A Statistical Separation Standard and Risk-Throughput Modeling of the Aircraft Landing Process

A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy at George Mason University

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DEDICATION

I would like to dedicate my dissertation to independent thinkers, whose thoughts, research and words has been bringing wisdom to peace and human well-being. I shall dedicate the dissertation to those who have ever encouraged, invigorated or tried to improve Human Rights at GMU. The last, but not the least, I shall dedicate my dissertation to honesty, peace and freedom of speech without which no healthy and objective research can be maintained.

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LIST OF ABBRIVIATIONS

CDF cumulative distribution function
DTW Detroit metropolitan Wayne county airport
FAA Federal Aviation Administration
FAF final approach fix
GA go-around
IAD inter arrival distance
IAF initial approach fix
IAP instrument approach procedure
IAT inter arrival time to FAF
IFR instrument flight rule
IMC instrument meteorological condition
LTI landing time interval to the runway threshold
MAP missed approach point
PDF probability distribution function
ROT runway occupancy time
SRO simultaneous runway occupancy
TRACON terminal radar approach control
WV wake vortex
nmi nautical mile
s second

ABSTRACT

A STATISTICAL SEPARATION STANDARD AND RISK-THROUGHPUT MODELING OF THE AIRCRAFT LANDING PROCESS

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In the context of a high demand for runways as important scarce resources of the national air transportation system, this dissertation is concerned with the problem of determining the best separation between aircraft to maximize the *output* of the *landing system*. The risks of *wake vortex hazard* on the following aircraft and *simultaneous runway occupancy* shall be controlled. The following specific questions are addressed:

1. What are the stochastic characteristics of the aircraft landing process?
2. What parameters should a separation standard include?
3. How should the optimal levels of separation standard parameters be decided to maximize the system output?

The first question is answered by statistical analysis of aircraft landing track data using "multilateration surveillance system" at Detroit airport (DTW). We present probability distribution functions of Landing Time Intervals to the runway threshold, and aircraft Runway Occupancy Time, among other distributions. We suggest that the current

"minimum separation" standards for a given type of follow lead aircraft, e.g. a large aircraft following another large aircraft, (under Instrument Flight Rule) should be replaced by statistical separation standards (SSS). Our proposed standard, for a given type of follow-lead pair, specifies a target separation value, a lower specification limit, and a standard for the variance of the process.

The optimal level of target separation, which defines the optimal level of the system output, depends on the cost of avoiding the risks and the benefits gained from closer and more frequent landings. An operational procedure will be proposed to avoid the wake vortex hazard. We present optimization models to maximize the system output given cost and benefit factors. The models also provide a framework to estimate runway landing capacity (defined as average sustainable risk-free/safe landing) taking into account the uncertainty of the landing process. The capacity estimation is critical for planning and scheduling purposes. Estimated effects/benefits of reducing variance, of Landing Time Interval, on landing capacity are presented.

CHAPTER 6: CONCLUSION

In this dissertation, we studied the landing and approach process to a single independent runway which is solely used for landing operations. The goal is to take the most advantage of runways as a scarce and increasingly demanded resource of the air transportation network. Increasing utilization is achievable by reducing aircraft separation spacing; however, it has trade offs with risking landing safety and human lives. Through this research, we initiated several steps to manage this trade off and to maximize the utilization:

1. We analyzed stochastic properties of the landing process to obtain estimates for the PDF's of inter-arrival distances, landing-time intervals at FAF and runway threshold, and runway occupancy times. From the observed data, the frequency of simultaneous runway occupancy was on the order of 10^{-3}. These results were obtained through processing of multilateration surveillance system data at Detroit airport (DTW).
2. As separation standard parameters, we proposed a statistical separation standard, which includes a *target value* and a *lower control limit* for separation of a given type of aircraft pair. The proposed standard can reduce the variability of the landing separation. Such a standard has the possibility to lead to a quicker realization of safety degradation before observing a major incident. In addition, we demonstrated

how specifying different levels of target separations leads to a trade-off between risk and throughput.

3. These first steps formed the basic building blocks for a model to optimize throughput level without compromising safety, i.e. without increasing the risk. To maintain safety, we proposed a go-around procedure to avoid wake vortex incidents and to assure the landing safety. These go-around (or missed approach) procedures shall be enforced for the sake of safety.
4. Under the enforced go-around procedures, shortening the average separation spacing will increase the go-around rate. We suggested that despite the increased go-around rate, the overall landing throughput rate can still be increased. One optimization model developed to mimic this dynamic of the system. This model is solved for the peak period landing distributions of Detroit airport, and the results supported our hypothesis of increased throughput.
5. The aforementioned optimization model estimates *landing capacity* of the runway, with or, hypothetically, without the presence of wake vortex effect. The maximum achievable safe throughput for 3 nmi pairs, mainly large-large aircraft, is 39.4 per hour when wake vortex effect is ignored. This maximum reduces to 36.5 when 55 sec is considered as the safe wake vortex missed approach threshold. The difference between these estimates provides a logical framework to estimate the economic effect of wake vortex phenomenon in the system. Using these figures we roughly estimated the cost of WV phenomenon (for Detroit airport case assuming two landing runways and 10 hours of peak period per day) as about 10,600 landings of large aircraft per

year. This translates to WV cost of tens of millions of dollars per year in a moderately busy airport.

6. We hypothesized that maximizing the throughput (by adjusting the average separation spacing) does not necessarily assure the most economic use of the runway. Another model developed to mimic these economic dynamics of the approach operations accounting for the go-around cost (to all economic beneficiaries) and the befit of every successful landing (to all economic beneficiaries). System beneficiaries include airlines, passengers, airports, employees, etc. We showed that economically optimal level of operations depends on cost to benefit ratio rather than depending on specific values of go-around cost and successful landing benefit. This validated the hypothesis.
7. We extended the optimization models, which described in conclusions 5 and 6, to obtain the optimize level of landing operations for a given landing fleet mix.
8. We discussed and demonstrated the effect of reducing separation variance on the landing risks, go-around rate, and on the optimal level of landing operations (or throughputs).

We illustrated the methodologies for specific pairs of follow-lead aircraft (using landing distributions of Detroit airport) without loss of generality. Numerical results further validated the methodologies.

CURRICULUM VITAE

Babak Ghalebsaz Jeddi received his BS degree in Industrial Engineering (IE) in 1994. While in undergraduate program, he co-founded and established the first technical journal of Industrial Engineering and Operations Research (OR) in Iran, which has been managed and operated by students. After obtaining his degree in IE, he worked as a Project Control expert, Strategic Planning expert and Strategic Planning Supervisor while continuing his graduate studies. In addition to IE and OR, his academic studies include courses in Master of Business Administration. He has done consulting in the areas of quality and productivity engineering, including ISO 2000 quality standards. His research interests are in uncertainty, probabilistic and optimization modeling of service and manufacturing systems. He considers economic aspects as critical part of his pragmatic research. His papers and innovative ideas have been awarded in international conferences.