduling, and (3) tour scheduling, which is a combination of the first two. Ernst *et al.* (2004) provide a detailed review of literature on all types of labour scheduling problems.

This survey focuses on recent approaches to employee days-off scheduling, especially in relation to maintenance workforce scheduling. Several approaches have been developed for the (5,7) problem in which each employee is assigned five consecutive workdays per week. Vohra (1987) developed an expression for the minimum workforce for the (5,7) problem. Burns and Carter (1985) used workforce size lower bounds as additional constraints in a linear programming model. Alfares (1998) presented a two-phase algorithm for solving the cyclic manpower (5,7) days-off scheduling problem. Alfares (2001) developed an efficient optimization algorithm for the cyclic (5,7) days-off scheduling problem without linear or integer programming.

Emmons and Fuh (1997) presented formulas and an algorithm to determine the optimum number and schedule of a mixed workforce, composed of full-time workers and two types of part-time workers, where full-timers must have two days off per week and A out of B weekends off. Caprara *et al.* (2003) presented a two-step algorithm to solve a days-off staff scheduling problem in which the durations (in days) of the work and rest periods are specified in advance for each employee. The objective is to determine the sequence of these work and rest periods to satisfy daily labour demands with the minimum number of employees. Hung (2006) illustrated the cost savings possible under compressed workweek schedules, provided formulas for calculating the optimum workforce size, and presented methods to construct feasible employee days-off assignments.

Roberts and Escudero (1983) used integer programming (IP) to formulate and solve the problem of scheduling plant maintenance personnel and jobs to minimize personnel idle time, assuming limited manpower availability for each skill type. Duffuaa and Al-Sultan (1999) presented a stochastic programming model for scheduling maintenance personnel. The model is a stochastic version of Robert and Escudero (1983) deterministic model. Coleman (1995) discussed the use of shift scheduling systems known as Best Cost Schedules in the context of the electric utility industry, describing how to match the work load to the amount of staffing.

Brusco and Johns (1998) used IP to determine the minimum-cost cross-training policy for maintenance operations at a large US paper mill. Assuming a single work shift, their objective was to minimize staffing costs while satisfying labour demands during the planning horizon. Ahire *et al.* (2000) applied evolution strategies to the problem of minimizing the makespan for a set of preventive maintenance tasks, requiring single or multiple skills, subject to workforce availability constraints. They used a large set of test problems to compare their approach to both exhaustive enumeration and simulated annealing.

Alfares (1999) described a real life aircraft maintenance labour scheduling study. The objective was to determine the optimum maintenance workforce size and schedule to satisfy labour requirements with minimum cost. Alfares (1999) utilizes a unique integer programming formulation to obtain an optimum seven-day workweek schedule with no increase in workforce size. In this paper, an approach similar to that of Alfares (1999) is followed in obtaining an optimum seven-day work schedule for Afam Power Station. However, instead of using integer programming software, a simple Quick Basic computer programme based on Alfares (2001) algorithm is used for solving the (5,7) problem. The computer programme is a better alternative to integer programming software, since it does not require specialized training.

3. PROBLEM AND BACKGROUND

The first major gas turbine station built in Nigeria is the Afam Gas Turbine Power Station. The power station is located in the Niger Delta because of the large reserve of natural gas in the region. The first phase of the power station was commissioned in 1963 as Afam I, consisting of four generating units with total capacity of 54 MW. Consumption growth experienced in the seventies necessitated the construction of Afam II, which was commissioned in 1976. Afam II consists of four additional generating units with installed capacity totalling

92 MW. This was followed by Afam III, which was commissioned in 1978, consisting of four units with installed capacity totalling 108 MW. In 1982, six generating units were commissioned as Afam IV with total capacity of 450 MW. Finally, Afam V was commissioned in 2002, made up of two units with a total capacity of 138 MW. This brought the number of units in Afam power station to 20, with a total installed capacity of 980 MW. With only 413 MW currently being produced, the power generated is less than 43% of the installed capacity.

The station has been generating power far below installed capacity due to maintenance problems. These problems have affected the availability and reliability of the power plant. In order to minimize these maintenance problems, there is a need for effective maintenance scheduling, which is a major determinant of the productivity of the workforce. Improved labour productivity leads to more efficient handling of maintenance activities. Hence the purpose of this paper is the optimisation of the workforce scheduling for solving maintenance problems.

Afam power station maintenance line comprises of the following departments: Mechanical, Electrical, Instrumentation & Control, Workshop Services, and Planning. The maintenance management functions in Afam Power Station include both reactive (run-to-failure) and preventive maintenance (PM). The PM type in place is time based, which is not effectively carried out, not to talk of practicing the state-of-the-art, predictive maintenance. The preventive maintenance procedure and intervals are not well defined. Poor plant history records make it difficult to retrieve PM history and reports of plant/equipment, especially for old plants.

The power plant maintenance in Afam power station is performed by combined effort of the various departments that make up the maintenance line. The maintenance crews of the various departments carry out daily plant maintenance checks. The checks involve taking plant parameters like load, compressor inlet temperature, and plant evaluated operating hours to mention but a few. Apart from daily plant checks, maintenance line crews carry out 3 types of inspections:

1. First minor inspection, also referred to as small or type A inspection.
2. Second minor inspection, also referred to as normal or type B inspection.
3. Major inspection, or type C inspection.

The first minor inspection of the plant is carried out every 4,000 evaluated operating hours (EOH). The second minor inspection is carried out every 8,000 EOH. The major inspection is usually carried out every 16,000 EOH.

Eight mechanical workers are needed for type A inspection on a particular plant, 8-10 workers are needed for type B inspection, while 15 workers are needed for type C inspection. For daily plant checks, only one maintenance worker is needed to handle a plant. Information from plant daily checks, inspections, and other parameters are used by the planning department to develop an annual maintenance schedule.

This study is concerned with scheduling the Mechanical Department (MD) maintenance line, which is in charge of inspections and daily plant maintenance checks of the mechanical components of the power plant. Based on inspection requirements and past experience, the maintenance engineer of the MD estimated the number of workers needed to satisfy the daily routine of maintenance activities for a typical week. As shown in Table 1, the plant maintenance needs up to 16 workers daily for the morning shift (8:00 am – 4:00 pm), and up to 7 workers daily for each of the afternoon shift (4:00 pm – 12:00 am) and the night shift (12:00 am – 8:00 am).

4. MODELS AND SCHEDULING

To satisfy the labour demands shown in Table 1 most efficiently, the optimum number and work schedule of maintenance workers needs to determined. The (5,7) work schedule assigns workers to seven day-off patterns with two successive days off per week. The (5,7) days-off scheduling problem can be represented as an integer linear programming model as follows:

$$\text{Minimize } W = \sum_{i=1}^{7} x_j \cdots \tag{1}$$

Subject to

$$\left(\sum_{i=1}^{7} x_j\right) - x_i - x_{i-1} \geq r_i, \qquad i = 1, \cdots, 7 \tag{2}$$

$$x_j \geq 0 \text{ and an integer}, \qquad j = 1, \cdots, 7 \tag{3}$$

where

x_j = number of workers assigned to a days-off-pattern j, i.e. number of workers off on days, j and 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.

Alfares (1998) developed a simple equation that yields the minimum workforce size W for the (5,7) problem. After determining the workforce size, Alfares (2001) uses a simple algorithm to determine the number of workers assigned to each days-off pattern, $x_1, \cdots, x_7$, completing the optimum solution of the (5,7) problem without linear or integer programming. Based on Alfares (2001) algorithm, a simple computer programme was written in Quick Basic to determine the workforce size W and the number of workers assigned to days-off pattern $x_1, \cdots, x_7$.

Three alternative work schedules are available to satisfy the labour demands given in Table 1. The first

Table 1. Daily maintenance labour demands for the three shifts

Day – i	Mo – 1	Tu – 2	We – 3	Th – 4	Fr – 5	Sa – 6	Su – 7
Morning labour demand	16	16	16	16	16	8	7
Afternoon labour demand	6	6	7	7	7	6	6
Night labour demand	6	6	7	7	7	6	6

Table 2. Calculation of the total pay hours per week for Alternative I

Work Times	No. of Workers (W)	Hours/day $H = 8\times$days	Hours/Week $T = W\times H$	Pay Rate (%) R	Pay Hours $P = T \times R$
Mo-Fr morning	16	40	640	100	640
Sa morning	8	8	64	150	96
Su morning	7	8	56	150	84
Mo-Fr afternoon	7	40	280	110	308
Sa afternoon	6	8	48	160	76.8
Su afternoon	6	8	48	160	76.8
Mo-Fr night	7	40	280	115	322
Sa night	6	8	48	165	79.2
Su night	6	8	48	165	79.2

alternative is to continue with the existing regular time Monday-to-Friday workweek, scheduling workers for the weekend on an overtime basis. The second alternative is to switch to a seven-day workweek schedule for the morning shift only, continuing with the five-day workweek for both the afternoon and night shifts. Therefore, the second alternative would require weekend overtime only for the afternoon and night shifts. The third alternative is to switch to a seven-day workweek schedule for all three shifts. Under the third alternative, weekend overtime would be eliminated.

4.1 Alternative I: Continue with the Current 5-Day Schedule

The maximum labour demand for the morning shift on weekdays is 16. Thus, 16 workers are assigned to the morning shift work on the five weekdays (Mo-Fr) on regular-time basis. Similarly, seven workers are assigned to each of the afternoon and night shifts on weekdays on regular time basis. Therefore, the total workforce is equal to 16 + 7 + 7 = 30 workers. Out of this workforce, 6-8 employees are assigned to weekend work on overtime basis.

The shift premium pay rate is 110% for the afternoon shift and 115% for the night shift. The weekend pay rate for any shift is 50% higher than the weekdays pay rate. The details of the pay hours calculations are shown in Table 2. The morning shift requires 820 weekly pay hours, while the afternoon and night shift require a total of 942 weekly pay hours. The total workforce size is 30 workers and the weekly pay hours are equal to 1,762.

4.2 Alternative II: Switch to a 7–Day Workweek for the Morning Shift Only

The afternoon and night shift assignments in Alternative II are the same as in Alternative I. However, a seven-day schedule is determined for the morning-shift assignment, using the Quick Basic computer programme for solving (5,7) problem. The seven morning-time daily labour requirements shown in Table 1 were used as input data. The optimum solution requires 19 maintenance workers ($W = 19$) to satisfy morning labour demands as shown below. Days-off assignments for the 19 morning shift workers are as follows

$x_1 = 1,\quad x_2 = 2,\quad x_3 = 1,\quad x_4 = 2,$
$x_5 = 1,\quad x_6 = 10,\quad x_7 = 2.$

Each worker is paid for five workdays per week, at eight hours per day, all at regular time. Hence:

Morning shift pay hours per week $= 19 \times 5 \times 8$
$= 760$

Adding up the afternoon and night shift assignment, which is the same as in Alternative I (requiring a total of 14 employees and 942 weekly pay hours), we obtain:

Total number of employees $= 19 + 14 = 33$

Total pay hours per week $= 760 + 942$
$= 1{,}702$

4.3 Alternative III: Switch to a Seven-Day Workweek for all 3 Shifts

This alternative is used to satisfy all labour demands with a seven-day workweek schedule for all three work shifts.

We have already considered the morning-shift assignment as in alternative II, with 19 workers and 760 weekly pay hours. We now consider a seven-day schedule for both the afternoon and night shift assignments. We also use the Quick Basic computer programme for solving (5,7) problem, where the seven afternoon- or night-time daily labour requirements shown in Table 1 were used as input data. The optimum solution requires nine workers ($W = 9$) for each of the afternoon and the night shift, whose days-off assignments are as follows:

$$x_1 = 2, \quad x_2 = 1, \quad x_3 = 1, \quad x_4 = 1,$$
$$x_5 = 1, \quad x_6 = 2, \quad x_7 = 1.$$

In order to calculate the pay hours, it must be noted that the afternoon shift is paid at a premium rate of 110%, while the night shift is paid at a premium rate of 115%.

Afternoon shift pay hours per week $= 9 \times 5 \times 8 \times 1.10 = 396$

Night shift pay hours per week $= 9 \times 5 \times 8 \times 1.15 = 414$

Adding up the day-shift assignment, which is the same as in Alternative II (requiring 19 employees and 760 weekly pay hours), we obtain:

Total pay hours per week $= 760 + 396 + 414 = 1{,}570$

Total number of employees $= 19 + 9 + 9 = 37$

Comparison of the three alternative work schedules is shown in Table 3 below. From Table 3 it is obvious that Alternative III, which leads to 11 percent labour cost saving, is the best alternative. Therefore, Alternative III was recommended to the management of Afam power station. Though the proposed schedule requires seven more maintenance workers, this is not a serious draw back because Afam power station has an abundant pool of underutilized mechanical maintenance workers. Hence with the current workforce, the proposed schedule can be implemented even without employing more maintenance workers.

Table 3. Comparison of various alternative work schedule

Alternative schedule	Pay hours per week	Savings in pay hours	Workforce size
I	1,762	-	30
II	1,702	3.4%	33
III	1,570	10.9%	37

5. CONCLUSIONS

The objective of this paper is to determine the optimum maintenance workforce schedule that satisfies increasing maintenance labour requirements with minimum cost and highest efficiency. The traditional five-day work schedule currently being practiced at Afam power station is neither efficient nor cost effective. Hence, to satisfy labour demands for each day of the week, a seven-day workweek schedule is proposed for all three shifts. Switching to the proposed schedule would eliminate weekend overtime assignment. This is expected to yield an estimated saving of 11 percent in maintenance labour cost.

A computer programme written in Quick Basic for solving (5,7) problem was used to obtain the proposed seven-day schedule. The computer programme will ease the implementation of the proposed schedule. If there is a future change in daily labour demands, the computer programme can automatically generate the size of the workforce and the days-off assignments to satisfy the new demands.

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