

# 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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36 Simulation-based workforce scheduling has also been utilized in service facilities. Smith et al. (2002) use simulation with integer programming (IP) to staff  
37 geographically distributed service facilities. Chong et al. (2003) apply simulation  
38 to model an airline's flight and staff schedules and to generate staff rosters for  
39 check-in agents. Guttkuhn et al. (2003) use simulation to assign train crews in  
40 order to meet train traffic and labor rules. Gupta et al. (2003) combine simulation  
41 with optimization to schedule the aircraft line maintenance employees of Continental Airlines. Bazargan and McGrath (2003) use a similar approach to allocate  
42 maintenance mechanics to various shifts. Li and Li (2000) combine simulation  
43 and goal programming to investigate the costs and benefits of staff flexibility in  
44 a Chinese clinic. Centeno et al. (2003) integrate simulation with an IP model to  
45 determine staffing requirements and optimal schedules for ER staff.  
47

## 48 **2 The current maintenance work order process**

49 The pipelines maintenance workforce is responsible for scheduled and emergency repairs and maintenance of all pipelines throughout a designated area. It consists  
50 of 19 employees divided into five crafts: 2 air conditioning (AC) technicians, 6  
51 digital (DG) technicians, 5 electrical (EL) technicians, 3 machinist (MA) technicians, and 3 metal (ME) technicians. The maintenance employees can work for a  
52 maximum of 12 hours per day, and they can be assigned to only three types of  
53 days-off schedules:  
54  
55

- 56 1. The (5/2) schedule: 5 consecutive workdays followed by 2 consecutive off  
57 days (weekend) per week. Initially, 13 technicians (1 AC, 6 DG, 3 EL, 1  
58 MA, and 2 ME) are on this schedule.
- 59 2. The (14/7) schedule: 14 consecutive workdays followed by 7 consecutive off  
60 days per three-week cycle. Initially, four technicians (1 AC, 1 EL, and 2  
61 MA) are on this schedule.
- 62 3. The (7/3-7/4) schedule: two work stretches each of 7 consecutive workdays  
63 separated by two breaks of 3 and 4 consecutive off days, per three-week cycle.  
64 Initially, only two technicians (1 EL and 1 ME) are on this schedule.

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

- 72 1. Hold (HLD) phase: waiting to receive the materials or approval to start.
- 73 2. Work (WRK) phase: being processed and undergoing maintenance work.
- 74 3. Finish (FIN) phase: completed, but waiting for approval to close.

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

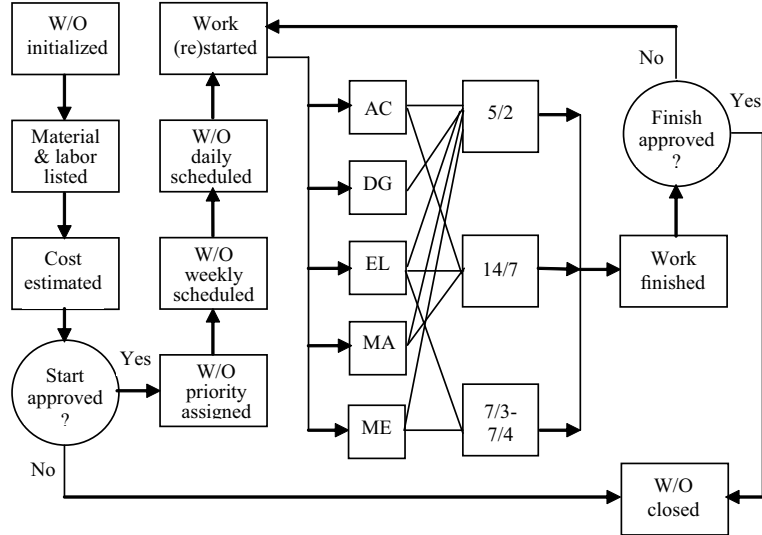


Figure 1: Simplified flowchart of the maintenance W/O process.

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)

### 86 3 Simulation model

87 The simulation model's assumptions include the following:

- 88 1. Any W/O requiring several crafts is processed by each craft in parallel, and  
89 consequently considered as multiple W/Os, each requiring a single craft type.
- 90 2. The number of technicians from each craft type assigned to each W/O is a  
91 random variable calculated from empirical probability distributions.
- 92 3. During their work times, the pace of work of maintenance craft employees is  
93 represented by the service time probability distributions given in Table 1.

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

104 For each craft type, the simulation output gives information about the number  
105 of completed W/Os, average waiting time of W/Os, average number of orders  
106 waiting to be served, and average utilization of employees. However, the main  
107 performance measure is the average W/O throughput time for each craft, which  
108 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]

#### 109 3.1 Alternative MA days-off schedules

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

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

Alternative number	No. assigned to days-off schedules			Ave. throughput time (hrs)
	5/2	14/7	7/3-7/4	
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

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

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

### 122 3.2 Alternative schedules for other crafts

123 Following the same procedure, the best days-off schedules were determined for AC,  
 124 DG, EL, and ME technicians. Since the work orders are processed in parallel, the  
 125 inter-dependence among the different crafts is minimal. Therefore, the different  
 126 scenarios (days-off schedules) for each craft were run while fixing the other crafts  
 127 at their current schedules. The most efficient days-off schedules and corresponding  
 128 reductions in work order throughput times for all crafts are summarized in Table 4.  
 129 The reductions in throughput times range from 4% to 67%, with an average of  
 130 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

## 131 4 Conclusions

132 A simulation model for stochastic workforce days-off scheduling has been pre-  
133 sented. This approach has been applied to real-life days-off scheduling of a pipelines  
134 maintenance workforce consisting of five types of crafts. The simulation model de-  
135 termined the optimum allocation of technicians of each craft type to three applica-  
136 ble days-off schedules. A 25% increase in productivity is expected due to reduction  
137 in average work order throughput times. This improvement can be obtained sim-  
138 ply by changing the employee scheduling assignments, without increasing either  
139 the size or the cost of the maintenance workforce.

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