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A SIMULATION APPROACH TO MANPOWER PLANNING

Massoud Bazargan-Lari
Payal Gupta
Seth Young

Embry-Riddle Aeronautical University
College of Business
600 S. Clyde Morris Blvd.
Daytona Beach, FL 32114, U.S.A.

ABSTRACT

This paper describes the development of a computerized line maintenance simulation model for strategic manpower planning at Continental Airlines for one of their major maintenance stations at Newark airport. The simulation model provides guidelines to the development of enhanced staffing models and a better understanding of resource requirements on a daily basis. The proposed simulation model could be used as a tool to support the management of the line maintenance department in solving various capacity planning issues related to the manpower requirement and scheduling. The recent capabilities of simulation modeling, namely optimization modeling is adopted in search of enhanced shift schedule of technicians that would improve the efficiency of the existing system.

1 INTRODUCTION

Maintenance activities are the backbone of a successful and profitable airline company. In the airline industry, the role of maintenance is to provide safe, airworthy, on-time aircraft every day. The proper and efficient maintenance of the growing fleet of aircraft presents a unique challenge, which requires necessary capacity and technical competence.

Aircraft maintenance must be planned and performed according to prescribed procedures and standards. An airline generally has a diverse fleet of aircraft. Each fleet type has a predetermined maintenance program established by the manufacturer. Based upon the airline experience and mode of operation, the original program is adapted under the FAA approval. The maintenance task standards (norms) specify in which time interval each task must be scheduled and how much time must be spent on each task.

Line maintenance (referred to as short routine maintenance) includes the regular short haul inspections of aircraft between their arrival, and consecutive departure from the airport. Line maintenance has the greatest effect on flight schedules and maintenance delay rates. Hence, it requires meticulous planning and foresight. Though line maintenance requires neither an extensive investment in elapsed time or manpower, but due to their high frequency of occurrence, these tasks represent a significant fraction of aircraft maintenance costs. Ninety percent of the cost of line maintenance is attributable to labor (Lam, 1995).

Line maintenance is driven by flight scheduling forecasts. Once the flight schedule is set, a maintenance schedule is assigned to each maintenance station. The maintenance schedule takes into consideration the fleet/equipment type flying to that station, the number and type of maintenance programs to be carried out, the capabilities of the specific station, task standards for each of those maintenance programs, ground time available and other resources such as tooling, hangars, weather and events that would conflict with one another. Management then has to build a staffing model for that station which specifies the manpower requirement and scheduling to meet the maintenance schedule's objectives in the most efficient manner. Manpower planning is thus crucial to improving system performance and efficiency and minimizes costs.

Mathematical modeling techniques have been used in the area of maintenance planning. Dijkstra, et al (1991), proposed a Decision Support System (DSS) for capacity planning of aircraft maintenance personnel and to solve problems related to the size and the composition of the workforce. The DSS was also used to evaluate the quality of matching between a given workload and workforce, thus assessing the sensitivity of the matching with respect to variations in the size of the teams (cluster of engineers), the composition of the teams, the number of shifts per day, the begin and end times of the shifts, and the number of teams per shift. Also the DSS was used to support the determination of the size and the composition of the teams. The approximation algorithm used to solve the problem neglected all stochastic elements. Clarke et al. (1996) reviewed the maintenance and crew considerations in the basic fleet assignment problem proposed by Hane et al. (1995). They included long maintenance and crew constraints, but did not implement the special modeling devices for dealing with short maintenance. Rushmeier and Kontogiorgis (1997) proposed an advanced model for the formulation and solution of large-scale fleet assignment problems that arise in the scheduling of air transportation. Barnhart et al. (1998) modified the fleet assignment problem using a string-based model and solution approach to solve simultaneously the fleet assignment and aircraft routing problem, which included maintenance requirements as a constraint. Talluri (1998) addressed the aircraft maintenance four-day routing problem. Mathematical programming models that utilize polynomial time algorithms were used. Sachon and Pate-Cornell (2000) addressed the issues of delays and safety in airline maintenance. A probabilistic risk analysis model to quantify the effect of an airline's maintenance policies on delays, cancellations and in-flight safety was used.

Over the past few years it has become apparent that better decision support tools and methods are needed in the maintenance department. Simulation is a valuable tool because it can handle complex system requirements. Duffuaa and Andijani (1999), consider that the application of computer simulation to maintenance functions provides a better and more viable alternative to analytical modeling and analysis. This is because of the difficulty of the mathematical models in capturing the complexities of maintenance operations, uncertainty of parameters in arrivals, sequencing, job contents and availability of resources.

Simulation modeling techniques were applied in the area of maintenance planning and scheduling at the Sacramento Air Logistics Center, by Mortenson (1981). Q-GERT and computer generated graphics were used for planning and scheduling of aircraft at the Air Force maintenance depot at Sacramento. In spite of the scope of the simulation application, it had a list of drawbacks, one of which was that it did not include stochastic features. The problem of representing a maintenance system is complex in nature with many random variables and therefore stochastic simulation offers a viable alternative for its modeling and analysis. Stochastic simulation (see Law and Kelton, 2000) is the process of representing a system on the computer, and based on well-designed experiments the system performance can be evaluated. A stochastic model contains one or more random sets of input that produce random output. This approach has been applied intensively in production systems as compared to maintenance. Also, simulation works especially well in diagnosing how systems respond to changes in flow patterns. Gatland et al. (1997) used simulation-modeling techniques to solve engine maintenance capacity problems. The Arena (see Kelton, 1998) simulation package and its analytical tool were chosen. Duffuaa and Andijani (1999) developed an integrated simulation model for effective planning of maintenance operations for the Saudi Arabian Airlines (SAUDIA). They used Alternate Modeling Simulation Language (SLAM II), Pritsker (1987).

All the above-mentioned studies confirm the increasing applicability of simulation modeling techniques, especially stochastic simulation in the field of airline maintenance planning. Most of the simulation models focus on the long term capacity planning or evaluation of different maintenance policies influencing long term managerial decisions. Also most of the mathematical models include maintenance as a constraint in the fleet assignment problem rather than treating maintenance as the primary goal of study.

This proposed research involves the development of a computerized simulation model for the aircraft line maintenance department at Continental Airlines. The study aims at duplicating the maintenance operations at Continental's major maintenance station at Newark (EWR). AutoMod Simulation Software (Banks, 2000) has been used as the developmental platform for the study. Modeling the day-to-day maintenance activities would lead to the development of enhanced staffing models and a better understanding of resource requirements on a daily basis. The model would be used as a tool to develop efficient manpower staffing models.

The remainder of the paper is organized as follows. Section 2 presents a case description of Continental's line maintenance facility at Newark and the problems faced by the management. Section 3 describes the development of the line maintenance simulation model. Section 4 analyzes the results obtained from the simulation model developed for Newark. Section 5 deals with sensitivity analysis, followed by Section 6, which states the results of the optimization analysis. Finally Section 7 presents the conclusions and includes a discussion about areas where future work needs to be done.

2 CONTINENTAL LINE MAINTENANCE DEPARTMENT

Continental Airlines, based in Houston, Texas, is the fifth largest airline in the United States serving 136 Domestic and 87 International destinations from its Newark, Houston and Cleveland hubs with a total of 2,238 daily departures. Continental Airlines operates 43 Wide Body and 327 Narrow Body jets.

The study focuses on one of their major maintenance stations at Newark (EWR). The following sections describe the line maintenance facility at Newark.

2.1 Equipment / Fleet Type

The aircraft equipment/fleet type operating through Newark is presented in Figure 1 below. In figure 1 below the numbers represent Boeing 737-300, 737-500, etc.

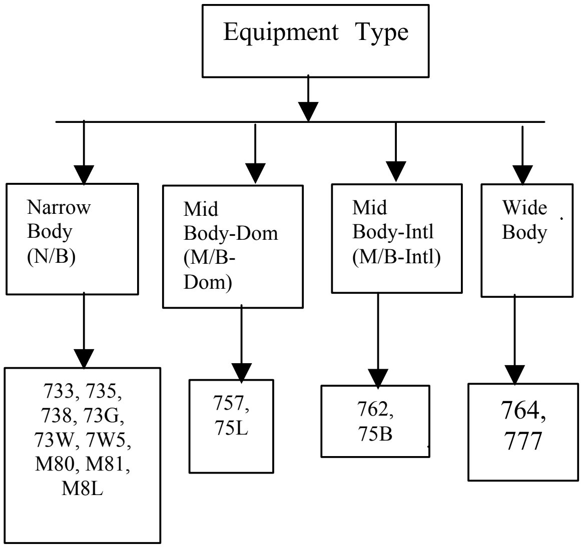

Figure 1: Equipment Type

2.2 Maintenance Schedules

Line maintenance includes the regular short haul inspections of aircraft between their arrival at and consecutive departure from the airport. An aircraft flying into a station can be a Through, a Day Hold or a Remains Overnight flight.

Through Flight: The aircraft is on a transit through the station with minimal ground time. The through flight schedule gives information regarding the transit flights through the station (extracted from the station activity report). Every through flight goes through a departure check while it is on the ground. The analysis of the through flight schedule reveals that on a given day the total number of Narrow Body, Mid Body–Domestic, Mid Body-International, Wide body aircrafts flying into Newark are as given in Table 1. Figure 2. shows the workload of through flights on a typical day in March.

Day Hold: The aircraft is scheduled for one of the routine checks held during the daytime before its subsequent departure.

Remains Overnight (RON): The aircraft remains overnight for one of the routine checks before its subsequent departure.

Drop-ins: 10% of the RONs are scheduled as Drop-in aircrafts. They undergo only the Service Check (explained in Section 2.3).

Table 1: Number of Through Flights in a Day

Equipment Type	Number of Through Flights in a Day
Narrow Body	145
Mid Body – Domestic	15
Mid Body – International	16
Wide Body	7

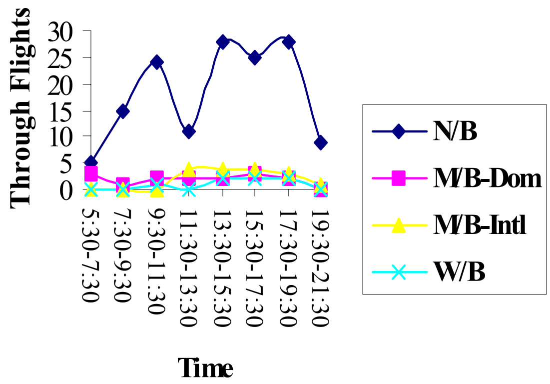

Figure 2: Through Flights on a Typical Day

The maintenance Day Hold/Remains Overnights schedule provides details of the aircraft flying into the station for routine maintenance checks either on a day or an overnight hold respectively. The schedule includes the aircraft equipment type (fleet type), ground time, arrival time, departure time and lay over (information whether an aircraft is scheduled for an overnight hold).

2.3 Maintenance Programs

The maintenance programs that an aircraft goes through are as follows:

- Service Check (SVC): A walk around service level and system check applicable to all fleets generally done on an overnight. Wide body gets this check done on day holds as well as overnights. If an aircraft remains overnight at a station with sufficient ground time, a service check will be performed. So, if an aircraft remains overnight at a station regardless of how many days it has been since its last service check, a service check is performed on that aircraft unless there is a higher-level check being performed that will sign off the service check.
- Level 3 Service Check (SC3): It is a more in depth version of the service check and applicable to all fleets except Boeing 767-200, 767-400 and D1H. This check is done on an overnight. It takes generally 8-10 hours on Narrow body aircrafts. Wide body aircrafts can have the level 3 service check done on either day or overnight holds of generally 12 hours or more. A level 3 service check is a higher-level check than a service check, so a service check is not performed if a higher-level check is due.
- Line Package Visit (LPV): It is a scheduled check applicable to all Narrow body aircrafts, generally done on an overnight. It requires 75 man-hours and generally one line package visit is scheduled

at Newark in a day and the workload is handled by the night shift technicians (refer to Table 2).

Table 2: Total Number of Checks Scheduled On Each Equipment Type

Equipment Type	Total Number of Checks		
	SVC	SC3	LPV
Narrow Body	35	7	1
Mid Body -Domestic	4	1	0
Mid Body – International	5	1	0
Wide Body	9	1	0

The analysis of the Day Hold/Remains Overnight schedule reveals that on a given day the total number of service checks and level 3 service checks scheduled on Narrow body, Mid body–Domestic, Mid body–International and Wide body aircrafts in Newark are as given in Table 2.

2.4 Standard Maintenance Timings

Table 3 gives the standard man-hours (M/H), ground time (in hours) and technician requirements for each maintenance program for Day Holds and Remains Overnights for all fleet types at Newark.

Table 3: M/H, Ground Time and Technician Requirements for Day Holds and RONs

Fleet Type	Ground Time	Number of Technicians	Actual Time Worked
N/B	<0.75 hrs	2	Ground Time
	≥0.75 hrs	1	0.75 hrs
M/B-Dom	<0.75 hrs	2	Ground Time
	≥0.75 hrs	1	0.75 hrs
M/B-Intl	<1.5 hrs	3	Ground Time
	≥1.5 hrs	2	1.5 hrs
W/B	<1.5 hrs	3	Ground Time
	≥1.5 hrs	2	1.5 hrs

2.5 Shift Schedule

Table 4 shows the standard man-hours (M/H), ground time (in hours) and technician requirements for through flights for all fleet types at Newark.

There are three working shifts in a day: day, swing (afternoon) and night shift. Each shift is divided into sub-shifts. Table 5 projects the shift and sub shifts schedule at Newark.

The study focuses on one of their major maintenance stations at Newark (EWR). The following sections describe the line maintenance facility at Newark.

Table 4: Man-Hours and Number of Technicians Required

Fleet Type	SVC				SC3			
	M/H	GT	+/- (hrs)	NT	M/H	GT	+/- (hrs)	NT
N/B	6	6	0.25	1	16	8	0.25	2
M/B-Dom	8	8	0.25	1	18	9	0.25	2
M/B-Intl	10	5	0.25	2	30	7.5	0.25	4
W/B	25	6.25	0.25	4	75	18.8	0.5	4

Table 5: Shift Schedule

Shifts	Sub Shifts	Start Time	End Time
Day	Shift 1	05:30	14:00
	Shift 2	06:00	14:30
	Shift 3	06:00	16:30
	Shift 4	11:00	21:30
Swing	Shift 1	13:00	21:30
	Shift 2	13:30	22:00
	Shift 3	14:00	22:30
	Shift 4	14:30	23:00
Night	Shift 1	20:30	07:00
	Shift 2	21:30	08:00

2.6 Management Problems

The important problem that the management department is confronted with is forecasting the number of technicians required and their shift schedules based upon the flight schedule and the maintenance programs to be carried out.

The management has been using mathematical models to come up with a head count. But these models are incapable of capturing the peaks and valleys in the arrivals and departures and estimating the technician requirement on a sub shift basis. Also, other issues such as capacity planning problems exist that need to be addressed. It is proposed that these problems can be solved by using simulation-modeling techniques described in the following sections.

3 PROPOSED LINE MAINTENANCE SIMULATION MODEL

Considering the advantages of simulation models discussed in Section 1, a simulation modeling approach looks promising. The simulation model aims at duplicating the operations of the line maintenance department of the airline, at Newark, as described in the previous section, for a given period of time.

3.1 Assumptions of the Simulation Model

The simulation model is based on the following assumptions:

- There are three technician pools - day, swing and night shift, each divided into several sub-shifts.

- The model extracts the technicians from the requisite pool whenever there is a requirement.
- A technician already involved in a job cannot be utilized for another job until he/she finishes the job, which has currently started.
- A technician becomes available to work on a new job immediately after finishing a previous job.
- Every technician is qualified to work on any job. There is no distinction between the technicians who work on through flights and routine checks (Day Hold and Remains Overnight).

3.2 Process Logic

The process logic is captured using AutoMod simulation software (Banks, 2000). This software was used due to the extensive ability it provides to capture complex system requirements and its focus on capacity planning. The following flowcharts present the sample logic behind the development of the simulation model and the flow pattern.

- Maintenance cycle for through flights: Narrow body, Mid body – Domestic, Mid body – International and Wide body aircraft.
- Maintenance cycle for Day-Holds and Remains Overnight: Narrow body and Mid body – Domestic aircraft. A similar logic exists for the maintenance cycle for Mid body – International and Wide body aircraft.

4 ANALYSIS (BASE SCENARIO)

The following section gives an analysis of the proposed line maintenance simulation model described in the previous section. AutoStat analysis tool (Banks, 2000) was used to derive the various performance measures for the system. The simulation time runs for one whole day of operations. 50 replications are made for each scenario for increased reliability of the output.

4.1 Total Technician Requirement

The total technician requirement during each sub shift is given in Figure 3. The total technician requirement during the day, swing and night shifts, are given in Table 6. As can be seen the technician requirement during the night shift is the maximum.

The model was validated by comparing the actual technicians required on the given day with the simulation results.

4.2 Total Number of Aircraft Serviced by Each Technician

Figure 4 summarizes the average workload on a technician in each shift. As can be seen the number of aircrafts serviced by the day and swing shift technicians is more as the major work load during the day and swing shift is of through flights, which requires lesser ground time.

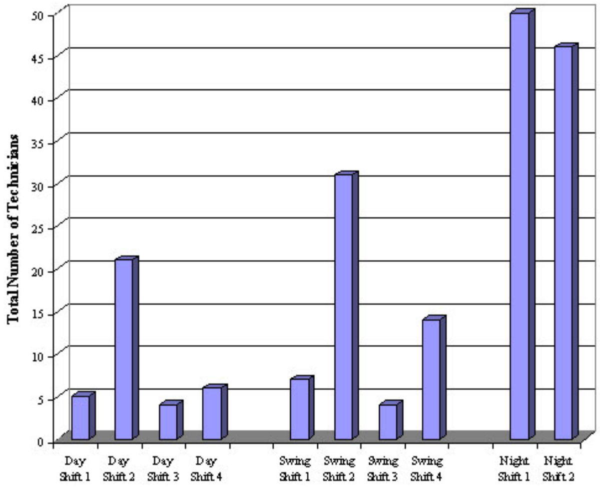

Figure 3: Total Technician Requirements in Each Sub Shift in a Day

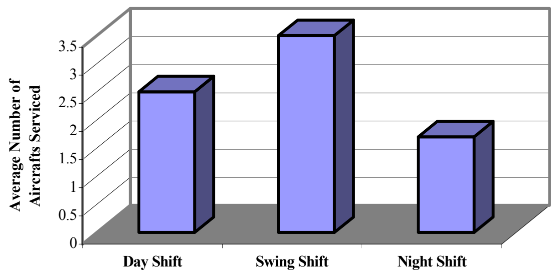

Figure 4: Average Workload on a Technician in Each Shift

Whereas the major workload during the night shift is of routine checks that require comparatively more ground time to finish, thus decreasing the total number of aircraft serviced by night shift technicians.

4.3 Utilization of Technicians

The utilization of each technician is calculated by adding the total amount of time a technician works on each job divided by the total shift time (calculated as a percentage). A technician working near to its maximum capacity represents a bottleneck and a technician with low percentage utilization is under-utilized. Figure 5 summarizes the average percentage utilization of technicians in each shift. The Day Shift technician utilization is quite less compared to the other shifts. This can be attributed to the nature of workload (through flights) that the Day Shift technicians are subjected to. The policy requiring a technician to be available to greet an aircraft on its arrival generates under-

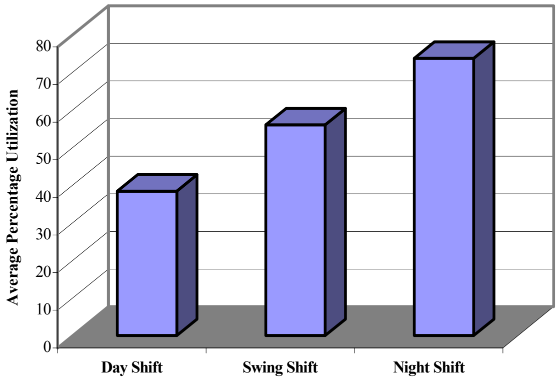

Figure 5: Average Percentage Utilization of Technicians in a Day.

utilized technicians. In reality this number is higher as the technicians can also be utilized elsewhere as needed to work on other unscheduled jobs. The introduction of part-time technicians could improve the utilization of Day Shift technicians.

4.4 Total Number of Technicians with Unfinished Jobs

The shift schedule given in Section 2.5 is the shift schedule for the base scenario. A technician will only take up a job if it arrives between its shifts start and end times. If a technician is still busy on a job after the shift end time, the job is transferred to a technician in the next shift. Lesser number of jobs transferred to the following shift, correspond to a better spread of workload across all shifts. Thus it is a crucial performance measure in evaluating the efficiency of the existing shift schedule.

The total number of technicians with unfinished jobs after their shift end times for each shift is shown in Table 6. The number of technicians with unfinished jobs for other shifts is zero. As can be observed the later swing shift and especially the night shifts need to better scheduled for a more uniform spread of workload.

5 SENSITIVITY ANALYSIS

This section describes the impact of changing model parameters on certain resource requirements.

Table 6: Number of Technicians with Unfinished Jobs at the End of their Shift

Shift	Number of Technicians with Unfinished Jobs
Swing Shift 4	4
Night Shift 1	8
Night Shift 2	34

Any variation in the flight schedule can easily be made by modifying the input flight schedule data file, and its impact on various resource requirements can be analyzed. As an example, the November 2001, (post September 11) flight schedule was compared with that of March 2001. Figure 6 shows the effect of the changing flight schedule on the total number of technician requirement in each sub shift during March and November, 2001. The day and swing shift technician requirement has gone down in November as the through flights have decreased (as expected). Whereas the night shift technician requirement has gone up, reflecting an increase in the scheduled routine checks, as more aircrafts sit on the ground (Figure 7)

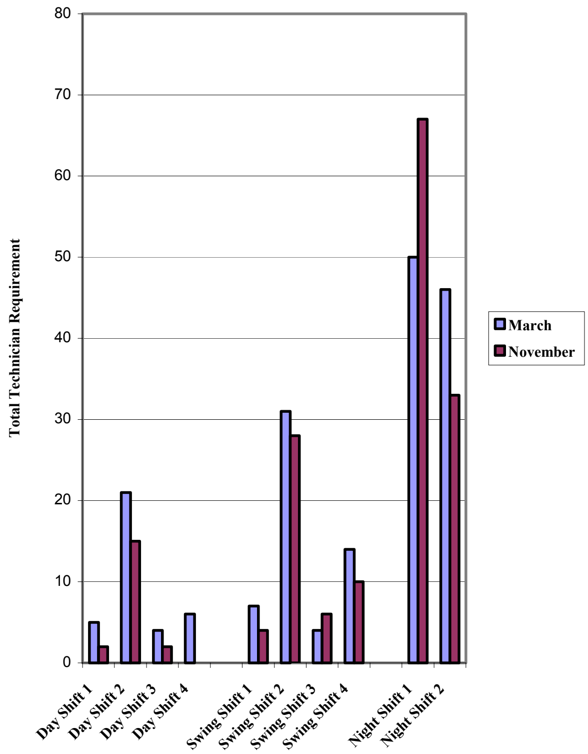

Figure 6: Comparison of Total Technician Requirement in Each Sub Shift in March and November, 2001

6 OPTIMIZATION ANALYSIS

The optimal scenario corresponds to the situation where the system uses its resources to its maximum capability. The optimization algorithm of AutoMod simulation software is used to find the best set of factors for the system. The total number of technicians working overtime is used as an objective function to be minimized.

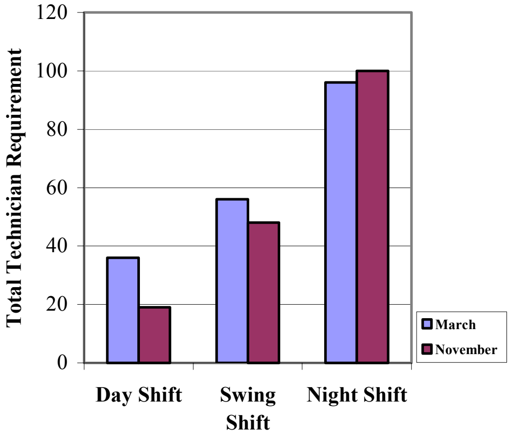

Figure 7: Comparison of Total Technician Requirement in March and November, 2001

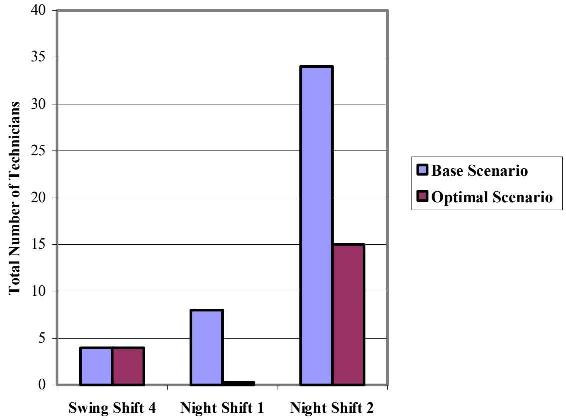

Figure 8: Comparison of Total Number of Unfinished Jobs in Any Shift For the Base and Optimal Scenario.

6.1 Optimal Shift Schedule

The day, swing and night shift schedules have the maximum impact on the optimum utilization of technicians and spread of workload. The day, swing and night shift schedule was varied, and the software was allowed to determine the best set of values for the shift start and end times. The software finds the best combination possible using its optimization algorithm. Optimal shift start and end times are summarized in Table 7.

Table 7: Optimal Shift Schedule

Shifts	Sub Shifts	Start Time	End Time
Day	Shift 1	05:30	14:00
	Shift 2	06:00	14:30
	Shift 3	06:00	16:30
	Shift 4	11:00	21:30
Swing	Shift 1	13:0	21:30
	Shift 2	13:30	22:00
	Shift 3	14:00	22:30
	Shift 4	15:00	22:30
Night	Shift 1	19:30	06:30
	Shift 2	23:00	08:30

6.2 Total Number of Technicians with Unfinished Jobs in any Shift (Optimal Scenario)

The Shift Schedule given in Section 6.1 is the shift schedule for the optimal scenario. The comparison of the total number of technicians with unfinished jobs at their shift end times for the base scenario (described in Section 4) and the optimal scenario (described in Section 6.1) is presented in Figure 8. As the figure shows, the optimal scenario corresponds to a better spread of workload across shifts, by reducing the workload that is passed on to the next shift.

7 CONCLUSIONS AND SUGGESTIONS FOR FUTURE WORK

The simulation model developed, captures the daily operations of the line maintenance facility at Newark. Various system parameters were evaluated and their validity confirmed by comparison with the airline's existing figures. The model could be used by the management to solve various capacity planning issues related to the size of the workforce and its efficient utilization. The results were presented to the management.

Some of the benefits of using simulation-modeling techniques in extending the capability of the staffing model are listed below.

- Simulation modeling was effectively used in estimation of technician requirement on a sub shift basis. The model results compared very well with the actual numbers.
- Simulation analysis generates performance measures, like technician utilization and work overflow which could not be estimated earlier.
- The low utilization of technicians brings forth the idea of using part time technicians especially during the day shifts.
- Simulation offers a viable tool to study the impact of changing flight schedule on system parameters, like technician requirement.
- The optimization studies show that changing of the shift schedule can greatly enhance the efficiency of the existing system by spreading the workload more uniformly across shifts.

The present model needs to be further modified to more accurately represent the real world operations. Some of the constraints that have not been addressed by the present study are:

- The gate outlay and the effect on technician requirement especially during the day and swing shift period.
- The planned and out of service/other checks. The present model incorporates only the routine and scheduled checks.
- The whole week's flight schedule. The present model takes as input only one day of flight schedule (both the through flight and maintenance schedule).

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AUTHOR BIOGRAPHIES

MASSOUD BAZARGAN is currently an Associate Professor of Business at Embry-Riddle Aeronautical University - Daytona Beach Campus. He teaches Production Operations Management, Operations Research, Simulation and Optimization. Dr. Bazargan received his Ph.D. in Manufacturing Engineering, MA in Operations Research and a B.Sc. in Mathematics and Economics. He has spent his last 15 years of employment in consulting, research, teaching and supervising. He has research/consulting experiences with aviation, household appliances, mining, electronics, food, packaging and timber industries. Dr. Bazargan has published two book chapters and more than 20 technical papers in international journals. His research interests include facilities design, cellular manufacturing, warehousing, material handling, scheduling, Simulation, and Optimization. His email address is <bazargam@erau.edu>.

PAYAL GUPTA is currently working as an analyst in the Corporate Planning Department for Atlantic Coast Airlines. She completed her Master of Business Administration in Aviation at Embry Riddle Aeronautical University. In 2000 she received the Link Foundation Scholarship for work that is partially documented in this paper. Her email address is <payal_gupta@mailcity.com>.

SETH YOUNG is currently an Associate Professor of Business at Embry-Riddle Aeronautical University – Daytona Beach Campus. He teaches Airport Operations Management, Airport Planning and Design, Airport Finance and Strategic Management, and Quantitative Methods. Dr. Young received his Ph.D. in Civil and Environmental Engineering / Transportation and M.S. in Industrial Engineer-

ing / Operations Research from the University of California, Berkeley, and his B.A. in Applied Mathematics from the State University of New York at Buffalo. He has spent over 10 years in teaching, research, and consulting in the field of airport operations and planning. Dr. Young is published in international technical journals and book chapters, and co-authors a leading collegiate level airport planning and management text. His research interests include aviation system optimization, particularly through the use of technological innovations. His email address is <youngs@erau.edu>.