Simulation Model for Aircraft Line Maintenance Planning

Payal Gupta • Embry-Riddle Aeronautical University • Daytona Beach

Massoud Bazargan • Embry-Riddle Aeronautical University • Daytona Beach

Robert N. McGrath • Embry-Riddle Aeronautical University • Daytona Beach

Key Words: Simulation, Aircraft Maintenance, Airline

SUMMARY AND CONCLUSIONS

This paper reports results of research that developed a computerized simulation model for the aircraft line maintenance department in Continental Airlines. The original AUTOMOD model that was created duplicated the maintenance operations at Continental's major maintenance station at Newark. Modeling the day-to-day maintenance activities lead to the development of enhanced staffing models and a better understanding of resource requirements on a daily basis.

This study had immediate and practical application as well as advancing an important frontier in operations research. Simulation modeling was effectively used in the estimation of technician requirements on a subshift basis. Simulation modeling generated performance measures, like technician utilization and work overflow, which could not be estimated earlier. The model gave objective justification for simple solutions like staggered shifts and part-time labor, which can meet resistance in a workforce.Simulation offers a viable tool for studying the impact of changing flight schedule on system parameters, like technician requirements. The optimization studies showed that changing the shift schedule could greatly enhance the efficiency of the existing system by spreading the workload more uniformly across shifts.

Simulation, especially stochastic simulation, has advantages over mathematical modeling, especially in situations where flows have an *apparent* randomness in their character. Airline maintenance operations, and many maintenance operations in general, are plagued by planning difficulties because failures *seem* random at high levels of analysis, and/or because scheduling is tighly coupled with (and slaved to) other operations which are erstwhile irregular in their natures. Airline maintenance is one of the most important applications of maintenance in industry, as it has a profound impact on cost, customer satisfaction, and safety. This study applied stochastic modeling to flightline maintenance at an important airline, and illustrated the opportunity for improved maintenance management that only hints of its overall potential.

1. INTRODUCTION

In the airline industry, the role of maintenance is to provide safe, airworthy, on-time aircraft, every day. 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 on an airline's experience and mode of operation, an original program is adapted to meet FAA approval. Maintenance task standards (norms) specify when each task is scheduled and how much time is spent on each task.

Line maintenance (also called short routine maintenance) includes regular short inspections of aircraft between arrival and departure at an 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 nor manpower per task, due to its high frequency, it represents a significant fraction of aircraft maintenance costs. Ninety percent of the cost of line maintenance is attributable to labor (Ref. 1).

Line maintenance is driven by flight scheduling forecasts. Once a 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 maintenance program, ground time and other resources such as tooling, hangars, etc., and also considers weather and events that would generate conflicts. Management then builds a staffing model for that station which specifies the manpower requirement and scheduling to meet the schedule's objectives. Human resources planning is thus crucial to improving system performance and efficiency and minimizing costs.

Though this depiction is somewhat generic, maintenance operations in Continental Airlines at the Newark, New Jersey facility fully fit the description. Management was particularly concerned about what were believed to be low labor utilization rates, which the above description illustrates as a costly and important problem. After some preliminary dialogue between the airline and the Department of Business Administration at the Daytona Beach campus of Embry-

0-7803-7717-6/03/$17.00 © 2003 IEEE

Riddle Aeronautical University, it was agreed to study the labor utilization problem through the latter's expertise in Operations Research and computer simulation. The project was organized and managed as an MBA student's thesis. This paper is derived from the results of that thesis.

2. LITERATURE REVIEW

Mathematical modeling techniques have typically been used in maintenance planning. Dijkstra, et al. (Ref. 2) 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 a workforce. The DSS was also used to evaluate the quality of matching a given workload to a workforce, assessing the sensitivity of a match with respect to variations in the size of teams (clusters of engineers), the composition of teams, the number of shifts per day, the beginning and ending times of shifts, and the number of teams per shift. Also the DSS was used to determine of the size and the composition of teams. However, the approximation algorithm used to solve the problem neglected all stochastic elements. Clarke et al. (Ref. 3) studied the maintenance and crew considerations in the basic fleet assignment problem considered by Hane et al. (Ref. 4). They included long maintenance and crew constraints, but did not implement special modeling devices for dealing with short maintenance. Rushmeier and Kontogiorgis (Ref. 5) 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. (Ref. 6) modified the fleet assignment problem using a string-based model and solution approach to simultaneously solve the fleet assignment and aircraft routing problem, which included maintenance requirements as a constraint. Talluri (Ref. 7) addressed the aircraft maintenance four-day routing problem. Mathematical programming models that utilize polynomial time algorithms were used. Sachon and Pate-Cornell (Ref. 8) 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.

In light of the above, it has become apparent that better decision support tools and methods are needed in maintenance departments. Notably, simulation is a valuable tool because it can handle complex requirements. Duffuaa and Andijani (Ref. 9) considered that the application of computer simulation to maintenance functions provided a better and more viable alternative to analytical modeling and analysis, because of the difficulty of mathematical models in capturing the complexities of maintenance operations, uncertainty of parameters in arrivals, sequencing, job contents, and the availability of resources.

Simulation modeling techniques have been applied in maintenance planning and scheduling at the Air Force Sacramento Air Logistics Center (Ref. 10). Q-GERT and computer generated graphics were used for planning and scheduling. In spite of the scope of the simulation application, it had a list of drawbacks, such as not including 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 (Ref. 1) is the process of representing a system on a computer, and based on well-designed experiments, system performance can be evaluated. A stochastic model contains one or more random sets of inputs that produce random outputs. This approach has been applied intensively in production systems as compared to maintenance. Simulation works especially well in diagnosing how systems respond to changes in flow patterns. Gatland et al. (Ref. 12) used simulation-modeling techniques to solve engine maintenance capacity problems. The ARENA simulation package was chosen. Duffuaa and Andijani (Ref. 9) developed an integrated simulation model for effective planning of maintenance operations for the Saudi Arabian Airlines. Simulation language for Alternate Modeling (SLAM 11), Pritsker (Ref. 13) and the statistical package, STATGRAPH (1989) were used.

These studies demonstrate the increasing applicability of simulation modeling techniques, especially stochastic simulation, in the field of airline maintenance planning. Most simulation models focused on long term capacity planning or the evaluation of different maintenance policies influencing long term management decisions. Most of the mathematical models included maintenance as a constraint in the fleet assignment problem rather than treating maintenance as the primary focus of study. The study presented in this paper thus advances the extant literature by its focus on maintenance labor utilization plus the use of stochastic simulation modeling.

3. AIRLINE MAINTENANCE CONCEPT AND SIMULATION MODEL

Space limitations prohibit a full description or graphical display of the complexities of an airline maintenance scenario. The following description is meant to provide a glimpse into the logic of the simulation model that was developed.

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

Line maintenance includes the regular short haul inspections of aircraft between their arrival at, and subsequent departure from anairport. An aircraft flying into a station could be designated and managed as a Through Flight, a Day Hold flight or a Routine Overnight (RON) flight.

During Through Flight maintenance, aircraft transits through the station with minimal ground time. The Through Flight schedule gives information regarding transit flights through a station (extracted from a station activity report). Every Through Flight gets a departure check while it is on the ground.

The Day Hold/RONs maintenance schedule provids details of the aircraft flying into a 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 time (information about whether an aircraft was scheduled for an overnight hold).

During Service Checks (SVC), a walk around service level and system check applicable to all fleets is generally done overnight in 4-6 hours. Widebodies get this check done on Day Holds as well as overnights.

If an aircraft "RON's" at a station with sufficient ground time, a SVC is performed. So, if an aircraft RON's at a station regardless of how many days since its last SVC, a SVC is performed on that aircraft unless there is a higher-level check being performed that would complete the SVC.

A Level 3 Service Check (SC3) is a more in depth version of the SVC,d applicable to all fleets except Boeing 767-200, 767-400 and D1H. This check is done overnight. It takes generally 8-10 hours on Narrowbody aircraft. Widebody aircraft can have the SC3 done on either day or overnight holds of generally 12 hours or more. A SC3 is a higher-level check than SVC, so an SVC is not performed if a higher-level check is due.

Finally, a Line Package Visit (LPV) is a scheduled check applicable to all Narrowbody aircraft, generally done overnight

This dynamic and complex operation was simulated on a computer (below.) Naturally, any simulation simplifies reality and is based on necessary sets of assumptions. As concerns the present focus on labor utilization rates, the most noteworthy assumptions are:

- There are three technician pools - day, swing and night shift, each divided into several subshifts.
- Any technician can be taken from the requisite pool whenever there was a requirement.
- A technician already involved in a job can not be utilized for another job until he/she finishes the job which has currently been started.
- A technician becomes available to work on a new job immediately after finishing a previous job.
- Every technician iss qualified to work on any job. There is no distinction between the technicians who work on Through Flights and routine checks (Day Hold and RONs).

4. RESULTS AND DISCUSSION

AUTOMOD Simulation Software (Ref. 14) was used for this study. With an orientation towards capacity planning and scheduling in a manufacturing environment, AUTOMOD is designed to model facilities where there are multiple products that have different process routings, and where products compete for the use of common resources. Obviously there is a maintenance analogy to this abstraction, providing the opportunity to use it for this study. The software also has an extensive statistical capability, allowing techniques such as sensitivity analysis and optimization.

The model simulated one whole day of operations. Fifty replications were made for each scenario. In consideration of the goals of this paper, and because of space limitations, a minimum of data is presented here, and only for illustrative purposes. More extensive and graphical analysis will be made at the 2003 RAMS conference, and is available from the authors.

4.1 Labor Utilization

The utilization of each technician was calculated by adding the total amount of time a technician worked on each job divided by the total shift time (calculated as a percentage). It should be noted that in this environment, resource utilization can appear low compared to other production environments. This is due to the method of calculation and the inherent nature of flightline maintenance. In the aircraft maintenance environment, especially in environments physically at or near real-time flight operations, there is much time when aircraft are not even present to be maintained, so technicians do other maintenance chores that do not require actual contact with aircraft. Direct labor, measured traditionally, can be a relatively small percentage of the total labor resource. In other words the maintenance operation is very tightly coupled with revenue operations (regularly scheduled passenger flights,) so maintenance resource utilization is secondary to customer satisfaction and can appear "inefficient" when compared to more traditional production scenarios like manufacturing

"At any rate," in terms of the simulation, a technician working at or above his/her maximum capacity was interpreted as a bottleneck, while a technician with relatively low percentage utilization was considered under-utilized. Summary observations are:

Day shift 1 utilization varied between about 8.7% and 9.3%. In contrast, Day shift 2 utilization varied from over 80% to under 10% for 9 of the 21 technicians, suggesting the possible need for managerial attention. Day shift 3 and 4 utilization varied from about 35% to 60%, and was fairly uniform, technician to technician

The Swing shift 1 utilization pattern was not too unlike Day shift 1, but was a little higher generally, varying from about 9% to 20%. During Swing shift 2, utilization varied from about 85% to about 10%, and like in Day shift 2, utilization of 6 of the 31 technicians looked very low. Swing shift 3 and 4 utilization varied from over 50% to almost 80%.

In Night shift 1, 6 of the 49 technicians were being utilized at over 100%, so they were bottlenecks. In contrast, 8 technicians were utilized well under 20%. Most others were utilized from 60% to 80%. The pattern in Night shift 2 was more uniform; utilization ranged from 60% to 90%, but there were 7 bottlenecks among the 46 assigned technicians.

By shift, average technician utilization was calculated as 38.4%, 56.0%, and 73.7%, respectively. Obviously the day shift technician utilization was quite less than in the other shifts, while at the same time there were bottlenecks at night. The interim speculation, then, was that shift rescheduling, reassignment of technicians, and/or the use of part-time technicians, could improve the overall labor utilization, and became the object of further analysis.

4.2 Unassigned Jobs.

In order to properly interpret a bottleneck condition, it was useful to consider the concept of unassigned jobs as a more penetrating indicator of the problem.

Implicit in the assumptions stated in a preceding section, a technician only took up a job if it arrived between his/her shift's start and end times. If a technician was still busy on a job after the shift end time, the job would be transferred to a technician in the next shift. This transfer of workload to the next shift, coupled with the arrival of new jobs in the new shift, generated a very uneven balance of workload among shifts. This resulted in continuously increasing work-in-process passed on to the next shift. It was therefore ideal to plan shifts in a way where the workload received in a shift was accomplished as much as possible, without the need to pass on unfinished work to the next shift. Therefore the number of jobs passed to the next shift was calculated and used as a crucial performance measure in evaluating the efficiency of the existing shift schedule. An efficient shift schedule would be one that minimized this number.

It was unsurprising, then, that the total number of technicians with unfinished jobs after their shift end times, by shift, was calculated as 4, 8, and 34, respectively. Thus it became increasingly clear that the later swing shift and especially the night shifts needed to be better scheduled for a more uniform spread of workload.

5. CONCLUSION

In general, an optimal scenario where the system uses its resources to its maximum capability. The software's optimization algorithm was used to find the best set of factors for the system. This is a new and important feature of emerging simulation software, where meta-heuristics such as Genetic Algorithm (GA) techniques are adopted to perform an optimization process. Traditionally, one has to vary and search for the best set of parameters manually within a simulation model, on a trial and error basis, to determine the desired performance measures. The optimization module of simulation packages, however, performs this task without this time consuming process. The user selects the objective functions or performance measures that must be improved. The software then attempts to achieve these goals by varying the parameters that the user has specified according to the optimization algorithm embedded in the software. In our model, the total number of technicians working overtime was used as an objective function and the optimization algorithm was set to minimize this entity.

The day, swing and night shift technician *workday schedules* had the maximum impact on the optimum utilization of technicians and spread of workload. The day, swing and night shift schedules were varied, and the software was allowed to determine the best set of values for shift start and end times. The software found the best combination possible using its optimization algorithm, resulting in slightly staggered start and end times for various subshifts.

The proposed staggered schedule suggested by the software indicated a likely drop in unfinished jobs in the Swing shift to 0, and a drop in the Night shift by over half, to 15. In sum, the optimal scenario corresponded to a better spread of workload across shifts, measured as a reduced workload passed on to the next shift.

The schedule suggested by the model was actually comforting to the airline's experienced maintenance managers, as it has been known for many years that a good way to handle transitions among shifts is for some people to stay at work late, and for others to arrive early. By organizing an *official* staggered shift schedule that accomplished the same thing, personal heroism and sacrifice might be avoided, as well as overtime pay. And though it was not directly simulated, it was evident to management that replacing full-time labor with part-time labor, and/or reassigning technicians among shifts, were viable approaches to managing underutilized technicians and bottlenecks. Of course, realities like union rules would need to be addressed in the actual implementation of any solution, but at least management now had objective and concrete data to support any change in operations.

ACKNOWLEDGEMENTS

We express thanks to the management of Continental Airlines for supporting the students and faculty at Embry-Riddle Aeronautical University, and for allowing publication of results towards the overall benefit of industry.

REFERENCES

1. M. Lam, "An introduction to airline maintenance", *The Handbook of Airline Economics*, 1995, pp 397-406.
2. M.C. Dijkstra, L.G. Kroon, A.E.E. van Nunen, M. Salomon, "A DSS for capacity planning of aircraft maintenance personnel", *International Journal of Production Economics,* vol. 23, 1999, pp 69-78.
3. L.W. Clarke, C.A. Hane, E.L. Johnson, G.L. Nemhauser, "Maintenance and crew considerations in fleet assignment", *Transportation Science*, vol. 30, 1996, pp 249-260.
4. C.A. Hane, C. Barnhart, E.J. Johnson, R.E. Marsten, G.L. Nemhauser, G. Sigisimondi, "The fleet assignment problem: Solving a large-scale integer program", *Math. Program,* vol. 70, 1995, pp 211-232.
5. R.A. Rushmeier, S.A. Kontogiorgis, "Advances in the optimization of airline fleet assignment", *Transportation Science*, vol. 31, 1997, pp 159-169.
6. C. Barnhart, N.L. Boland, L.W. Clarke, G.L. Johnson, G.L. Nemhauser, R.G. Shenoi, "Flight string models for aircraft fleeting and routing", *Transportation Science*, vol. 32, 1998, pp 208-220.
7. K.T. Talluri, "The four-day aircraft maintenance routing problem", *Transportation Science,* vol. 32, 1998, pp 43-53.
8. M. Sachon, E. Pate-Cornell, "Delays and safety in airline maintenance", *Reliability Engineering and System Safety,* vol. 67, 2000, pp 301-309.
9. S.O. Duffua, A.A. Andijani, "An integrated simulation model for effective planning of maintenance operations for Saudi Arabian Airlines (SAUDIA)", *Production Planning and Control,* vol. 10, 1999, pp 579-584.
10. R.E. Mortenson, "Maintenance planning and scheduling using network simulations", *Winter Simulation Conference Proceedings*, 1981, pp 333-340.
11. A.M. Law, W.D. Kelton, *Simulation Modeling and Analysis,* 1993; McGraw-Hill.
12. R. Gatland, E. Yang, K. Buxton, "Solving engine maintenance capacity problems with simulation", *Winter Simulation Conference Proceedings*, 1997, pp 892-899.
13. A. Pritsker, *Introduction to Simulation and SLAM II.*, 1987; Systems Publishing Corporation.
14. J. Banks, *Getting Started with AutoMod*, 2000 AutoSimulations, Inc.

BIOGRAPHIES

Payal Gupta
c/o Department of Business Administration
Embry-Riddle Aeronautical University
600 S. Clyde Morris Blvd.
Daytona Beach, Florida 32114-3900 USA
payal_gupta@mailcity.com

Payal Gupta holds a Master of Business Administration degree from Embry-Riddle Aeronautical University. This paper is derived from her Master's thesis. Her home of origin is India. Her academic background includes a Bachelor's of Science degree in Physics, followed by a Master of Science in Physics from the Institute of Technology, Kanpur. She has taught undergraduate physics and holds several pilot ratings.

Massoud Bazargan, Ph.D.
Department of Business Administration
Embry-Riddle Aeronautical University
600 S. Clyde Morris Blvd.
Daytona Beach, Florida 32114-3900 USA
bazargam@erau.edu

Dr. Massoud Bazargan is an Associate Professor in the Department of Business Administration in Embry-Riddle Aeronautical University. He earned his Ph.D. in Manufacturing Engineering from the University of New South Wales, Australia, his MA in Operations Research from the University of Lancaster, UK, and his BS in Mathematics and Economics from the University of Manchester, UK. He presently teaches courses, and does research, in Production / Operations Management and related topics.

Robert N. McGrath
Department of Business Administration
Embry-Riddle Aeronautical University
600 S. Clyde Morris Blvd.
Daytona Beach, Florida 32114-3900 USA
mcgrathr@dn.erau.edu

Dr. Bob McGrath is an Associate Professor in the Department of Business Administration at Embry-Riddle Aeronautical University. He earned his Ph.D. in Business Administration from Louisiana State Univesity, his MBA from Xavier University (Ohio,) and his BS in Organizational Behavior and Leadership from the United States Air Force Academy. He is a former Air Force maintenance officer and logistics engineer at F500 firms. He teaches courses, and conducts research, in Strategic Management and Technology Management.