VALIDATION OF AN AIRPORT SIMULATION MODEL

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ABSTRACT

This paper describes the validation of an airport simulation model, called DELCAP for DELay CAPacity, the two quantities which it measures, for use in estimating the traffic rates attainable at major busy U.S. airports. The simulation model outputs are compared to those of other models for simple cases to which both apply and to actual throughput data for several airports, with differences usually less than 6 to 8 percent.

1. DESCRIPTION OF THE MODEL

DELCAP is an airport simulation model developed by the National Bureau of Standards (NBS) in 1970 [1] to assist the Federal Aviation Administration (FAA) in estimating airport capacity. In 1974 the FAA asked NBS to validate the model for use in assessing air traffic controller performance at the major busy airports. This paper describes both the model and the validation effort performed in response to the FAA's request.

DELCAP models an airport's airside operations, those occurring in the air in the vicinity of the airport and under the control of airport-based air traffic controllers. The model does not include activities on the ground or in the terminal building, except for movements on the runways and those taxiing operations which could affect airborne movement.

Outputs from the model include hourly throughput (numbers of takeoffs and landings occurring during the hour) and the hourly delay profile for landings, takeoffs, and all aircraft. "Delay", as calculated by DELCAP, includes only that delay occurring because of activity in the particular terminal area being modeled; it is calculated as the difference between the time actually required to complete the landing or takeoff, as computed by the simulation with other traffic competing for facilities, and the time required for that operation were no other traffic present.

The model inputs describe the airport, traffic and regulations which apply for the run. Input parameters include:

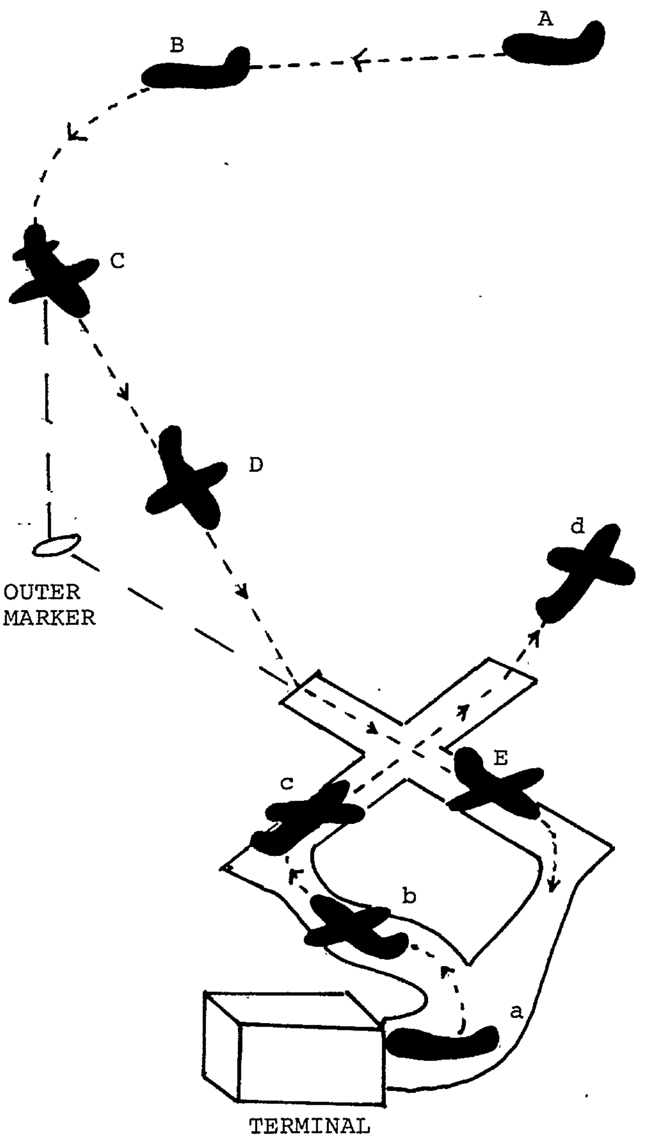
- separation rules describing the distances or times between aircraft required by FAA regulations,
- characteristics of various aircraft types operating at this airport, including approach and liftoff speeds and runway occupancy times on landing and takeoff,
- mix of aircraft types: the fraction of aircraft operations performed by each type of aircraft,
- traffic levels described either by a list of explicit arriving and departing flights, or by expected traffic levels per hour, or some combination of the two,
- airport runway configuration: how the runways intersect or how far apart they are,
- airport operating policy: which runways handle only landings, only takeoffs, which allow both and how they are to be sequenced.

Figure 1 depicts a hypothetical terminal area as seen by the DELCAP model. Aircraft denoted by capital letters are landings; those designated by lowercase letters are takeoffs.

It is convenient to describe DELCAP's treatment of landing and takeoff streams separately, since DELCAP is an event-oriented model (time is incremented to the next "critical event," rather than stepped along at preset intervals), and each critical event in an aircraft's path anticipates the next one along that path. A landing enters the simulation at handoff to tower approach control (A in Figure 1) when it first makes contact with the terminal. The next critical point along a landing path is the outer marker, the point at which the aircraft intersects the glideslope for the runway on which it will land. DELCAP requires that at least a preset minimum time interval ensue between handoff and the landing's passage of the outer marker. However the presence of other aircraft in front of A in the landing stream may necessitate that it be placed in a holding pattern or that it fly a longer path to the outer marker, either of which would require extra time. DELCAP does not model the actual route flown by A, but this extra time requirement is imposed by the modeling device of "tying up" the outer marker, i.e., prohibiting A from passing it, until all those in front have done so.

FIGURE 1

The Terminal Area as Seen by DELCAP



B's final approach can be scheduled once the aircraft in front of B (C in the figure) has passed the outer marker. B must remain separated from C by the required amount, which depends on the types of aircraft involved, along the whole final approach path. DELCAP employs the idealization of constant final approach speeds (dependent on aircraft type), and so the actual separation required between C and B when B crosses the outer market is either (if C is faster) the minimum required spacing between these aircraft, or (if B is faster) a spacing such that when C touches down B will be at the required minimum separation distance from the end of the runway. Of course D cannot land as long as E is on the runway surface. That is, in addition to the airborne separation requirements, runway occupancy time also can affect the prescribed separation between D and E. DELCAP includes the "tying up" effects of runway occupancy, though in practice, it is usually the airborne separation which is critical. A landing leaves the simulation when it turns off the runway.

Takeoffs enter the simulation several minutes before scheduled departure time. A minimum taxi time between gate and runway is specified. Since in Figure 1, landing E passed the runway intersection, takeoff c can be cleared to start its roll, if takeoff d had sufficient separation from takeoff c; this presently is 2 minutes after d lifts off if d is a heavy and c is not, and is a shorter, constant time interval--approximated as 20 seconds after liftoff--for all other aircraft-type combinations.

The DELCAP simulation model is written in SIMSCRIPT 1.5, a computer simulation language which facilitates the programming of critical event simulations. In accordance with the modeling philosophy under which DELCAP was designed, in which ease of use is a major criterion, a FORTRAN preprocessing program has been written to allow users to provide inputs in a format less rigid than that required by SIMSCRIPT programs, to edit input and perform some consistency checks, and to provide a set of "nominal" input values. The user specifies values only for those input parameters which are to differ from their nominal settings.

2. VALIDATION OF DELCAP THROUGHPUT OUTPUT

Once a mathematical model has reached operational status, there is a natural temptation to put it directly to practical use, skipping over any substantial effort to verify that the model does in fact do what it was designed to do. Such an omission, however, courts disaster, since a model which has not been exercised on a variety of data (and had its outputs compared with what is actually observed in the situation being modeled) may contain unsuspected anomalies likely to exhibit themselves at embarrassing moments or (even worse) to remain undetected. To guard responsibly against this, it is necessary to subject the model to a pre-use validation and preliminary sensitivity analysis.

Validation involves two types of analysis. The first is an independent assessment of the appropriateness of the structure and methods used. A second element of validity checking is the comparison of model outputs with what is actually observed in specific instances of the type of situation being modeled. Comparison of model performance with that of other models which are well-based and accepted, for cases to which both apply, could also be part of this type of analysis. Absolute assurance of validity for all possible future uses is, of course, impossible. Replication of reality for a few test cases can only insure that in these particular examples, the model performs as it should, but if the test cases were chosen carefully to be representative of the spectrum of situations to which the model is expected to be applied, then increased confidence in model validity can be obtained.

Beyond the basic validity testing described above, some preliminary sensitivity analyses should be conducted--to identify those parameters having most critical (most sensitive) effect on model outputs, and to ascertain the degree to which model outputs can be expected to vary with input variations. Such sensitivity analyses should also help to determine the limits beyond which application of the model is inappropriate.

The validation exercises performed on the DELCAP model will be outlined below and are more fully described in [2]. Since the aim of the DELCAP validation effort was to check its appropriateness for a particular application--the setting of goals for the number of operations which could be handled by controllers at the busiest U.S. airports --the input values chosen for the sensitivity and validation runs were those representing the range of such variables at these facilities. The airport configurations included in the analysis were a single runway, two different intersecting runway configurations (differing in the placement of the intersection), a pair of close parallels (separated by 3000 to 4300 feet between centerlines), and a pair of close parallels with a third runway crossing the pair. Wide parallels (separated by more than 4300 feet) were not specifically included, since they can be modeled as two separate single runways. A variety of operating policies were chosen to approximate those used under different traffic situations: when landings balance takeoffs, when landings predominate, and when takeoffs predominate. This diversity also allows comparison of results, to evaluate the sensitivity of DELCAP throughputs to operating policy. The exercises included different mixes of aircraft types, focusing primarily on the fraction of heavy aircraft (i.e. wide bodied jets such as the Boeing 747, the DC 10 and the Lockheed 1011) in the mix, since different, larger separations are required behind heavies because of wake turbulence.

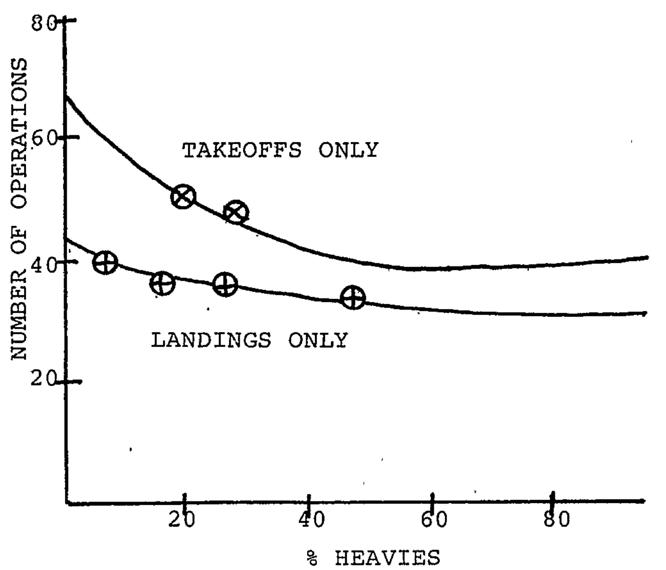
2.1 The Single Runway Case

The single runway case has been studied extensively, (see references [3]-[8]) and admits an analytical expression for capacity. This is the basis for the two curves in Figure 2, one for a runway handling only landings and the second for a runway handling only takeoffs,

FIGURE 2

Hourly Throughput for a Single Runway

Handling Only Takeoffs or Only Landings



which represent the variation of the maximum number of operations per hour with the percent of heavy aircraft in the traffic mix. The six points are results of computer runs of DELCAP (the x's are for takeoffs only, the +'s for landings only). Thus the computer simulation model agrees well with an accepted analytical model for cases to which both apply.

2.2 The Multiple Runway Case

Table 1 reports the results of comparison of the outputs from

VALIDATION.....Continued

TABLE 1

Comparison of DELCAP Calculated Hourly Throughput with FAA Throughput Estimates

Configuration/ Policy	FAA Estimates	DELCAP Estimates
WIDE PARALLELS		
JFK (pure*)	74	78
MIA (mixed)	106	113
ATL (mixed)	114	113
ORD (mixed)	104	109
CLOSE PARALLELS		
JFK (pure)	60	61
PHL (pure)	68	75
ORD-4 RUNWAY (pure)	152	143

*A "pure" operation policy is one handling only takeoffs or only landings. Parallels operated in a pure policy have one runway only for landings and a second for takeoffs only. "Mixed" operations refers to a policy allowing both landings and takeoffs on a runway.

the DELCAP model with estimates of the maximum sustainable throughput provided by the FAA. The DELCAP estimates are averages for 20 hours of operation for each combination of configuration, aircraft type mix, and operating strategy. Throughput for wide parallels with pure operations is calculated by adding the throughput for a single runway with only landings, to that for a single runway with only takeoffs. Throughput for wide parallels used in mixed operations is calculated as twice the throughput for a single runway serving alternating landings and takeoffs. Throughput for the ORD 4-parallels case is estimated as the sum of throughputs for a near-intersection ("V") configuration and a far intersection pair of runways, since this represents most nearly the actual operation of the facility.

Differences in throughput among airports depend in part on the aircraft type mix. The mix at JFK contains approximately 43 percent heavies, while that at the other airports is much lower. (At ORD, for instance, there are about 16 percent heavies.) For most of the airports of concern here, small aircraft account for a relatively small proportion of traffic (except for PHL where they account for about 40 percent).

The values calculated by DELCAP agree quite well with those provided by the FAA, generally within 10 percent. Additional checking of the internal logic of the model and sensitivity analyses reported in [2] have further established the validity and usefulness of DELCAP for use as an aid in setting controller performance standards.

Results of an exercise of the model using actual scheduled traffic data from LaGuardia Airport (LGA) for October 25, 1974, plus general aviation traffic generated in a stochastic manner are also reported in [2]. Simulated delays were compared with the "real" delays experienced by the scheduled aircraft--calculated as the difference between the actual arrival or departure and the corresponding scheduled time. This comparison proved on closer consideration to be improper, "real" delays necessarily being much greater than the simulated ones because they include the effects of interruptions or slow-ups attributable to other parts of the system (not in the LGA terminal area) and to other sources such as equipment- or crew-induced delays. Simulated delays did, however, agree quite well with the delay level reported by the facility, and the shapes of the distributions, "real" and simulated, were very similar. Included in [2] is a discussion of the data required to do a proper delay-figure validation, and suggested methods of acquiring these data.

3. CONCLUSION

The DELCAP simulation model is an existing analysis tool which has proven useful in aiding the setting of controller performance standards. It has been operated both on the UNIVAC 1108 at NBS and on a CDC computer chosen by the FAA, and has been run both by its designers at NBS and by FAA personnel. Its speed of operation (less than 15 seconds per run of a day's activity at a busy airport) and ease of operation, together with its demonstrated validity, make DELCAP a useful tool for analyzing airport capacity.

4. REFERENCES

1. Judith Gilsinn, with E. H. Short, W. A. Steele, D. Klavan, A Simulation Model for Estimating Airport Terminal Area Throughputs and Delays, NBS Report Number 10592, FAA Report Number FAA-RD 71-9, May 1971.

2. Judith F. Gilsinn, Validation of the DELCAP Airport Simulation Model, NBS Report Number NBSIR-75-783, FAA Report Number FAA-RD-75-154, July 1975.

3. Analysis of a Capacity Concept for Runway and Final-Approach Path Airspace, NBS Report Number 10111, FAA Report Number RD-69-47, November 1969.

4. A. J. Goldman and W. A. Steele with W. A. Horn, Continued Analyses of a Capacity Concept for Runway and Final- Approach Path Airspace, NBS Report Number 10589, April 1971.

5. W. A. Horn, Extension of A Capacity Concept to Dual-Use Runways and Multi-Runway Configurations, NBS Report Number 10593, 1971.

6. A. J. Goldman, A Capacity Concept for Runway and Final Approach Path Airspace, Navigation 17 pp. 253-259, 1970.

7. A. Blumstein, The Operations Capacity of a Runway used for Landings and Takeoffs, in Proc. Second Inter. Conf. on Operational Research, J. Banbury and J. Maitland (ed.), John Wiley and Sons, pp. 657-672, 1961.

8. R. M. Harris, Models for Runway Capacity Analysis, MITRE Corporation Technical Report Number MTR 4102, October 1969.