Aircraft maintenance workforce scheduling

A case study

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Keywords *Aircraft industry, Optimization, Personnel management, Saudi Arabia*

Abstract *This paper describes an actual aircraft maintenance labor scheduling study. The study's objective is to determine the optimum maintenance workforce schedule to satisfy growing labor requirements with minimum cost. The main recommendation of the study is to switch from a five-day to a seven-day workweek for aircraft maintenance workers. A new integer programming formulation, used to obtain an optimum seven-day work schedule with no increase in workforce size, is presented. In comparison to the existing five-day schedule, switching to a seven-day workweek is expected to produce savings of about 13 per cent, or $100,000 annually.*

1. Introduction

During the summer of 1997, a study of aircraft maintenance worker schedules was conducted at the aviation department of Saudi Aramco in Dhahran, Saudi Arabia (Alfares, 1997). The objective was to evaluate the current fixed-wing aircraft maintenance worker schedule, and come up with recommendations for improvement, if needed. The specific aim was to determine the optimum work schedule that satisfies increasing maintenance labor requirements with the minimum cost and highest efficiency.

Saudi Aramco is the main oil company in Saudi Arabia, and the largest oil company in the world. It is in charge of all phases of the oil business, from surveying and exploration, through producing and refining, all the way to marketing and distribution. Because oil revenues constitute the major part of the national income, the importance of the company to the Saudi industrial development cannot be overemphasized. The aviation department is responsible for the air transportation of the company's workers and equipment to remote areas, such as oil fields and exploration sites. The aircraft maintenance division of the department must ensure the safety and airworthiness of the company's large private fleet, which in 1997 included 13 fixed-wing aircraft and 19 helicopters.

The fixed-wing flight line maintenance had been operating on a five-day (Saturday-to-Wednesday) schedule, with two full eight-hour shifts per day. The line was experiencing excessive overtime, especially during the weekends where it has to support an increasing number of flights. The purchase of three new aircraft, more frequent maintenance checks, and additional flights to new

The author would like to acknowledge the generous support provided by King Fahd University of Petroleum and Minerals while carrying out this research project.

destinations were putting increasing pressures on aircraft maintenance. It was desired to determine the best schedule of aircraft maintenance to respond to these challenges.

Based on the analysis of labor demands, overtime statistics, current schedule, current workforce size, and other relevant statistics, a recommendation was made to switch to a seven-day workweek for the line. Compared to the current five-day workweek schedule for the flight line, the proposed seven-day workweek schedule is estimated to save 13 per cent, or $98,000, of annual labor costs.

2. Literature review

This literature review will focus, in order, on three subjects relevant to the study:

(1) aircraft maintenance;

(2) maintenance staffing; and

(3) personnel scheduling.

Starting with aircraft maintenance literature, recent studies emphasize the role of human factors and training in improving maintenance crew effectiveness. Ivaturi *et al.* (1995) developed a framework to analyze, identify, and evaluate team training strategies to improve teamwork effectiveness in aircraft inspection and maintenance operations. Dorn (1996) found human factors to have a significant effect in 101 maintenance-related aircraft accidents that he studied. Shepherd and Kraus (1997) described guidelines for human factors training of maintenance personnel in order to reduce human error in aircraft maintenance.

Maintenance staffing objectives include minimum cost, maximum availability, maximum reliability, or a combination of these measures. Dietz and Rosenshine (1997) developed a method to determine the optimal structure of a maintenance workforce, and used it to maximize military aircraft sortie generation subject to a limit on maintenance staffing cost. Hecht *et al.* (1998) presented a queueing model to determine average outage time in US air traffic control system as a function of the number of maintenance technicians assigned to each center. Galpin *et al.* (1993) surveyed operation and maintenance staffing practices in utility plants and compared theoretical and actual staffing levels. Al-Zubaidi and Christer (1997) constructed a maintenance manpower simulation model to estimate the costs of different manpower management and operational procedures. Duffuaa and Al-Sultan (1997) proposed mathematical programming approaches for planning and scheduling maintenance resources, including manpower, equipment, and parts.

Baker (1974) classifies labor scheduling into three types: shift (time-of-day) scheduling, days-off (days-of-week) scheduling, and tour (time-of-day and days-of-week) scheduling. Since we are concerned with obtaining a seven-day coverage per week, our focus is on the days-off scheduling problem. Nanda and Browne (1992) provide a comprehensive survey of literature on this problem.

Giving each worker two consecutive days off per week, Tiberwala *et al.* (1972) formulated an integer programming model for days-off scheduling. Alfares (1998) presented a two-stage linear programming algorithm for solving the same problem.

3. Problem and background

In July 1997, the aviation department of Saudi Aramco requested assistance in reviewing the existing work schedules and manpower distribution for the aircraft maintenance personnel. Aviation management expressed three concerns to be taken into account.

(1) The current excessive overtime to cover weekends and unplanned maintenance.

(2) The seven-day maintenance requirement associated with the flight schedule, which is active during the weekends.

(3) The significant increase in scheduled maintenance workload due to changes in both the maintenance program and the flight schedule.

At the time of this study, the fixed-wing aircraft maintenance division, based in Dhahran airport, had 13 aircraft and 103 employees. The division consists of six units:

(1) planning/engineering;

(2) avionics;

(3) line maintenance;

(4) special flights;

(5) hangar maintenance; and

(6) shops.

According to the division's management (Al-Sugair, 1994), aircraft maintenance manning requirements are affected by the following factors:

- different types of aircraft;
- continuous coverage (seven days a week, 24 hours a day);
- training requirements;
- US Federal Aviation Administration (FAA) Airworthiness Directives (Saudi Aramco aircraft have FAA registration);
- manufacturer service bulletins;
- aircraft age and condition; and
- Saudi Arabia's harsh environment.

Aircraft maintenance requirements can be broadly classified as follows:

- Scheduled maintenance: including pre-flight, post-flight, daily and phase checks, calendar time changes, time limited component changes, in addition to A, B, C, and D checks (periodic aircraft PM/inspection programs of increasing intensity).

- Unscheduled maintenance: to handle unplanned problems reported by flight or maintenance crews. As a rule of thumb, aviation department estimates unscheduled maintenance workload to be 50 per cent of scheduled maintenance workload.
- Special maintenance: as required to satisfy special instructions or directives by the manufacturer, FAA, or aviation management.

Maintenance workload is expected to significantly increase due to several factors. The first factor is the purchase of three additional aircraft in 1998. Second, more frequent inspections due to changes in the maintenance program, i.e. doubling the frequency of B and C checks. Third, new flights as a consequence of starting service to the new Shaybah oilfields. Fourth, doubling the number of flights to Northern Area Producing as a result of changing the days-on/days-off work schedule from (14/7) to (7/3, 7/4). Currently, line overtime is averaging 27 hours per employee per month, but is increasing due to growing maintenance requirements. Changing the aircraft maintenance labor schedule aims to reduce excessive overtime, and allow the workforce to handle workload increases indicated in Table I.

This study is concerned with scheduling the line maintenance unit's workforce, which is responsible for maintaining aircraft that are actively in service. There are two full eight-hour shifts per day, morning and afternoon. Two full line maintenance crews, each with its own foreman, are bi-weekly rotated between the two shifts. Both crews are made up of one trade, namely airframe and power (A&P) technicians. The workload of line maintenance workers includes the following duties: pre-flight, through-flight, post-flight checks, calendar and 50-hour inspections, A checks, time limited component changes, supporting special flights, fixing pilot-reported problems and maintenance discrepancies, and on the job training.

If we exclude unscheduled maintenance, i.e. fixing pilot-reported problems and discrepancies found during inspections, the workload of line maintenance is highly deterministic. Given the weekly flight and maintenance schedules, we can accurately estimate the time and number of workers needed for each scheduled maintenance activity. For example, a team of two workers will take one to two hours for a preflight check, half an hour to an hour for through-flight check, two hours for a post flight check, and 24 hours for an A check. To

Workload indicator	1997	1998	% increase
Projected manweeks of aircraft maintenance	755	1010	34
No. of weekly flights	64	79	23
No. of fixed-wing aircraft	13	16	23

Table I. Aircraft maintenance workload indicators for 1997 and 1998 include unscheduled maintenance workload, we can add 50 per cent to labor requirements, or consider averaging actual past data. Whenever the two estimates differed considerably, the higher of the two was used.

Information on aircraft maintenance processes and policies was obtained by interviewing the concerned people, gaining insights and experience-based points of view on problems and possible solutions. For each shift, data were collected on the current schedule, current workforce size, and average overtime hours per month. Information was also gathered on each shift's daily manpower requirements, relation to the flight schedule, and relation to the other shift. Other relevant statistics were also collected. In addition to interviews, sources of data included:

- weekly flight schedules;
- weekly maintenance planning schedules;
- weekend work schedules;
- yearly maintenance projections;
- employee time sheets;
- maintenance work log books; and
- company manual on work schedules (Saudi Aramco, 1996).

The most important step in data collection was determining the daily labor demands for each shift for each day of the week. This was accomplished by considering the projected flight schedule for 1998, with 15 added flights for new destinations. In addition, the actual workload (from the work logbook) was considered for a sample of several typical weeks. The line foremen were asked to estimate the number of workers that would be needed to satisfy the labor requirements of both the flight schedule and actual work recorded in the logbook. The average labor demands was determined for each shift during the workweek are shown in Table II (please note that the weekend in Saudi Arabia is Thursday and Friday).

4. Modeling and scheduling

Since line maintenance crews include only A&P technicians, homogeneous workforce scheduling techniques can be applied. The company policies (Saudi Aramco, 1996) specify that the minimum off period for any worker during a given work stretch must be at least two days. Tiberwala *et al.* (1972) formulated the following single-shift integer programming model for scheduling workers

Table II. Daily maintenance labor demands for morning and afternoon shifts

Day-i	Sa-1	Su-2	Mo-3	Tu-4	We-5	Th-6	Fr-7
Morning shift labor demand (m_i)	10	8	8	8	9	2	2
Afternoon shift labor demand (a_i)	10	9	9	9	11	2	5

with two consecutive days off per week.

$$\text{Minimize } Z = \sum_{i=1}^{7} x_i \tag{1}$$

Subject to

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

$$x_i, r_i \geq 0 \text{ and integer}, \qquad i = 1, \ldots, 7 \tag{3}$$

where

x_i =number of workers assigned to days-off pattern i, off on days i and $i+1$

r_i =minimum number of workers required on day i.

Three alternative work schedules are available for satisfying labor demands given in Table II. The first is to continue with the existing regular time Saturday-to-Wednesday five-day workweek, scheduling workers for the weekend on an overtime basis. The second alternative is to switch to a separate seven-day workweek schedule for each shift, in which workers may work on regular time during the weekends, and have two days off during the weekdays. The third alternative is similar to the second, but the morning and afternoon shifts are linked on Friday. Shift assignments and costs of the three alternatives are compared next.

4.1. Alternative 1: continue with the current five-day schedule

The maximum labor demand for weekdays is 11, which occurs on Wednesday afternoon. Since two work groups alternate between the morning and afternoon shifts, 11 workers are assigned to each shift. These workers are assigned to weekdays on a regular-time basis, and to weekends on voluntary, overtime basis. The pay hours are calculated in Table III, adding up to 1,012 per week.

4.2. Alternative 2: switch to seven-day workweek, separating the two shifts

To satisfy labor demands with a seven-day schedule, Tiberwala *et al.*'s (1972) integer programming model was modified to incorporate two shifts, with the

Shift work times	Workers W	Hours/shift H = 8*days	Hours/week $T = W * H$	Pay rate (%) R	Pay hours/week $P = T * R$
Sa-We morning	11	40	440	100	440
Sa-We afternoon	11	40	440	100	440
Th-Fr morning	2	16	32	150	48
Th afternoon	2	8	16	150	24
Fr afternoon	5	8	40	150	60

Table III. Calculation of the total pay hours per week for Alternative 1 objective of minimizing the total number of workers. Since labor demands for the two shifts are different, r_i in constraint (2) is replaced by m_i for the morning shift, and by a_i for the afternoon shift. Moreover, redefining x_i as morning shift assignments and defining y_i as afternoon shift assignments, x_i is replaced by y_i for the afternoon shift. Table IV shows the optimum solution of the modified model, which is displayed below.

$$\text{Minimize } Z = \sum_{i=1}^{7} x_i + y_i \tag{4}$$

Subject to

$$\left(\sum_{j=1}^{7} x_j\right) - x_{i-1} - x_i \geq m_i, \qquad i = 1, \ldots, 7 \tag{5}$$

$$\left(\sum_{j=1}^{7} y_j\right) - y_{i-1} - y_i \geq a_i, \qquad i = 1, \ldots, 7 \tag{6}$$

$$x_i, y_i \geq 0 \text{ and integer}, \qquad i = 1, \ldots, 7 \tag{7}$$

where

x_i =number of morning shift workers off on days i and $i+1$

y_i =number of afternoon shift workers off on days i and $i+1$

Since there is no overlap in the constraints involving the x_i's and y_i's, we can solve independently for the two sets of variables. Alternatively, we can develop two separate models for the two shifts, simply by splitting (4) into two objectives of the form (1). Since two full maintenance crews are rotated between the two shifts, the minimum size of each crew must be 12 workers. Therefore, Alternative 2 requires 24 workers for the two shifts. Moreover, since each worker is given two days off per week, each worker is paid for five work days per week, at eight hours per day, all regular time. Therefore, the total pay hours per week are calculated as follows:

Alternative 2 pay hours = 24×5×8 = 960 hours/week

The above figure represents a significant saving compared to the 1,012 hours/week obtained by Alternative 1. However, this saving is obtained at the expense of increasing the workforce size from 22 to 24 workers. Alternative 3 utilizes a unique approach to produce even greater savings without any increase in the workforce size, as discussed next.

Table IV. Morning and afternoon shift assignments for Alternative 2

Shift i	1	2	3	4	5	6	7	Total
Morning workers x_i	0	1	0	1	0	8	0	10
Afternoon workers y_i	2	0	2	1	0	7	0	12

4.3. Alternative 3: switch to seven-day workweek, linking the two shifts

Although Alternative 2 reduces pay hours compared to Alternative 1 (current schedule), it requires more workers. This is a serious drawback in a developing country like Saudi Arabia, where skilled workers are scarce, particularly in a highly specialized field such as aircraft maintenance. In order to avoid the need for more workers while providing seven-day coverage, the following integer programming model was formulated. This model is similar to the modified two-shift model developed above, but replacing constraints (5) and (6) with the following constraints combines Friday's demands:

$$\left(\sum_{j=1}^{7} x_j\right) - x_{i-1} - x_i \geq m_i, \qquad i = 1, \ldots, 6 \tag{8}$$

$$\left(\sum_{j=1}^{7} y_j\right) - y_{i-1} - y_i \geq a_i, \qquad i = 1, \ldots, 6 \tag{9}$$

$$\left(\sum_{j=1}^{7} x_j + y_j\right) \geq m_7 + a_7 \tag{10}$$

A unique feature of the above integer programming model is combining Friday's morning and afternoon labor demands in one constraint (10). The objective is to add flexibility for minimizing the workforce size. The model does succeed in providing seven-day coverage with the same workforce size used to provide only five-day coverage. The solution specifies that 11 workers are needed for each shift, assigned as shown in Table V.

Assigning 11 workers to each shift, the total workforce size is only 22. Moreover, the total pay hours per week are further reduced to:

$$\text{Alternative 3 pay hours} = 22 \times 5 \times 8 = 880 \text{ hours/week}$$

To realize the benefits of this alternative, certain adjustments are needed on Fridays. Table VI shows the result of the Friday-combined solution, assigning four workers to Friday morning (greater than the two needed), but only three workers to Friday afternoon (less than the five needed). To solve this problem, two workers from the morning shift must join the afternoon shift on Fridays. This makes the assignment two workers for the morning and five for the afternoon on Friday, satisfying labor requirements of both shifts. For fairness, workers should be rotated periodically among the 22 assignments, allowing every worker to have 15 full weekends off in each 22-week cycle.

Obviously the third alternative, which requires no increase in the number of workers, is the best since it has the fewest pay hours per week. Alternative 3

Shift i	1	2	3	4	5	6	7	Total
Morning workers x_i	1	1	0	0	2	7	0	11
Afternoon workers y_i	1	1	1	0	0	8	0	11

Table V. Morning and afternoon shift assignments for Alternative 3 outperforms Alternative 2 because it satisfies daily labor demands with minimum overstaffing. Figure 1 compares the daily slack (number of workers assigned in excess of demand) for Alternatives 2 and 3. The total weekly slack is 18 mandays for Alternative 2, but only 8 mandays for Alternative 3. Compared to Alternative 1 (current schedule), the savings produced by Alternative 3 are calculated as follows:

Saving in pay hours per week = 1,012 – 880 = 132 hours

Percentage savings = $100 \times 132 \div 1012 = 13.04$ per cent

Average labor pay rate (given) = $14.23/hour

Annual saving in US dollars = $14.23 \times 132 \times 52 =$ \$97,675/year

5. Practical considerations

Some employees have expressed a degree of reservation towards the new seven-day schedule, because they think it would force them to work all weekends without overtime pay. Therefore, implementation of the seven-day schedule must be done with careful attention to employee morale. As emphasized in the literature survey, human factors are significant to the performance of aircraft maintenance. It is recommended that the following two points are explained to workers. First, weekend work will be rotated, thus each worker will have 15 out of 22 (about 70 per cent) weekends off. Second, some compensation will be given for weekend work, possibly in the form of on-call

Table VI. Total morning and afternoon daily worker assignments for Alternative 3

Day	Morning shifts x_1	x_2	x_5	x_6	Total	Afternoon shifts y_1	y_2	y_3	y_6	Total
Saturday	[a]	1	2	7	10	[a]	1	1	8	10
Sunday	[a]	[a]	2	7	9	[a]	[a]	1	8	9
Monday	1	[a]	2	7	10	1	[a]	[a]	8	9
Tuesday	1	1	2	7	11	1	1	[a]	8	10
Wednesday	1	1	[a]	7	9	1	1	1	8	11
Thursday	1	1	[a]	[a]	2	1	1	1	[a]	3
Friday	1	1	2	[a]	4	1	1	1	[a]	3

Note: [a] = offday

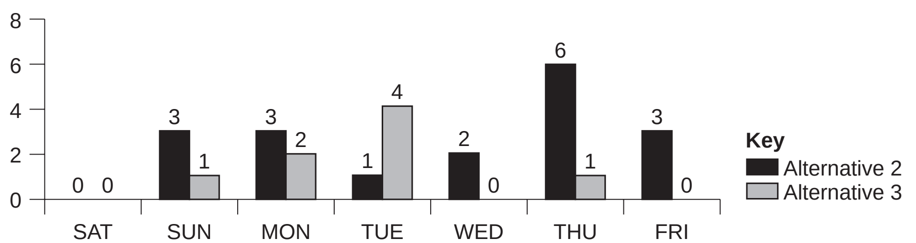

Figure 1. Excessive number of workers assigned on each weekday for Alternatives 2 and 3

pay. The third and final point is that the nature of the work, i.e. regularly scheduled weekend flights, imposes a requirement for regularly scheduled weekend work.

Management must also highlight the indirect benefits to the workforce. First, a more effective allocation of workers should lead to improved performance, and ultimately to tangible rewards such as merit increases. Second, the new schedule is fair, assigning an equal share of work, pay hours, and experience among all workers. To successfully sell this schedule to aircraft maintenance workforce, management itself has to be totally comfortable with it. In the final analysis, both management commitment and worker understanding and cooperation will play a vital role in the success of the proposed work schedule. In the aircraft maintenance case, it seems that a good measure of both is available in the organization.

6. Conclusions

To satisfy maintenance labor demands for each day of the week, especially increasing weekend demands, a seven-day workweek schedule is proposed for both morning and afternoon shifts. Switching to this schedule would eliminate the need for weekend overtime, yielding an estimated saving of $98,000 per year. By using a unique integer programming formulation, no increase is required in the number of workers as a result of the proposed schedule. The results of the study were accepted by the aviation department's management. However, implementation of the proposed schedule is planned to start when the department moves to the new international airport in Dammam, as soon as it is officially opened in May 1999.

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