A Simulation Based Approach for Contingency Planning for Aircraft Turnaround Operation System Activities in Airline Hubs

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ABSTRACT

Commercial aircraft undergo a significant number of maintenance and logistical activities during the turnaround operation at the departure gate. By analyzing the sequencing of these activities, more effective turnaround contingency plans may be developed for logistical and maintenance disruptions. Turnaround contingency plans are particularly important as any kind of delay in a hub based system may cascade into further delays with subsequent connections. The contingency sequencing of the maintenance and logistical turnaround activities were analyzed using a combined network and computer simulation modeling approach. Experimental analysis of both current and alternative policies provides a framework to aid in more effective tactical decision making.

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INTRODUCTION

Federal deregulation of U.S. airlines in 1978 resulted in significant changes to the air transportation industry. One of the most significant consequences continues to be the phenomenal growth in the number of air passengers. According to Department of Transportation (DOT), between 1975 and 1999, the number of air passenger enplanements in the U.S. rose by 210 percent from 197 million to 611 million (DOT, 2001). In 2003 alone, there were 642 million enplanements and this is expected to exceed 1 billion by the year 2010. As Table 1 illustrates, in recent years, a large percentage of these flights have been subjected to delays. DOT estimates the cost of these air traffic delays at approximately $3 billion per year, and projects that delays will continue to increase as the demand for air traffic grows (DOT, 2003).

Table 1. U.S. airlines delays, 2001-2003
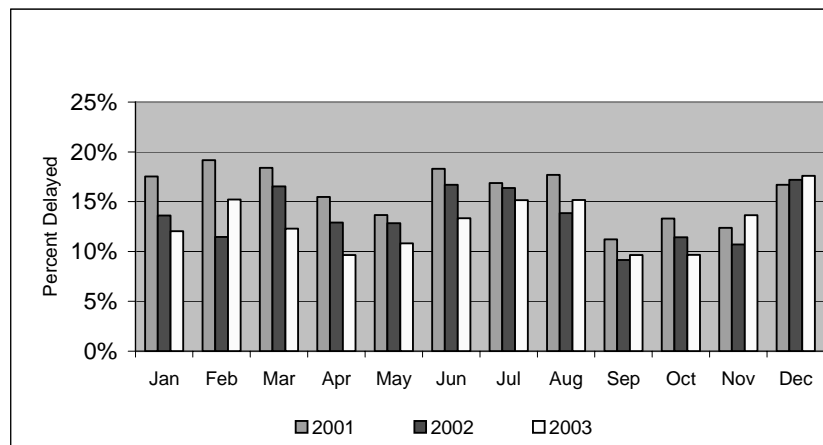
Note. The data are from *Airline Industry Metrics: Report Number: CC-2003-007*, by Department of Transportation, 2003. Washington, DC.

A major source of flight delays involves turnaround operations. Turnaround operations are defined as the activities that take place in the intervening period between the arrival of an airplane at an airport and departure of the same airplane. These activities include baggage handling, passenger deplaning and enplaning, security checks, cleaning, catering supplies, aircraft maintenance, and fueling. Some of these activities are mandatory, and are statutory requirements of government agencies such as Federal Airports Administration and the new Transportation Security

Administration. Other activities are routine and are guided by the operational policies of the airline.

Turnaround activities consume significant time and resources. Walkways must be set up for passengers to deplane and enplane; material handling equipment placed and operated for baggage offloading and uploading; and maintenance, fueling, cleaning and stocking of catering supplies scheduled. The efficiency and duration of the turnaround operation has a significant impact on the punctuality of flight departures. If turnaround activities are not completed on time, flight departure may be delayed.

Flight departure delays can have increased impact at hub and spoke airport systems. In these types of systems, banks of flights are scheduled to depart and/or arrive at the same time. This enables an airline to have several connections to many destinations, several times a day. The main attraction of a hub-and-spoke network is the ability of airlines to sustain a higher level of aircraft utilization while passengers enjoy increased frequency of service. This has led all the top 10 major airlines in U.S. (except Southwest Airlines which has a point-to-point operation) to utilize the hub-and-spoke network to route their airplane traffic. However, the hub-and-spoke network is not without some disadvantages. The high volume of air traffic generated at an airline hub airport invariably leads to congestion and delays (Ghobrial & Kanafani, 1995). This is even more critical because of the multiplier effect of a delay on other flights.

PREVIOUS RELEVANT RESEARCH

A number of different research approaches can be found in the literature dealing with various aspects of airline delays and congestion. Many researchers have adopted common types of mathematical modeling to examine air traffic delay and congestion. For example, Teodorovic and Stojkovic (1995) proposed a heuristic model based on dynamic programming to reduce airline schedule disturbances. Similarly, Gu and Chung (1999) studied the aircraft gate reassignment problem using a genetic algorithm approach.

Although these types of mathematical modeling can be a useful tool to provide several solutions simultaneously, it is frequently necessary to make a large number of simplifying assumptions. A more effective tool for large and complex problems that may not be very appropriate for mathematical modeling is discrete event simulation (Cheng, 1998). Simulation in particular allows researchers to experiment with different resource and operating policy alternatives without disturbing the actual system.

These advantages have resulted in simulation being used in a wide variety of applications in the air transportation industry. Tunas, Young and Bender. (1998) described the use of discrete-event simulation in modeling

curbside vehicular traffic which was used in planning and designing a new airport. Gatersleben and Van der Weij (1999) developed a model to analyze and simulate passenger flow in an airport terminal. The application was used to identify bottlenecks in passenger handling, and also to provide integral solutions for these bottlenecks. Ottman, Ford and Reinhardt (1999) investigated aircraft departure procedures at the United Parcel Service Louisville Air Park. These researchers developed a simulation model to determine taxi times, taxi delays, and ramp delays during changes in flight departure schedules and parking plans. The model was also used to analyze stages involved in an airport expansion and potential changes in the airport property.

Rosenberger et al. (2000) conducted extensive research on a stochastic model of airline daily operations. Chung and Sodeinde (2000) used simulation modeling to analyze the sequencing of passenger procedures at the ticketing counter. Hafizoguillari, Chinnusamy and Tunasar (2002) studied how simulation is used to reduce airline misconnections in the analysis of Delta Airlines' new planned facility at JFK Airport. The simulation evaluated the airline's minimum connect time.

Many air traffic delays can be directly attributed to turnaround activities but there is very little research in this particular area. Braaksma and Shortreed (1971) analyzed aircraft turnaround activities using a critical path method. This was a pioneering effort. It was, however, limited to a single turnaround operation at one gate, and did not consider the occurrence of unusual delays during turnaround. Manivannan and Zeimer (1996) described an application of discrete-event simulation in the modeling and analysis of aircraft cargo offloading operations at an air-cargo hub. The simulation was implemented in *Automod II* software and included a base model that showed existing cargo offloading operation. Findings from the experimentation and statistical analysis revealed the best configurations for resource planning. Andersson, Carr, Feron and Hall (2000) carried out a study of ground operations at hub airports in order to build an airport congestion prediction capability. Maintenance activities during the turnaround period for commercial aircraft have been investigated. However, this has been from a maintenance worker resource level planning perspective (Gupta, Bazargan & McGrath, 2003).

Turnaround delays associated with passenger boarding have been examined by Landeghem and Beuselinck (2002). They conducted a simulation analysis investigating different boarding patterns and operating strategies, and suggested ways to improve the existing system. Lastly, Wu and Caves (2002a, 2002b) developed a simulation model to simulate aircraft turnaround using data from a European airline. However, their model is limited to baggage/cargo flow and passenger/crew flow. The model does not

include other aircraft turnaround activities (such as refueling, aircraft maintenance, and catering).

PROBLEM STATEMENT

There are several consequences of flight delays. First is customer dissatisfaction (missed meetings, lost personal time, anxiety and stress), which may eventually lead to the boycotting of the airlines, and loss of business (Bethune, 1998). Second is lower system productivity because flight delays may lead to flight cancellation or reduction in the number of available flights. This implies that less revenue is being earned from the utilization of the airlines' assets. Third is the multiplier effect on the system. One particular flight delay can cause congestion and disruption of several flights, especially during peak periods in hub networks. All of these contribute negatively to the bottom-line of airlines and airports.

In order to better understand the impact of flight delays associated with turnaround operations, a simulation model was developed that specifically focused on the activities related to the turnaround operation. This model was used to analyze the effects of different maintenance, logistical, and operational delays on the aircraft's turnaround time. By analyzing these effects, more effective contingency plans can be formulated to respond to these delays.

RESEARCH METHODOLOGY

This section describes the research methodology that was utilized to analyze the aircraft turnaround operation. The research methodology section includes system definition, data collection and analysis, model translation, verification and validation, and experimental design. The research methodology section is followed by research results and discussion sections.

System Definition

A flow chart showing a high-level conceptual description of the system is shown in Figure 1. An aircraft arrives at the hub and is assigned a gate for parking by the air traffic control tower. A Jetway is prepared and the turnaround activities begin. As previously discussed, these activities include the positioning of baggage material handling equipment, baggage offloading and uploading, maintenance operations, fueling, cleaning and stocking catering supplies. Some of these activities are not necessarily sequential. When the turnaround operation is completed, the aircraft is dispatched and ready for departure.

Data collection and analysis

Input data associated with the turnaround process was collected at the principal hub of a major U.S. passenger air carrier. The collected input data was analyzed and fitted to a theoretical probability distribution using the *Arena* Input Analyzer (version 7.0; Rockwell Automation, 2005) simulation modeling software. Table 2 summarizes the theoretical probability distributions related to each turnaround operation activity. These probability distributions were utilized as input to drive the turnaround simulation model.

Figure 1. Conceptual description of an aircraft turnaround operation system
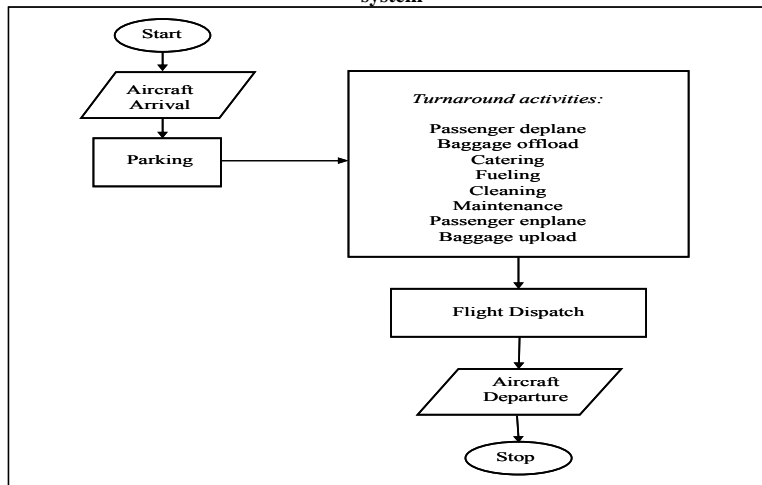
Table 2. Summary of input data distributions related to each activity of an aircraft turnaround operation system

Variable	Expression
Passenger deplane	Triangular (3.50,8,12.50)
Baggage offload	6.50 + 24 * Beta (0.67,0.86)
Catering	Normal (22.10, 3.44)
Fueling	6.50 + 29 * Beta (0.58,0.70)
Cleaning	4.50 + 16 * Beta (0.96,1.30)
Maintenance	3.50 + Weibul (7.91, 0.92)
Passenger enplane	Triangular (13.50,21.30,22.50)
Baggage upload	16.50 + 18 * Beta (0.99,1.12)
Scheduled turnaround	Poisson (68.10)

Model translation

The simulation was developed with the simulation modeling software *Arena* (version 7.0; Rockwell Automation, 2005). The simulation is divided into model, experiment, and animation components. The model component describes the physical elements of the system (aircraft, material handling equipment, ground personnel, passenger and baggage flow, etc.) and their logical interrelationships. The experiment component defines the experimental condition under which the model runs. It specifies conditions such as resource availability, initial conditions, and number of replications.

The animation component of the model graphically represents the activities being simulated by the program. In this model, the activities include catering, fueling, maintenance, passenger/crew deplaning, cleaning, passenger/crew enplaning, baggage offloading, and baggage uploading. Figure 2 illustrates the animation component.

Figure 2. Graphical representation of the activities of an aircraft turnaround operation system, in Arena simulation modeling software (version 7.0)
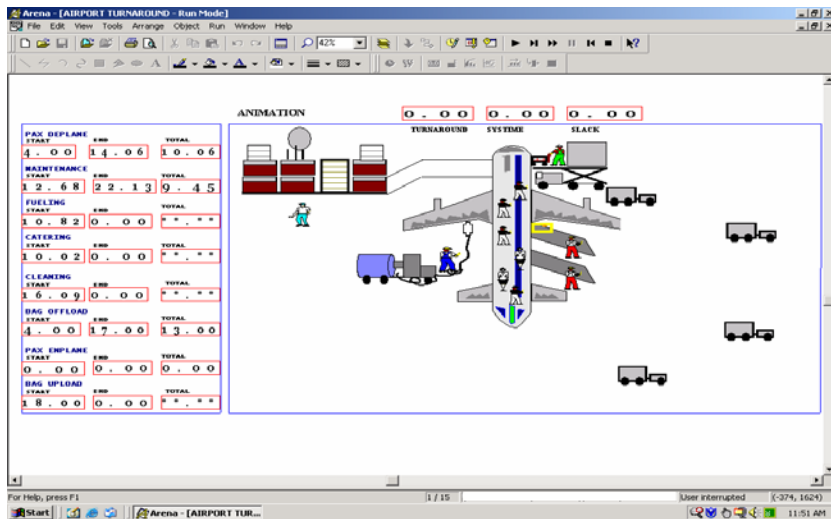
Note. Source and permission from Rockwell Automation.

Verification and validation

Verification is the process of ensuring that the model operates as intended. This means that the program is not only bug free, but also includes all of the components that need to be modeled. The animation component of the model is particularly helpful in the debugging process as it provides a

visual representation of what is going on in the system. Any unusual or unexpected model behavior can be identified and corrected.

Validation is the process of ensuring that the model represents reality. There are two stages in the validation process, namely face validity and statistical validity. The face validity involves a critical appraisal of the model by domain experts who understand the modeled system and intended operation. Two industrial engineers provided this critique for the improvement of the model and their suggestions were integrated into the model.

Statistical validity, involves a statistical comparison of the system and model performance under identical system loading conditions. One of many different comparison of means tests is used. The comparison of means test is typically applied to a measure of performance such as system time. In this effort, system times are defined as the time between the arrival and departure of the aircraft from the gate. The actual system time had a mean of 66.13 and a standard deviation of 12.39, while the simulation model system time had a mean of 67.55 and a standard deviation of 6.80. A non-parametric u test was used to perform the comparison of means. Formally stated:

1. H_o: There is no difference between the actual system and model system times;
   H_a: There is a difference between the actual system and model system times;
2. Alpha = 0.05;
3. The critical values for the Z distribution at 0.05 are -1.96 and 1.96;
4. The test statistic for the non-parametric u test is -0.48; and
5. -0.48 is between -1.96 and 1.96, cannot reject the H_o.

Since Ho cannot be rejected at a 0.05 level of significance, there is evidence to support the claim that the model is statistically valid. Since the basic model can be assumed to be valid, the next step was to determine what experimental alternatives to examine.

Experimental design

The essence of the research experimental design was to conduct an analysis of the effects of altering different system parameters and input variables. It was however, not feasible to carry out an infinite number of experiments to investigate all the different combinations of parameters and input variables. A combination of network analysis and one-factor experimental design was used to select the appropriate experiments.
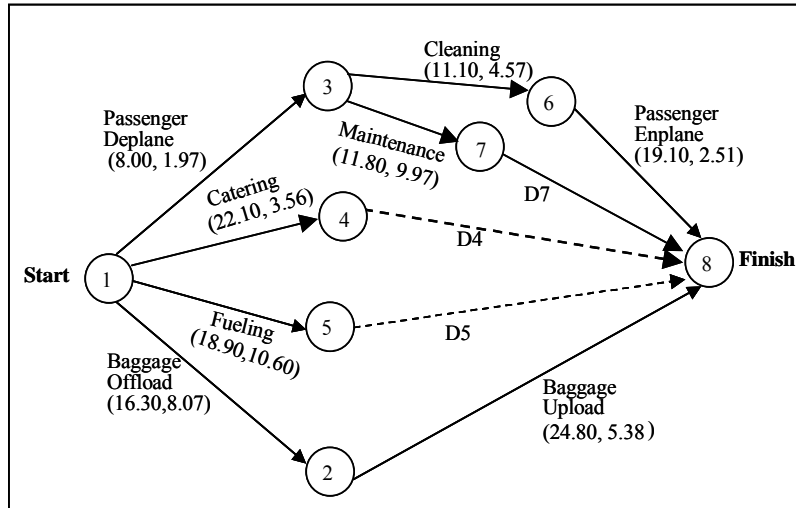
Representing the turnaround operation as a network

To guide the choice of experimental design, the turnaround operation is represented as a set of paths as illustrated in Figure 3. Each individual path

represents a set of particular activities that can only be completed in the specified sequence. For example, the plane cannot be cleaned until the passengers deplane. To complete the entire turnaround process, all activities on each of the paths must be completed. Paths are classified as critical or non-critical. The critical path represents the sequence of activities which if delayed will results in a longer overall delay in the completion of the entire turnaround operation. In contrast, non-critical paths have slack. This means that the activities on these paths may be delayed to some extent without delaying the overall process. However, in some instances, a significant delay in a non-critical path activity can result in the activity's path becoming the critical path.

Figure 3. Network of activities in an aircraft turnaround operation system and the mean and standard deviation of each path, in minutes

Calculating the critical path

There are five possible paths. The paths and the duration of each are presented in Table 3. To complete the turnaround operation, all five paths must be completed. The longest path in duration is the critical path. The critical path activities are *baggage offload* and *baggage upload*. Any delay in these activities result in longer duration of the turnaround operation. Now that the critical activities have been identified, it is necessary to investigate the delays in the critical path and the effect on the completion time of the turnaround operation.

Table 3. Paths of activities of an aircraft turnaround operation system

Path	Activities	Duration (minutes)
1 – 5 – 8	Fueling	18.90
1 – 3 – 7 – 8	Passenger deplane; Maintenance	19.80
1 – 4 – 8	Catering	22.10
1 – 3 – 6 – 8	Passenger deplane; Cleaning; Passenger enplane	38.20
1 – 2 – 8	Baggage offload; Baggage upload	41.01

The network indicates that the fueling process may be delayed by as much as 22.11 minutes before the fueling process becomes critical. Similarly, the passenger unloading/maintenance operations can be delayed by 21.21 minutes. The catering operation may be delayed by 18.91 minutes. Lastly, the passenger unloading, cleaning, and passenger loading process may be delayed by up to 2.81 minutes before becoming critical.

A one-factor experimental policy was used to examine the operation policy of *baggage upload* delay at seven different levels. This means that in addition to the base model, there are seven additional alternatives (D0-D24) as shown in Table 4. The configurations examined the impact of *baggage upload* delay at an increment of four minutes each. *Baggage upload* delay is defined as the time between the end of *offload* and the start of *upload*. With the base model, E40, *baggage upload* is initiated 40 minutes before scheduled departure.

Table 4. Design of one-factor experiment to determine impact of a delay in the baggage upload activity on the aircraft turnaround operation system

1	2	3	4	5	6	7	8
D0	D4	D8	D12	D16	D20	D24	E40 (Existing System)
0 min (no delay)	4 mins	8 mins	12 mins	16 mins	20 mins	24 mins	40 mins (before departure)

RESEARCH RESULTS

This section includes research results for the simulation replication analysis, the Analysis of Variance of the simulation alternatives, and Duncan Multiple Ranges test results.

Replication Analysis

In order to make a statistical robust comparison between alternatives, a sufficient number of simulation replications must be run. The commonly accepted 0.10 Desired Relative Precision approach to replication analysis

was utilized for the analysis (Law & Kelton, 2000). This method calculates the number of replications or simulation runs that must be conducted so that the ratio of the half-width confidence interval divided by the mean of replication means is less than 10%. To begin this method, an initial 10 replications are run. The final number of replications that are needed to achieve the desired relative precision are then calculated for each alternative. All of the alternatives are then rerun for the highest number of replications required for any of the individual alternatives.

Table 5. Replication analysis of eight alternatives of the duration of the baggage upload activity of an aircraft turnaround operation system

IDENTIFIER	D0	D4	D8	D12	D16	D20	D24	E40
Operating policy of "Delay"	0 mins	4 mins	8 mins	12 mins	16 mins	20 mins	24 mins	40 mins
Mean of 10 reps (mins)	61.10	63.30	65.70	69.00	73.00	77.00	81.00	68.86
STD of 10 rep	6.18	7.86	9.45	10.40	10.40	10.40	10.40	6.93
T value @ TINV(0.05,9)	2.26	2.26	2.26	2.26	2.26	2.26	2.26	2.26
Replications required	10	10	14	15	13	12	11	10

Table 5 indicates that the 12 minute delay alternative (D12) requires a minimum of 15 replications in order to achieve a desired relative precision of 0.10. Each of the eight alternatives was then rerun for a total of 15 replications in order to perform a robust statistical comparison. The results from the 15 replications were then analyzed for differences in the means of the alternatives.

Analysis of Variance (ANOVA)
ANOVA is used to determine if there is any significant statistical difference in the means of the alternatives. The analysis is based on a ratio of the variance between and within the different alternatives. This tests the null hypothesis (H_o) of the experimentation that the means of the alternatives are equal, and the alternate hypothesis (H_1) that the means of the alternatives are not equal.

At 0.05 level of significance, the $F_{experiment}$ (10.32) is greater than the $F_{critical}$ (2.09). The null hypothesis was rejected, implying that the means are not equal. The ANOVA results are presented in Table 6.

Table 6. Results of an analysis of variances of eight alternatives of the duration of the baggage upload activity of an aircraft turnaround operation system

Source of Variation	Sum Squares	DF	Mean Squares	F Experiment	F Critical
Between Treatments	5395	7	770.70	10.32	2.09
Error (Within Treatments)	8366	112	74.70		
Total	**13761**	**119**			

Duncan multiple range test

If the ANOVA null hypothesis is rejected, then one or more of the alternatives are statistically significantly different from the others. However, ANOVA by itself does not indicate which of the alternatives are statistically significantly different from the others. The Duncan multiple range test provides this information. After sorting the data in ascending order, the test compares the range of a given sized group of adjacent values to a calculated least significant range value. The calculated least significant range values are listed in Table 7.

Table 7. Least significant range of adjacent means of eight alternatives of the duration of the baggage upload activity of an aircraft turnaround operation system

P	2	3	4	5	6	7	8
R	6.25	6.58	6.78	6.96	7.07	7.19	7.25

Where:

p = number of adjacent values in the range; and
R = Least significant range value for alpha = 0.05.

If the range of a given sized set of adjacent values is less than the least significant range value at a given alpha level, then there is no statistically significant difference among the adjacent values. Conversely, if the range of the given sized set of adjacent values is greater than the least significant range value, one or more of the values is statistically significantly different. Non-significant ranges of adjacent values are represented by an underline. The Duncan Multiple Range Test Results are presented in Table 8.

Table 8. Duncan Multiple Range Test results of eight alternatives of the duration of the baggage upload activity of an aircraft turnaround operation system

Alternative	D0	D4	D8	E40	D12	D16	D20	D24
Delay (mins)	0	4	8	40	12	16	20	24
Means (mins)	61.10	63.50	66.40	67.55	69.90	73.90	77.90	81.90

DISCUSSION

The Duncan Multiple Range Test Results presented in Table 8 can be interpreted as follows. At an alpha level of 0.05, there is no statistically significant difference among the alternatives in the following groups of delays:

1. delays of 2 minutes, 4 minutes, 8 minutes and the existing system (D0, D4, D8 and E40, respectively);
2. delays of 8 minutes, 12 minutes and the existing system (D8, D12, and E40, respectively);
3. delays of 16 minutes and 20 minutes (D16 and D20, respectively); and
4. delays of 20 minutes and 24 minutes (D20 and D24, respectively).

This means that there is no performance difference between the existing policy of loading the baggage 40 minutes before the scheduled departure and loading the baggage either 0, 4, or 8 minutes after offloading the baggage. Similarly, there is no difference between the existing policy and loading the baggage either 8 minutes or 12 minutes after offloading the baggage. There is also no performance difference between loading the baggage either 16 or 20 minutes later. Lastly, there is no performance difference between loading the luggage either 20 or 24 minutes later.

All other differences are statistically significant at an alpha level of 0.05. This means, among other things, that:

1. delays of 0 minutes, 4 minutes 8 minutes and the existing system D0, D4, D8 and E40, respectively) are statistically significantly different than delays of 16 minutes, 20 minutes and 24 minutes (D16, D20, and D24, respectively);
2. a delay of 12 minutes (D12) is statistically significantly different from delays of 16 minutes, 20 minutes and 24 minutes (D16, D20, and D24, respectively); and
3. a delay of 16 minutes (D16) is statistically significantly different from a delay of 24 minutes (D24).

CONCLUSIONS AND RECOMMENDATIONS

If the turnaround process operates without incident, the airline will be able to follow normal procedures without extending the length of the turnaround process. As previously noted, several turnaround activities are not on the critical path. These activities need not be started immediately when the plane arrives at the gate. However, if any of these activities are delayed past the slack, they will possibly result in an extended turnaround time. These slack times are summarized below:

      1.   Fueling, 22.11 minutes;
      2.   Passenger unloading and maintenance, 21.21 minutes;
      3.   Catering 18.91 minutes; and
      4.   Passenger unloading, cleaning, passenger loading 2.81 minutes

Since the baggage unloading and loading processes are on the critical path, additional attention was directed at this process. Under regular conditions, the baggage upload is started 40 minutes before the scheduled departure. This approach does not necessarily provide the airline with the opportunity to take early action in the event of a problem. The airline can only determine that a problem is initially developing if the 40 minute start window is exceeded. A more proactive approach involves examining the upload delay period. This was defined as the delay between the end of the baggage unloading process and the start of the baggage uploading process.

As previously noted, alternatives of delays of 0 minutes, 4 minutes, 8 minutes and the existing system (D0, D4, D8, and E40, respectively), perform statistically significantly the same at an alpha level of 0.05. Alternatives of delays of 8 minutes, existing system, and 12 minutes (D8, E40, and D12, respectively) also perform statistically significantly the same. This means that if the baggage upload delay is longer than 16 minutes than the turnaround time for the flight will be extended. Since the baggage upload is contingent on the luggage download, the flight turnaround time will also be extended, if the beginning of the baggage off load is delayed by greater than 16 minutes. Similarly, if the baggage offload process takes longer than 16 minutes past the normal expected time of 16.30 minutes, the turnaround time will also be extended. This information means that the airline has a buffer of approximately sixteen minutes for accommodating the luggage of passengers arriving late from connecting flights before there is an effect on the duration of the turnaround operation.

The airline should closely monitor this buffer period and plan accordingly. As the buffer is consumed, additional attention should be focused on the causes of the delay. In some cases, such as the late arrival of other luggage, there may be no option but to delay the departure of the flight.

In this case, the contingency plan would include the assignment of additional resources to reduce the baggage upload time. Similarly, if the baggage upload was started within 16 minutes, but is taking longer than normal, the contingency plan would include additional resources being assigned to help insure that the flight can leave on schedule. If the buffer period is properly managed, there is a greater likelihood that the flight will leave on schedule. This in turn will help reduce the cascade effect of delays inherent in the hub-and-spoke network system.

FUTURE RESEARCH

One of the underlying principles of this research is the maintaining of current resource levels so that no additional cost is incurred. It is suggested that further research examine the resource policy of baggage offload and upload activities, and especially the concept of crashing the turnaround operation, that is, compressing the operation without regard to the operating cost.

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