SIMULATION MODELS FOR EVALUATION OF AIRPORT BAGGAGE-HANDLING SYSTEMS

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Abstract

Computer simulation models were used to evaluate alternative designs of hypothetical baggage-handling systems for large-capacity aircraft under different baggage-per-passenger conditions. The program was written in GPSS III. Performance indices and criteria used in evaluating relative merits of various system-design alternatives include (1) average delay for individual passengers, (2) standard deviation of delay for individual passengers, (3) maximum delay for individual passengers, and (4) total delay for all passengers, in passenger-hours. Recommendations are made for refinements of the models and for further research.

1. INTRODUCTION

It is widely recognized that an airport crisis is rapidly developing. In the early 1970's, major airports will be faced with the staggering task of handling greatly increased volumes of passengers, freight, and baggage. Ground-vehicle traffic and parking also will pose serious problems. The advent of jumbo jets carrying as many as 500 people will impose particularly severe stresses on airport facilities.

This report considers one aspect of the airport problem – baggage handling. Even today the delay involved in baggage retrieval at airports is often a major inconvenience. In a few years, when much larger aircraft are in use, the delay could be intolerable unless major improvements are made in baggage-handling systems.

Prototypes of computer-controlled baggage handlers – such as the "electronic redcap" built by Teltrans, Inc. for the jumbo jets – have been demonstrated.[1] However, only a few major airports will be able to afford such sophisticated systems. Smaller airports require a workable system at a reasonable cost. This latter type of system is considered in this study.

Simulation models are used in the study to evaluate alternative designs of hypothetical baggage-handling systems for large-capacity aircraft. Recommendations are made for refinements to the models and for further research.

2. OBJECTIVES

The objectives of this study are to:

(1) Formulate a computer program using

GPSS III to simulate the operation of various design alternatives for baggage-handling systems under different bags-per-passenger conditions.

(2) Design simulation experiments for evaluating various system-design alternatives.

(3) Analyze simulation data to reach conclusions regarding the relative merits of various system-design alternatives.

(4) Demonstrate the applicability of simulation to the baggage-handling problem.

No attempt is made to consider system costs.

3. CRITERIA FOR SYSTEM EVALUATION

"Delay" is defined as the time spent by passengers waiting for and picking up their bag(s) in the baggage-claim area. This time forms the basis for performance indices and criteria used in evaluating the relative merits of various system-design alternatives. The following performance indices are considered:

(1) Average delay for individual passengers

(2) Standard deviation of delay for individual passengers

(3) Maximum delay for individual passengers

(4) Total delay for all passengers, in passenger-hours.

In a complete study, it would be necessary to relate the relevant costs for each system design to the benefits measured by such performance indices as those listed above. It also would be necessary to select a single criterion, or some combination of criteria with a weighting for each, to represent measures of benefits. Such cost-benefit analysis would provide a basis for selecting a system design.

The most appealing criterion appears to be based on the fourth performance index because it represents total man-hours (or human resources) expended due to delay. Such an index could be converted to an estimated dollar value of "lost" man-hours per flight. Thus, if the budget for a baggage-handling system were fixed, a rational approach to design selection could be based on the criterion of minimum estimated total delay. One approach, which includes the passengers and the baggage-handling system in a "total system", would be to select a design which would minimize the sum of the estimated annual dollar value of "lost" man-hours due to delays and the estimated annual costs of the baggage-handling system.

4. RATIONALE FOR SIMULATION

Computer simulation is used in this study for conducting experiments involving hypothetical baggage-handling systems. It would be extremely costly to conduct replicated physical experiments with baggage-handling systems involving 500 people. Also, simulation provides the capability of controlling variability in behavior of the elements of the experiment; this often cannot be done in physical experiments.

Further, the types of systems being considered are so complex that it is infeasible to describe them by mathematical models for which analytic solutions could be obtained.

Only a few combinations of system design and of bags-per-passenger conditions were considered. However, the GPSS III program developed for this study is flexible in that it may be adapted to simulate a wide range of system configurations with any probability function for bags per passenger. GPSS III was used because of its applicability to queueing problems.

5. HYPOTHETICAL SYSTEM DESCRIPTIONS

For purposes of this study, a hypothetical system is described and several configurations are simulated. Two different bags-per-passenger conditions are considered.

5.1 ASSUMPTIONS

The following assumptions are made regarding the aircraft, passengers, and bags for which the baggage-handling system is to be designed.

(1) The system must accomodate a fully loaded jumbo-jet aircraft with a capacity of 500 passengers.

(2) Passengers depart from the incoming aircraft at the rate of 120 per minute. They arrive at the baggage-claim area at the same rate.

(3) Half of the seats on the aircraft are first class and half are tourist class. The seats are arranged so that all first-class passengers disembark before any tourist-class passengers start to get off.

(4) It takes 3 minutes for each passenger to walk from the aircraft to the baggage-claim area.

(5) A baggage conveyor should not move at a speed greater than 2 feet per second. If this speed is exceeded, passengers will experience intolerable difficulties in picking up their bags. (An upper limit on speed could be determined by human-engineering studies.)

(6) Two alternate probability density functions, p(n), of bags per passenger, n, are considered as follows:

"Business" Flights		"Vacation" Flights	
n	p(n)	n	p(n)
0	0.4	0	0.1
1	0.5	1	0.5
2	0.1	2	0.4

5.2 DESIGN CONFIGURATIONS

The following hypothetical system design configurations are considered.

5.2.1 Conveyors are used for storage and for delivery of bags to the passengers who enter aisles which are marked by strips on the floor or by other means, to pick up their bags. Two-conveyor and three-conveyor systems are considered. The two-conveyor configuration is illustrated in Figure 1. Each of the conveyors has the following characteristics:

(1) Length, L = 120 feet

(2) Holding capacity = 120 bags

(3) Number of aisles = 30

(4) Aisle width = 4 feet.

It is assumed that conveyor speed is 2 feet per second and that bags are loaded onto conveyors at a rate of 120 bags per minute.

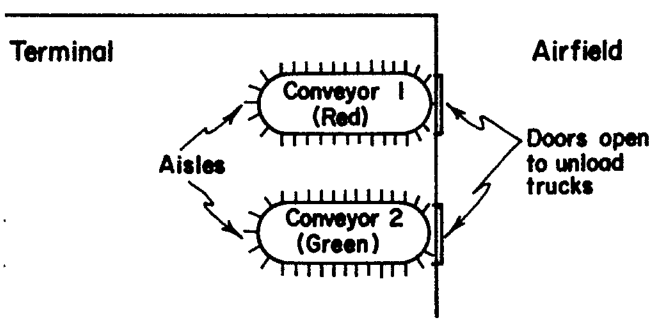

FIGURE 1. BAGGAGE CONVEYORS

5.2.2 Baggage claim checks are labeled "first class" or "tourist". This determines the "class" of the bag. For the two-conveyor system, half of the bags in each class have red claim checks and the other half have green. For the three-conveyor system, one-third of the bags in each class have red claim checks, one-third have green, and one-third have blue. Conveyors are marked with the color of the claim checks of the bags they carry, so that each passenger will go to the proper conveyor for his bag(s). Baggage is palletized with 20 bags of one class and color per pallet. Small trucks are used to move the pallets from the aircraft to the terminal for incoming flights. Each truck has a capacity of six pallets (120 bags). The pallets are loaded on the aircraft so that all first-class bags will be unloaded before tourist bags.

5.2.3 One truck for each conveyor is used to transport the baggage from the aircraft to the baggage claim area. Three alternate time patterns are considered:

	Fast	Medium	Slow
Loading six pallets on each truck	1 min	1-1/2 min	2 min
Truck transit time between aircraft and terminal	1 min	1-1/2 min	2 min
Total bag loading and transit time (aircraft to terminal), T_b	2 min	3 min	4 min

5.2.4 All first-class bags are loaded onto the trucks from the aircraft before any tourist bags are loaded. Each truck is loaded with 120 bags with one color of claim check. After the trucks are loaded, they transport the bags to the terminal where the bags are loaded onto the conveyors before the trucks return to the aircraft for a second load. Conveyor 1 is loaded with "red" bags, conveyor 2 with "green" bags, and, when used, conveyor 3 with "blue" bags. Doors in the terminal building open for unloading the bags from the trucks onto the conveyors. If necessary, the trucks deliver second and third loads of bags from the aircraft to the terminal.

5.2.5 The passengers enter the aisles and wait for their bags to be transported to them by the conveyors. Each passenger will select the queue with the shortest length. In case of a tie for shortest queue, the lowest queue number involved is selected. It is assumed that there will be no "jockeying" from queue to queue.

"Service time", t_s, for a passenger is defined as the time required to pick up his bag or bags from the conveyor after reaching the front of his queue. For a passenger with only one bag, t_s may be considered a random variable with a uniform probability density function over the range 0 to T, where T is the conveyor-rotation time. If only integer values of t_s and T are considered,

$$P(t_s \mid 1 \text{ bag}) = \begin{cases} \frac{1}{T+1} & \text{for } 0 \le t_s \le T \\ 0 & \text{otherwise} \end{cases} \qquad (1)$$

where t_s and T are expressed in seconds to the nearest integer, and $p(t_s \mid 1 \text{ bag})$ is the probability of a service time t_s given that a passenger has one bag.

For a passenger with two bags, t_s has a more complex probability density function which can be shown to be given approximately by (2):

$$\begin{aligned} &P(t_s \le \tfrac{T}{6} \mid 2 \text{ bags}) = .03 \\ &P(\tfrac{T}{6} < t_s \le \tfrac{T}{3} \mid 2 \text{ bags}) = .08 \\ &P(\tfrac{T}{3} < t_s \le \tfrac{T}{2} \mid 2 \text{ bags}) = .14 \\ &P(\tfrac{T}{2} < t_s \le \tfrac{2T}{3} \mid 2 \text{ bags}) = .19 \\ &P(\tfrac{2T}{3} < t_s \le \tfrac{5T}{6} \mid 2 \text{ bags}) = .25 \\ &P(\tfrac{5T}{6} < t_s \le T \mid 2 \text{ bags}) = .31 \end{aligned} \qquad (2)$$

where t_s and T are expressed in seconds to the nearest integer, and p( ) is the probability of a service time t_s in the indicated range, given that a passenger has two bags.

6. DESIGN OF THE SIMULATION EXPERIMENT

The alternative system configurations and bags-per-passenger conditions being considered have been described in the foregoing "Hypothetical System Description". The combinations for which simulation experiments were conducted are indicated in Table 1.

"Vacation" flights impose a more stringent test of baggage-handling system performance than "business" flights because of the larger number of bags. Thus most of the simulation experiments were based on vacation flights.

Three simulation experiments were conducted for the combination of a two-conveyor system and a vacation flight, each experiment being based on a different time for bag loading and transit to the terminal. Three experiments were run in this case because it represents the most stringent combination of conveyors and bags-per-passenger conditions considered. With data obtained from these three experiments, it is possible to plot curves (Figures 2 and 3) and estimate passenger delays by interpolating or extrapolating bag-loading and transit times not simulated.

Only one simulation experiment was run for a business flight. It was based on the combination of a two-conveyor system and a 4-minute time for bag loading and transit to the terminal. This

TABLE 1. SIMULATION DATA

T_b (Bag Loading and Transit Time, Aircraft to Terminal), minutes	Measures of Delay*	Delay Times* for Conveyor System and Bags/Passenger Condition: 2 Conveyors, Bags/Passenger Conditions: Business	2 Conveyors: Vacation	3 Conveyors, Bags/Passenger Conditions: Business	3 Conveyors: Vacation
2	u		4.41, 4.70		
	σ		2.80, 2.93		
	Max.		11.0, 10.5		
	Tot.		34.6, 38.6		
3	u		6.20, 6.58		
	σ		4.31, 4.48		
	Max.		14.5, 14.5		
	Tot.		47.9, 51.3		
4	u	4.99, 5.50	8.25, 8.63		5.27, 5.23
	σ	3.52, 3.58	5.60, 5.83		3.59, 3.54
	Max.	10.5, 11.5	19.5, 19.0		10.5, 11.0
	Tot.	26.9, 29.9	63.6, 68.5		41.8, 41.0

* u = Average delay for individual passengers, minutes
σ = Standard deviation of delay for individual passengers, minutes
Max. = Maximum delay for individual passengers, minutes
Tot. = Total delay for all passengers, passenger-hours
(The two entries on each line in each column represent the results of two replications for each simulation experiment.)

was the most stringent combination of the two physical-system factors considered. This combination was used because performance under other conditions may not need to be determined if system performance is acceptable under this the most stringent condition.

Only one simulation experiment was run for a three-conveyor system. It was based on the most stringent combination of the other factors considered – i.e., a vacation flight and a 4-minute time for bag loading and transit to the terminal. This combination was used for the same reason given in the previous paragraph.

Two replications were obtained for each simulation experiment. The purpose of replicating was to obtain more accurate estimates of the mean values of performance indices. Improved accuracy could have been obtained by a larger sample size, but more replications were not obtained because of considerations of computer-run time*.

The same sequence of pseudorandom numbers was generated for each system-design alternative simulated for a given bags-per-passenger probability distribution. In this manner, identical conditions (event sequences) apply for comparison of alternatives for a given bags-per-passenger probability distribution. This approach sharpens the contrast between alternatives by reducing the residual variation in the difference between performance indices. The same control over conditions would not be possible in comparable physical experiments. The hypothesis that the mean of a performance index of the system is different for two system-design alternatives can be tested with much smaller sample sizes than would be required if different sequences of random numbers were used for each alternative simulated.

The use of the same sequence of random numbers for different alternatives does not produce independent results for the different alternatives; therefore, the classical analysis of variance model cannot be used to test whether alternatives are equivalent or different because it requires the assumption of independent observations. However, the alternatives being considered generally will be expected to yield different performance indices, and it will be the extent of the difference rather than the existence of a difference that will be of concern. If there is doubt, in comparing any two alternatives, about whether a difference exists in their performance indices, then the hypothesis that the means of the performance indices for the two alternatives are the same may be tested using the Student's t-distribution.

7. RESULTS

Results of the simulation experiments are summarized in Table 1. Data shown in Table 1 are

*For highly accurate estimates of mean values of performance indices, the following procedure should be followed: Execute a series of replicated experiments for each desired combination of factors, with identical factors for any given series, but with an independent set of pseudorandom numbers for each replication in the series. This provides a sequence of statistically independent observations for the series which would tend to have an approximately normal distribution, according to the central-limit theorem. A confidence interval for the mean can be obtained by standard statistical procedures, and this confidence interval can be made as small as desired by making the number of replications sufficiently large.

plotted in Figures 2 and 3. The observed values of each of the four performance indices are plotted for each of the two replications of each of the five factor combinations simulated.

Single mean values for each performance index could have been given in Table 1 for each factor combination, and this would be normal practice. However, two values for each performance index are given in order to reveal the effects of using a different set of pseudorandom numbers for each replication. Likewise, two points are plotted in Figures 2 and 3 for each factor combination.

Additional results for each simulation experiment were obtained in the computer printouts, although they are not presented herein. These results include number of passengers with one and two bags, the maximum and average contents of each queue, the average time spent in each queue, cumulative percentage of passengers versus total time in system, and other data. The four performance indices which are included in Table 1 and Figures 2 and 3 were selected as being of most value to a decision maker.

The performance of the different system configurations simulated for vacation flights may be compared easily by use of Figures 2 and 3. The poorest performance, measured by any of the four performance indices, occurs with the two-conveyor system and a time T_b of 4 minutes. The best performance for vacation flights is not quite as clear-cut. Based on average delay, standard deviation of delay, and total delay, the two-conveyor system with a T_b of 2 minutes is the best by a narrow margin when compared with a three-conveyor system with a T_b of 4 minutes. However, based on maximum delay, these two systems tie for best.

Performance for the system configuration simulated for business flights is much better than its performance for vacation flights, based on all four performance indices. This suggests one approach which might be taken by a decision maker. If the majority of actual flights are expected to have a relatively low density of bags per passenger, as typified by the business flight simulation, it may be possible to use a two-conveyor system with a T_b of 4 minutes on a routine basis, provided the delays are within acceptable limits. Further, if this system design will result in violation of the acceptable delay limits infrequently and only when a high density of bags per person occurs – as typified by the vacation flight simulation – it may be possible in these instances to reduce T_b to meet the limits by use of extra loading crews and special airfield traffic-control measures.

8. CONCLUSIONS

It has been shown that results from simulation experiments can be useful to a decision maker in selecting a baggage-handling system design.

GPSS III has proved to be an appropriate simulation language for the baggage-handling problem, although it does have some capacity limitations which could present difficulties in simulating larger or more complex systems. For example, with the programs developed in this study, only 498 passengers could be simulated. This is because of a core limitation of 500 SAVEVALUE locations and the use of two of the locations for bag-counting purposes. If more than 498 passengers were to be simulated using GPSS III, circumvention of this limitation through programming techniques would be required.

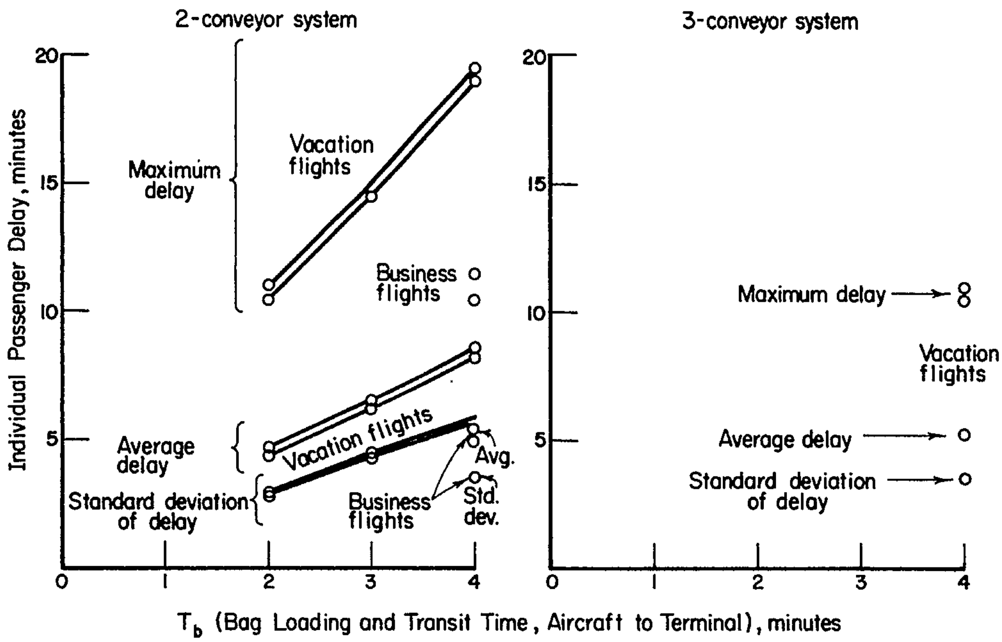

FIGURE 2. SYSTEM CONFIGURATION VERSUS INDIVIDUAL PASSENGER DELAY

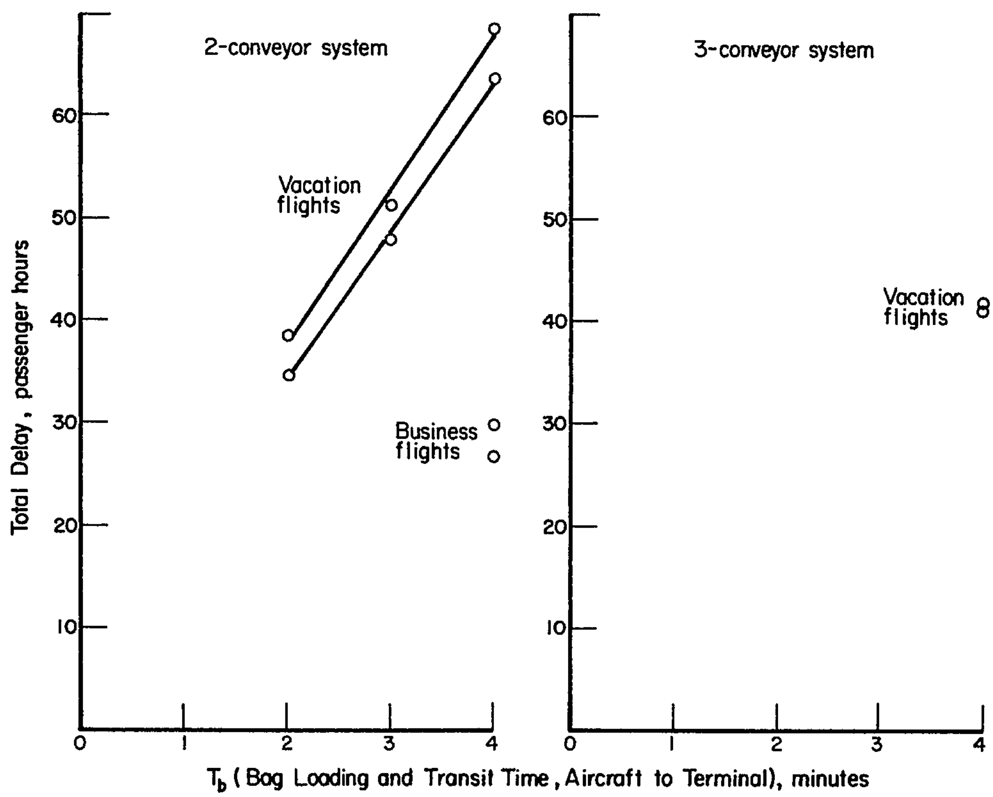

FIGURE 3. SYSTEM CONFIGURATION VERSUS TOTAL PASSENGER DELAY

9. FURTHER RESEARCH AND MODEL REFINEMENTS

This study was based on hypothetical data regarding both controllable and noncontrollable input variables as well as system operating characteristics. In order to apply the approach of this study to the practical decision problem of choosing a baggage-handling system design, it will be necessary to collect real-world data on the following: characteristics of aircraft, conveyors, trucks, and bags; loading and unloading rates; bags per passenger; arrival rate of passengers; and the constraint on conveyor speed imposed by human-engineering considerations. In addition, cost data will be required for each system design being considered.

Answers to the question of whether performance indices will be improved or degraded by single changes to the design configuration of baggage-handling systems can usually be anticipated without experimentation. For example, increasing (1) conveyor speed (within the human-engineering constraint on maximum speed), (2) number of conveyors, (3) truck speed or capacity, or (4) loading and unloading rates would tend to improve (or not degrade) any of the performance indices. However, the magnitude of the improvement and whether it is worth the cost cannot readily be anticipated. Also, effects of certain combinations of changes cannot readily be anticipated. These are cases where simulation of baggage-handling systems can be of value to the decision maker. The ultimate objective of a subsequent simulation study of a real-life baggage-handling system could be to determine the system-design configuration which yields an optimum performance index value within a specified cost. Or, it could be to determine the system-design configuration which yields minimum cost within specified limits on performance indices.

Certain model improvements, discussed in the following sections, should be made in any subsequent study.

9.1 RANDOM PLACEMENT OF BAGS ONTO CONVEYORS

The models used in this study assume that bags are loaded onto the conveyor in the same sequence (defined by passenger number) that passengers enter queues at the conveyor. In order to more closely approximate a real system, the bags from any truck should be loaded onto the conveyor in a random manner. The program modification could be achieved by use of LINK and UNLINK blocks creating a user chain for each truckload of 120 bags. The numbers 1 through 120 inclusive would be assigned randomly to a parameter of the bag transactions, and the transaction would be merged into the user chain according to the value of this parameter. As such transaction is unlinked, it would then be delayed by an appropriate number of clock units more than its predecessor, to represent the loading rate.

9.2 RETAINING A PASSENGER IN HIS QUEUE UNTIL BAG IS PICKED UP

The models used in this study treat a passenger who has reached the front of his line (to pick up his bag from the conveyor) as having left his queue. This is because GPSS III considers a transaction as having left its queue when it enters a "facility" for service. The effect is that, when empty lanes are available, some arriving passengers will nevertheless enter lanes containing one other passenger then being "served" by the conveyor. The distortion of the queue and delay statistics is not great because the expected service time is only slightly greater than a half minute per passenger. However, slightly more accurate statistics could be obtained by refinement of the model to eliminate this anomaly.

9.3 DELIVERY OF ALL BAGS TO TERMINAL IN ONE GROUP

The models used in this study assume that trucks will have to make two or three trips to deliver bags from the aircraft to the terminal. They also assume that when a truck-load of bags arrives at a conveyor, the loading rate of bags onto the conveyor is not reduced by the presence of unclaimed bags still on the conveyor. These assumptions are justified in this study because of the particular system configurations considered and the values used for variables and operating characteristics. However, differences in such configurations and values may require program changes. For example, if delivery of all bags to the terminal in one group by a large truck or several smaller trucks is to be simulated, the loading rate onto the conveyors will be reduced. The necessary program change may be accomplished by having the bag transactions enter a queue, be identified by color of claim check, and be loaded onto the conveyor only as spaces are made available by removal of bags by passengers.

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BIOGRAPHY

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From 1950 to 1962, Mr. Robinson was responsible for administration of major defense programs at Hazeltine Corporation, Little Neck, N. Y. From 1962 to 1965, he held positions in engineering administration, planning, and new-product development at Industrial Nucleonics Corporation, Columbus, Ohio. Since 1965, he has been a Senior Systems Analyst at Battelle Memorial Institute, Columbus, Ohio.

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