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Simulation-based multi-craft workforce scheduling

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Abstract

A simulation model is used for stochastic days-off scheduling of maintenance crews. In order to determine optimum employee work schedules, the model considers limited employee availability, stochastic workload demand, and labor scheduling regulations. The stochastic simulation model was implemented for actual days-off scheduling of a multi-craft pipeline maintenance workforce in a large oil company. Alternative employee days-off schedules generated by the model are expected to improve the productivity of the existing maintenance workforce by an average of 25%.

1 Introduction and Literature Review

A simulation model is presented for stochastic scheduling of a multi-craft maintenance workforce of an oil and gas pipelines department. The objective is to minimize the average throughput (waiting plus processing) time of maintenance work orders. The pipelines maintenance crews are composed of 19 technicians belonging to five different maintenance crafts. Current labor regulations allow only three possible days-off schedules for the maintenance workforce. The workload for each craft is stochastic because the majority of maintenance jobs are unscheduled and require multi-craft crews.

A simulation model was constructed to represent and analyze the maintenance work order and workforce scheduling system. This model was used to evaluate several days-off scheduling alternatives for the pipelines maintenance workforce. The model suggested alternative schedules for the five maintenance crafts that are expected to reduce the throughput time on average by 25%.

There is a lot of literature on employee scheduling, but here we focus on simulation-based approaches for employee scheduling. Such approaches have initially been applied in manufacturing facilities. Davis and Mabert (2000) use simulation to evaluate and compare two mathematical modeling techniques for order dispatching and labor assignment decisions in two alternative cellular manufacturing (CM) arrangements. Yang et al. (2002) use simulation to study the impact of several flexible workday policies for maximizing the flexibility and responsiveness of a job shop by adjusting the length of workdays. Zülch et al. (2004) employ the personnel-oriented simulation tool $ESPE$ to evaluate three techniques for planning and re-assigning personnel in manufacturing.

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Simulation-based workforce scheduling has also been utilized in service facilities. Smith et al. (2002) use simulation with integer programming (IP) to staff geographically distributed service facilities. Chong et al. (2003) apply simulation to model an airline's flight and staff schedules and to generate staff rosters for check-in agents. Guttkuhn et al. (2003) use simulation to assign train crews in order to meet train traffic and labor rules. Gupta et al. (2003) combine simulation with optimization to schedule the aircraft line maintenance employees of Continental Airlines. Bazargan and McGrath (2003) use a similar approach to allocate maintenance mechanics to various shifts. Li and Li (2000) combine simulation and goal programming to investigate the costs and benefits of staff flexibility in a Chinese clinic. Centeno et al. (2003) integrate simulation with an IP model to determine staffing requirements and optimal schedules for ER staff.

2 The current maintenance work order process

The pipelines maintenance workforce is responsible for scheduled and emergency repairs and maintenance of all pipelines throughout a designated area. It consists of 19 employees divided into five crafts: 2 air conditioning (AC) technicians, 6 digital (DG) technicians, 5 electrical (EL) technicians, 3 machinist (MA) technicians, and 3 metal (ME) technicians. The maintenance employees can work for a maximum of 12 hours per day, and they can be assigned to only three types of days-off schedules:

1. The (5/2) schedule: 5 consecutive workdays followed by 2 consecutive off days (weekend) per week. Initially, 13 technicians (1 AC, 6 DG, 3 EL, 1 MA, and 2 ME) are on this schedule.

2. The (14/7) schedule: 14 consecutive workdays followed by 7 consecutive off days per three-week cycle. Initially, four technicians (1 AC, 1 EL, and 2 MA) are on this schedule.

3. The (7/3-7/4) schedule: two work stretches each of 7 consecutive workdays separated by two breaks of 3 and 4 consecutive off days, per three-week cycle. Initially, only two technicians (1 EL and 1 ME) are on this schedule.

After a maintenance work order (W/O) is initiated, materials needed as well as labor requirements of each craft type are listed. Next, the maintenance cost is estimated and the originator's approval is obtained. Subsequently, the W/O is prioritized and scheduled and then work is started. After finishing the work, a report is sent to the originator for either comment or approval in order to close the W/O. A simplified flowchart of the system is shown in Figure 1. From the preceding description, each W/O must pass through the following phases:

1. Hold (HLD) phase: waiting to receive the materials or approval to start.

2. Work (WRK) phase: being processed and undergoing maintenance work.

3. Finish (FIN) phase: completed, but waiting for approval to close.

4. Close (CLS) phase: completed, approved, and entered into the database.

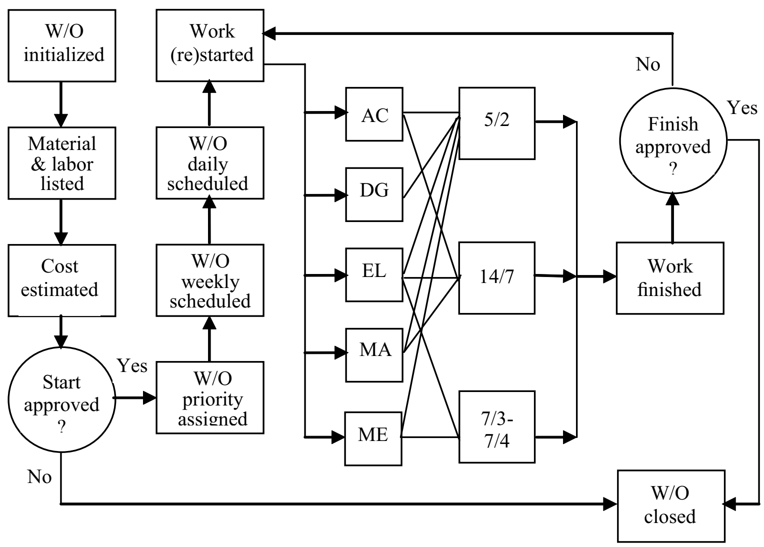

Figure 1: Simplified flowchart of the maintenance W/O process.

Data covering a period of 7 months was collected and analyzed. For each W/Os during the given period, data were collected on durations and inter-arrival times in hours, and also the required number of employees of each craft. To fit probability distributions, the data was plotted and the relevant statistics were calculated, and then the Chi-square goodness-of-fit test was used with $\alpha = 0.05$. The probability distribution for the W/O inter-arrival time was found to be EXPON (9.79). For each craft, Table 1 shows the fitted probability distributions for the service times (time spent on each work order per technician) and other relevant statistics. For each W/O, the number of men required of each craft has a discrete empirical distribution, and it must be fully available for starting the given W/O.

Table 1: Service time distributions and statistics for the five craft types.

Craft type	No. of men available	Avg. no. of men needed	Probability of craft (%)	Service time probability distribution (hours)
AC	2	1.3	18.5	WEIBL (0.83, 19.03)
DG	6	1.49	24.9	WEIBL (0.76, 22.77)
EL	5	1.59	21.3	LOGNR (2.48, 1.07)
MA	3	1.35	23.1	EXPON (13.78)
ME	3	1.11	12.2	WEIBL (0.89, 37.92)

3 Simulation model

The simulation model's assumptions include the following:

1. Any W/O requiring several crafts is processed by each craft in parallel, and consequently considered as multiple W/Os, each requiring a single craft type.

2. The number of technicians from each craft type assigned to each W/O is a random variable calculated from empirical probability distributions.

3. During their work times, the pace of work of maintenance craft employees is represented by the service time probability distributions given in Table 1.

The AweSim! simulation software was used. The program was run for 210 simulated days (7 work months), which is well into steady state. To validate the model, actual and simulation output values of W/O throughput times in hours were compared. For each craft, confidence intervals were constructed of the differences between the averages of five simulation runs and five randomly chosen actual system observations. Since the confidence intervals of the difference (error) for all five crafts contain zero, the simulation model can be accepted as a valid representation of the real system. The number of replications was determined to be 10, which is the sample size that gives the smallest confidence interval for the average throughput time.

For each craft type, the simulation output gives information about the number of completed W/Os, average waiting time of W/Os, average number of orders waiting to be served, and average utilization of employees. However, the main performance measure is the average W/O throughput time for each craft, which is illustrated in Table 2.

Table 2: Current W/O throughput time for each craft in hours.

Craft type	Average	Stand. dev.	95% Confidence interval
AC	9.07	2.24	[7.77, 10.37]
DG	16.85	1.70	[15.86, 17.84]
EL	7.47	1.43	[6.64, 8.3]
MA	24.43	3.29	[22.53, 26.33]
ME	9.14	2.65	[7.61, 10.68]

3.1 Alternative MA days-off schedules

As Table 2 shows that the throughput time is highest for the machinist (MA) craft, alternative days-off schedules were first tried for the MA technicians. Keeping the number of MA technicians as 3, but considering all their possible assignments to the 3 feasible days-off schedules, there are 10 possible scheduling scenarios (alternatives) shown in Table 3 (alternative 10 is the current schedule). For each scenario, the model was modified according to that scenario and then run again

Table 3: Days-off scheduling alternatives for 3 MA technicians.

Alternative	No. assigned to days-off schedules			Ave. throughput
number	5/2	14/7	7/3-7/4	time (hrs)
1	3			30.68
2		3		43.58
3	2	1		23.14
4	1	1	1	20.41
5	2		1	23.6
6		2	1	24.54
7		1	2	24.39
8	1		2	24.33
9			3	37.22
10	1	2		24.43

for 10 replications. The new average throughput time for the MA craft W/Os under each scenario is shown in Table 3.

As can be seen from Table 3, scenario number 4 (1 man on each of the 3 days-off schedules) is the best. Under this scenario, the average throughput time for MA work orders will be reduced by 16.4% from 24.43 hours to 20.41 hours. The hiring cost will not change since the pay is the same for all 3 days-off schedules.

3.2 Alternative schedules for other crafts

Following the same procedure, the best days-off schedules were determined for AC, DG, EL, and ME technicians. Since the work orders are processed in parallel, the inter-dependence among the different crafts is minimal. Therefore, the different scenarios (days-off schedules) for each craft were run while fixing the other crafts at their current schedules. The most efficient days-off schedules and corresponding reductions in work order throughput times for all crafts are summarized in Table 4. The reductions in throughput times range from 4% to 67%, with an average of 25%.

Table 4: Summary table of best days-off schedules for all crafts.

Craft	No. of schedules	5/2	14/7	7/3-7/4	From(hr)	To(hr)	%Reduction
AC	6	1		1	9.07	8.71	4
DG	27	1	2	3	16.85	5.57	66.9
EL	21	2	2	1	7.47	7.44	0.39
MA	10	1	1	1	24.43	20.41	16.4
ME	10	1	1	1	9.14	5.59	38.8

4 Conclusions

A simulation model for stochastic workforce days-off scheduling has been presented. This approach has been applied to real-life days-off scheduling of a pipelines maintenance workforce consisting of five types of crafts. The simulation model determined the optimum allocation of technicians of each craft type to three applicable days-off schedules. A 25% increase in productivity is expected due to reduction in average work order throughput times. This improvement can be obtained simply by changing the employee scheduling assignments, without increasing either the size or the cost of the maintenance workforce.

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