Proceedings of the 2024 Winter Simulation Conference
H. Lam, E. Azar, D. Batur, S. Gao, W. Xie, S. R. Hunter, and M. D. Rossetti, eds.

SIMULATION-BASED AIRPORT RUNWAY PERFORMANCE OPTIMIZATION BY MODELING MULTIPLE CONTROL TOWER OPERATIONS: A CASE STUDY

Ahmad Attar[1,3], Mahdi Babaee[2], Sadigh Raissi[2], and Majid Nojavan[2]

[1]Dep. of Engineering, Faculty of Environment, Science and Economy, University of Exeter, Exeter, UK
[2]Department of Industrial Engineering, Islamic Azad University, South Tehran Branch, Tehran, IRAN
[3]Exeter Digital Enterprise Systems (ExDES) Lab., University of Exeter, Exeter, UK

ABSTRACT

The substantial growth in the overall demand for air transportation makes the capacity of existing airports a key constraint for major cities in developing countries. One of any airport's main building blocks is its control tower, whose decisions influence the airport system's throughput and waiting times, particularly for civil purposes. This study investigates several operations and decisions involved in the landing and takeoff of airplanes. What makes the system more complex is the different time requirements for safely admitting various sizes of aircraft. This research develops a novel digital twin using discrete event simulation to study the outcome of different applicable expansion scenarios in the presence of such complex, realistic decisions. The study is applied to an international civil airport in the Middle East, yielding a substantial overall improvement in the realized runway capacity and a significant reduction in the aircraft waiting time.

1 INTRODUCTION

Airports are complex service providers in the transportation industry and one of the main infrastructures of any city in today's world. Airports' runway optimization is an inevitable challenge for policymakers and local governments. Congestion, delay, and increased passenger waiting times are among the possible consequences of the capacity imbalance in these facilities. Viewing airports as a network further highlights the importance of avoiding such delay propagations (Wong and Tsai 2012). Acting as the airport's brain, control towers coordinate aircraft movements anywhere within its airspace. Here, the runway is the key asset that is very expensive to build, and thus it is vital to optimize the decisions made by the tower and airport management to realize the maximum possible ratio of the nominal runway capacity. Due to the dynamic nature of such a decision system, numerous capacity approximation techniques were introduced with some known inaccuracy (Ashford et al. 2011).

The discrete event simulation (DES) has been successfully used in various industries to address realistic complexities while maintaining acceptable KPI estimation accuracy (Attar et al. 2015, 2016, 2023). Therefore, this study proposes a DES model for civil airports with a special focus on realistic representation of the guidelines used by the control tower, both for landing planes and departing ones. As seen in Figure 1, since the airplane enters the airspace of the airport, it goes through various events. First, the plane has to stay in an aerial queue (i.e., holding stack) and wait for the tower's approach permission. Once permission is granted, the plane enters the approach gate, gliding to the runway. To grant this permission, control towers must consider a number of factors, including weather and the specifications of the aircrafts that are using the glide path together with their runway time (ROT), and it should calculate the minimum time separation (MTS) between aircrafts (Horonjeff et al. 2010). After runway, the plane uses taxiways to get to the apron area. Here, the taxiing time (TOT) is estimated based on the airport layout. Un-boarding, fueling, boarding, and maintenance tasks, all take place in the apron. When ready for departure, the plane is to receive authorization to enter a queue in the taxiway, waiting for final takeoff permission. Eventually, the use of the runway for departure concludes the airplane's visit to this airport.

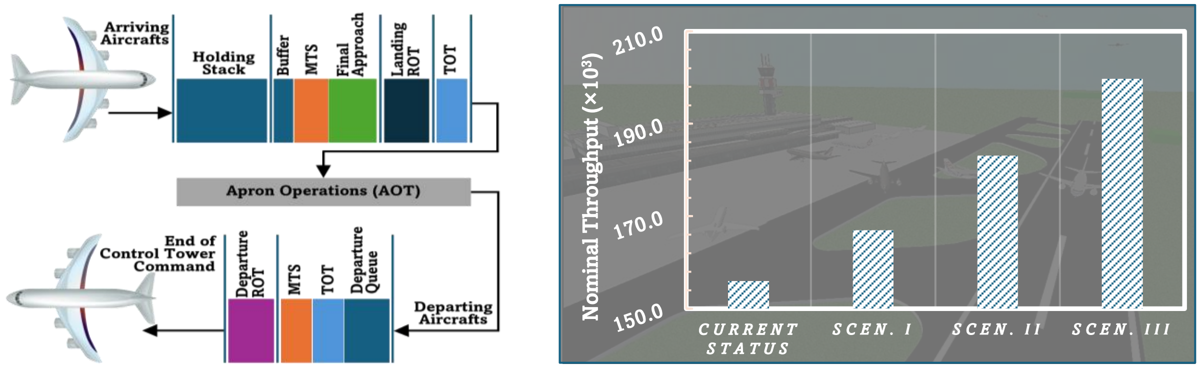

Figure 1: The main process sequence of airside operations (left), and performance of scenarios (right).

2 SIMULATION MODEL AND SCENARIOS

The occurrence of events in the described system follows non-exponential distributions (e.g., Weibull, Lognormal, Normal), for which DES has already been shown to be superior to the traditional modeling techniques (Attar et al. 2015, 2017). The model was developed using Enterprise Dynamics software, in which an advanced 3D representation was also created (see Figure 1). The model is validated using one year of historical data from this airport considering real flight schedules using a set of statistical hypothesis tests. With the *p*-values of the tests being in the range [0.4, 0.9], the model is statistically approved for the optimization phase of the project. Based on our observations, we identified that the apron operation time (i.e., AOT) contributes the most to the overall time spent by the plane in this airport. Thus, by consulting the industrial partners of the project, we define three potential improvement scenarios that incorporate: (i) adding an apron operation team; (ii) adding two operational parking locations in the apron area; and (iii) considering scenarios i and ii simultaneously. Figure 1 illustrates the system throughput for these scenarios.

3 CONCLUDING REMARKS

The results of our scenarios outperformed the existing runway state of the system by up to 28%. Our analysis revealed that the third scenario offers the highest improvement in runway throughput, while the second scenario is the most cost-efficient option. This study and its scenarios highlighted the capability of DES-based methods for airport optimizations. With its negligible run-time (~20s), this model has great potential as a near-real-time twin of such a system. Regarding the considerable similarities between our case and other airports, we expect the achieved results to provide insights for future airport optimization studies. Based on our experience in other projects, we can claim that, despite its complexities, the cost of acquiring such a twin for the airport is not significantly higher than that of other transportation systems.

REFERENCES

Ashford, N. J., S. A. Mumayiz, and P. H. Wright. 2011. *Airport Engineering*. 4th ed. New York: John Wiley & Sons.

Attar, A., Y. Jin, M. Luis, S. Zhong, and V. I. Sucala. 2023. "Simulation-Based Analyses and Improvements of the Smart Line Management System in Canned Beverage Industry: A Case Study in Europe". In *2023 Winter Simulation Conference (WSC)*, 2124-2135 https://doi.org/10.1109/WSC60868.2023.10407288.

Attar, A., S. Raissi, and K. Khalili-Damghani. 2015. "Multi-Objective Reliability-Redundancy Allocation for Non-Exponential Multi-State Repairable Components". In *11th International Conference of Industrial Engineering - IIEC2015*, January 7th-8th, Tehran, Iran, 1–8 https://doi.org/10.31224/3746.

Attar, A., S. Raissi, and K. Khalili-Damghani. 2016. "Simulation–optimization approach for a continuous-review, base-stock inventory model with general compound demands, random lead times, and lost sales". *Simulation* 92(6):547-564.

Attar, A., S. Raissi, and K. Khalili-Damghani. 2017. "A simulation-based optimization approach for free distributed repairable multi-state availability-redundancy allocation problems". *Reliability Engineering & System Safety* 157:177-191.

Horonjeff, R., F. McKelvey, W. Sproule, and S. Young. 2010. *Planning and design of airports*. 5th ed. New York: McGraw-Hill.

Wong, J. T. and S. C. Tsai. 2012. "A survival model for flight delay propagation". *Air Transport Management*, 23:5-11.