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Scheduling Aircraft Ground Handling Operations Under Uncertainty Using Critical Path Analysis and Monte Carlo Simulation:
Survey and Research Directions

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ABSTRACT

Aircraft ground handling is an integral part of airline operations. Although ground handling operations usually are straightforward, it could be very complicated in certain situations, such as troubling cargo loading and unloading incidents, weather conditions or improper use of equipment and breakdowns. Ground handlers need to orchestrate a number of activities within a confined area around airplane in a short period of time. Punctuality is important for airlines and resulting increased efficiencies. In this article, scheduling aircraft ground handling operations with uncertain durations using the critical path analysis and Monte Carlo simulation is considered with the aim of improving aircraft ground services during the turnaround. Having an accurate estimate of aircraft turnaround time considering its type and load, the recourses would be assigned to the ground operations more efficiently. A case study of a long-range wide-body twin-engine jet aircraft is discussed in detail. The results indicate that the proposed method gives improved scheduling relative to the routines observed at a hub airport.

KEYWORDS

Aircraft Ground Handling, Airport, Critical Path Analysis, Monte Carlo Simulation, Scheduling, Uncertainty

INTRODUCTION

Aircraft ground handling represents a crucial process among airport activities as it affects directly airline performance also passengers' service quality perception. Ground handling addresses a number of operations requirements of an aircraft between the time it arrives at a terminal gate of an airport and the time it departs on its next flight. Ground handlers need to orchestrate a number of activities, such as baggage handling, cabin servicing, catering, aircraft fueling, maintenance and so on. Indeed, safety, accuracy, and speed are important in ground handling operations for a minimum turnaround and resulting increased efficiencies. Due to the practical importance of the subject many books and articles have been published on its various aspects (Atkin, 2013; Bazargan, 2016). The 32nd International Air Transport Association (IATA) Ground Handling Conference took place in Madrid, Spain (IGHC, 2019). However, the majority of the research focused on the classical airport airside optimisation problems, such as gate assignment (Dijk et al., 2018; Chao et al., 2019), aircraft ground movement (Stergianos et al., 2016; Brownlee et al., 2018), and runway sequencing (Guépet et al., 2017; Solak et al., 2018). In this paper, scheduling aircraft ground handling operations with uncertain durations using the critical path analysis and Monte Carlo simulation is considered with the aim of improving aircraft ground services during the turnaround in general, and equipment availability, and the crew

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assignment in particular. A case study of a hub airport on a long-range wide-body twin-engine jet aircraft is discussed in detail.

There has been considerable research devoted to aircraft ground operations. Kuster and Jannach (2006) conducted a research in collaboration with Deutsche Lufthansa AG on handling airport ground processes based on the resource-constrained project scheduling for real-time decision support in the disruption management of the aircraft turnaround. Abdelghany et al. (2006) developed an activity selection algorithm for assigning the baggage of departing flights to available piers in the baggage-handling facility of a major US air-carrier hub. Bazargan (2007) proposed a particular mixed integer linear programming model for minimising the passenger interferences in boarding on a single-aisle aircraft considering various strategies and accommodating neighboring passengers boarding together. Nugroho et al. (2012) applied Lean solutions approach to the aircraft ground handling at PT Garuda Indonesia for categorising the ground handling operations into value-added activity, avoidable non-value-added activity, and unavoidable non-value added activity which resulted some suggestions for performance improvement. Burghouwt et al. (2014) investigated the impact of European Parliament amended airport ground handling regulation for competition on the ground handling market, at Amsterdam Schiphol Airport, and concluded that an open market will result lower ground handling costs for airlines but unlikely any serious market failure for the airports. Gok (2014) proposed a mixed integer linear programming model minimising the turnaround of a short- to medium-range, narrow-body with bulk cargo holds, twin-engine jet aircraft of a Turkish low-cost airline, and discussed the critical path in certain scenarios. Fitouri-Trabelsi et al. (2015) proposed a hierarchical approach for Palma de Mallorca Airport ground handling resources management considering both on time and delayed inbound and outbound flights. Kabongo et al. (2016) developed a forward multi-agent planning approach to airport ground handling management under a unified framework. Kierzkowski and Kisiel (2017) simulated the aircraft ground handling operations at Wrocław Airport on a category B aircraft according to International Civil Aviation Organization (ICAO) in order to evaluate the operational performance. Schmidt (2017) provides an introduction to aircraft ground operations focusing on the aircraft turnaround and passenger processes, including current challenges for airline operators, airport capacity constraints, and schedule disruptions. Studic et al. (2017) considered a systemic hybrid approach to safety risk management of ground handling operations based on a combination of functional resonance analysis, grounded theory, template analysis and goals-means task analysis. Frey et al. (2017) developed a hybrid metaheuristic based on a combination of reedy randomized adaptive search procedures with a guided local search and path-relinking, for scheduling inbound baggage handling at the baggage carousels of Munich's Franz Josef Strauss Airport. Malandri et al. (2018) considered a detailed discrete event model of inbound baggage handling at a large regional Italian airport in order to identify bottlenecks, critical operations, and study alternative scenarios in different situations for dynamic allocation of resources and personnel. Senvar and Akburak (2019) analysed improvements for the non-value adding processes in airline ground handling operations using lean six sigma methodology. Zeng et al. (2019) developed a branch-and-price approach to a hierarchical skills formulation for airport ground staff, based on the classical tour scheduling problem, minimising workforce mix that satisfies a target coverage rate with respect to a given demand profile, thereby staff with higher level skills is permitted to cover demands of lower levels. Tabares and Mora-Camino (2019) investigated the challenges of an automated aircraft ground handling operations, such as docking of ground support equipment to aircraft, and autonomous vehicles moving around the aircraft.

This paper consists of two main parts, the first part focuses on description of scheduling aircraft ground handling operations, and the second part demonstrates experimental results of the proposed critical path analysis and Monte Carlo simulation. The concluding remarks contain some suggestions for further research.

GROUND HANDLING OPERATIONS

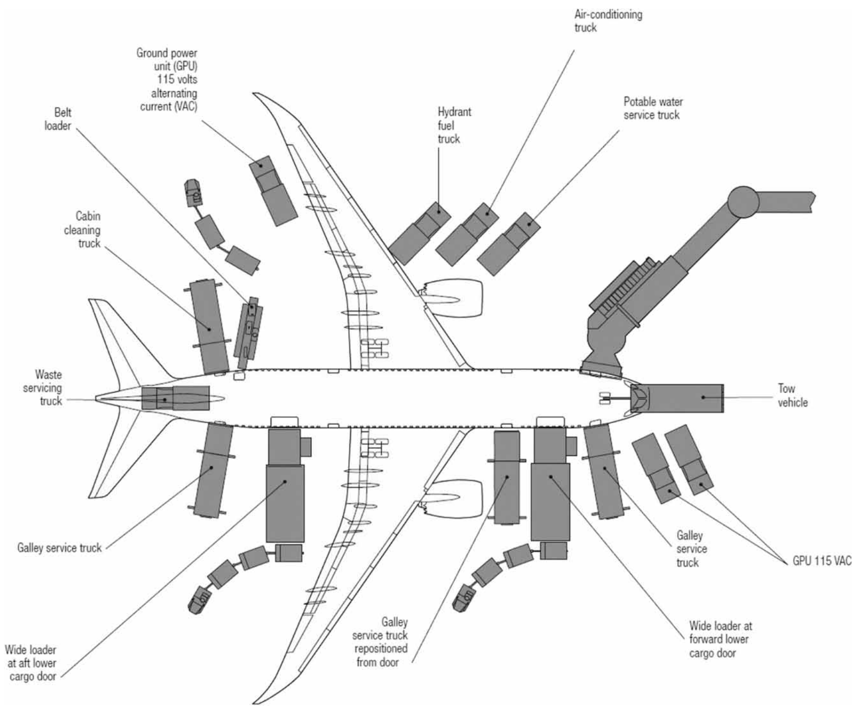
In aviation, ground operations define all aspects of aircraft handling at airports. An airport is an aerodrome with extended facilities, installations, and equipment, including terminals, hangers, aprons, maneuvering area, and air traffic control towers. An airport terminal is a building where passengers transfer between ground transportation for boarding and disembarking from an aircraft, often includes facilities such as restaurants, stores, and lounges. A hangar at an airport is a building structure to hold aircraft usually for maintenance and repairment. A runway is a defined rectangular area on the aerodrome for landing and takeoff of aircraft. A taxiway is a path for aircraft intended to provide a link between one part of the aerodrome to another, in particular connecting runways with aprons, hangars, and other facilities. The airport aprons or ramps (the terms 'ramp' and 'apron' are often used interchangeably) are congested areas of an airport where aircrafts are parked between flights for passenger boarding and disembarking, cargo loading and unloading, aircraft cabin services, and maintenance. A variety of aircraft ground handling operations is listed below:

- Air conditioning
- Aircraft cabin cleaning
- Aircraft wheel chocks placement
- Air start
- Cargo handling
- Catering and cabin food services
- Deicing
- Gate checked luggage, strollers, and wheelchairs
- Ground power
- Lavatory drainage
- Luggage handling
- Marshalling the aircraft into and out of ramp
- Mechanical maintenance
- Passenger boarding bridge positioning
- Pushback
- Refueling
- Safety cones placement around aircraft
- Towing
- Water cartage

GROUND SUPPORT EQUIPMENT

Ground support equipment (GSE) is primarily used to service aircraft during the turnaround, usually on the apron or aircraft hangar maintenance. There is a diversity of GSE types at airports (NASEM, 2012), amongst aircraft tow or pushback tugs, baggage tractors, belt loaders, cargo loaders, power units, air conditioning units, fuel trucks, water trucks, lavatory trucks, deicing trucks, and catering trucks. A brief description of those equipment that will be referred later in this paper are provided as follows. Container loaders are used for loading and unloading baggage and cargo containers and pallets from the aircraft. Belt loaders are used for loading and unloading of baggage from the aircraft bulk cargo hold. A ground power unit is used to supply electricity to an airplane while parked on the ground. Air conditioning unit is used to provide heated or cooled air to an airplane while parked on the ground. Passenger boarding bridge is an enclosed, elevated and movable corridor which extends from an airport terminal gate to an airplane. Aircraft wheel chocks are wedge-shaped durable solid material placed closely against an airplane's wheels to prevent accidental movement. Figure 1 shows a typical ground servicing arrangement for a Boeing 787, a long-range wide-body twin-engine jet aircraft.

Figure 1. A typical ground servicing arrangement for a Boeing wide-body jet aircraft



THE CRITICAL PATH ANALYSIS

Two of the most commonly used and closely related scheduling techniques in project management, CPM (critical path method) and PERT (program evaluation and review technique), are considered for scheduling aircraft ground handling operations. The original versions of these techniques had some differences but have been gradually merged over time on which even the terms CPM and PERT often used interchangeably (Hillier & Lieberman, 2015). In fact, today's project management software packages, such as Microsoft Project (commonly called MS Project) include all the important features from both techniques.

The ground operations for arrivals starts from the time that aircraft is stopped at the terminal gate. Table 1 exemplifies a general list of various ground handling operations requirement in arrivals for a long-range wide-body twin-engine jet airliner, with precedence relationships, and estimated durations (in seconds). It should be noted that the optimistic estimate (o), the most likely estimate (m), and the pessimistic estimate (p) reported in the table are discussed further in the experimental results section.

Activity Description

A. Aircraft wheel chocks placement;
B. Safety cones placement around aircraft;
C. Visual and tactile check of aircraft surfaces;
D. Position passenger bridge;
E. Provide ground power to the airplane;
F. Provide air-conditioning to the airplane;
G. Gate luggage, strollers, and wheelchairs;
H. Cargo and luggage unloading.

The PERT estimation formulae are based on a transformation of the beta distribution (Baker & Trietsch, 2018). The activity-on-node (AON) network is used to represent the ground handling operations for aircraft arrivals, where each activity is shown by a node and the arcs depict the precedence relationships between the activities. Figure 2 illustrates the ground operations network according to each activity and its immediate predecessors.

Because activity 'A' has no immediate predecessors, there is an arc leading from the start node to this activity. Similarly, since activities 'E', 'F', 'G', and 'H' have no immediate successors, arcs lead from these activities to the finish node. The estimated overall duration equals the length of the longest path through the network (Lester, 2017). This longest path is called the critical path. Thus, it is easy to observe that the critical path for the network is A-B-H with the duration 40+70+1800 = 1910 seconds. Figure 3 shows the critical path of the ground handling operations schedule.

Table 1. Activity information of aircraft ground handling for arrivals

Activity	Immediate Predecessors	Optimistic Estimate	Most Likely Estimate	Pessimistic Estimate	Mean	Variance
		o	m	p	$\mu = \frac{o+4m+p}{6}$	$\sigma^2 = \left(\frac{p-o}{6}\right)^2$
A	-	35	40	55	41.67	100
B	A	60	70	80	70	100
C	A	45	50	65	51.67	100
D	A	90	105	300	135	11025
E	D	70	90	120	91.67	625
F	B	50	60	75	60.83	156.25
G	B, D	120	240	360	240	14400
H	B, C	1500	1800	2400	1850	202500

m: The most likely estimate of the duration.
o: Optimistic estimate of the duration under the most favorable conditions.
p: Pessimistic estimate of the duration under the most unfavorable conditions.
μ : The mean of the durations (through the PERT estimation formula).
σ^2 : Variance of the durations (through the PERT estimation formula).

Figure 2. Activity-on-node network diagram of aircraft ground handling for arrivals

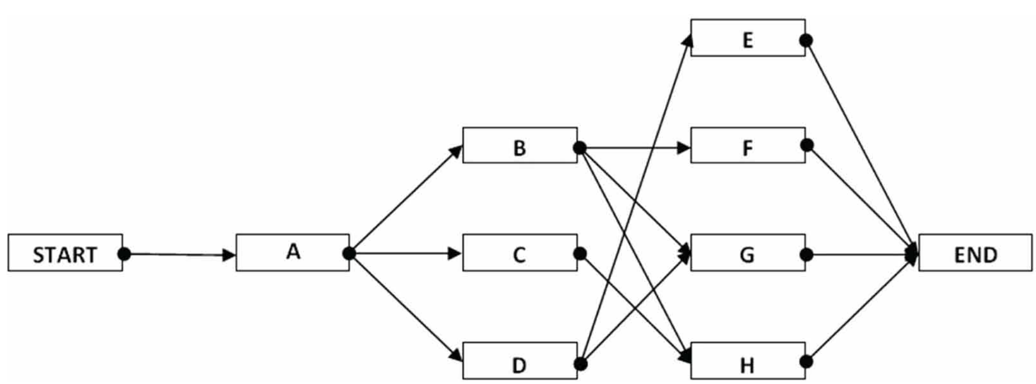
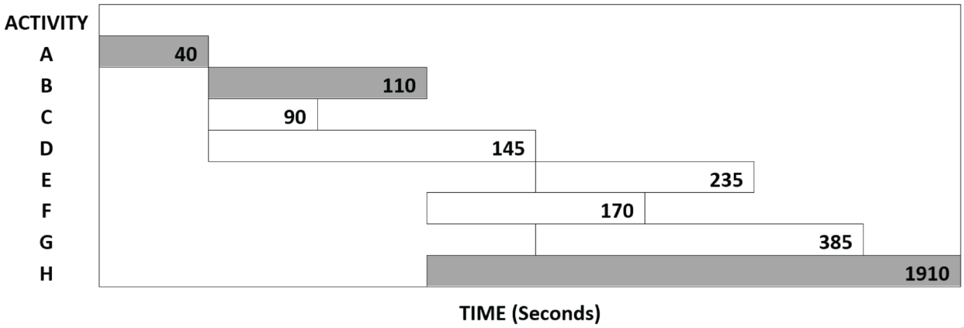


Figure 3. Gantt chart of the aircraft ground handling operations schedule



MONTE CARLO SIMULATION

In reality, the duration of each activity in aircraft ground handling is a random variable having a probability distribution. The basic idea behind Monte Carlo simulation is that the results are computed based on iterative random sampling trials and statistical analysis. An early concept of using Monte Carlo method for solving PERT problems was discussed in Van Slyke (1963).

Pseudo-random number sampling algorithms are used to transform uniformly distributed pseudo-random numbers into numbers that are distributed according to a given probability distribution. The normal distribution is a very common continuous probability distribution to represent random variables where distributions are not known. In this experiment, the values of a normal variable are simulated having the mean μ and the standard deviation σ through the PERT estimation formulae. The confidence level is set prior to examining the data. The 95% confidence level is used for the CPM duration as follows:

$$\overline{x} \pm 1.96 \frac{\sigma}{\sqrt{n}}$$

where, $\overline{x}$ is the sample mean, σ is the sample standard deviation, and n is the number of simulation trials or iterations. It is easy to observe that increasing the number of simulation iterations decreases the width of the confidence interval.

EXPERIMENTAL RESULTS

The data was collected partly by interviewing experts also observing of each operation of randomly selected arrivals for a Boeing 787, a long-range wide-body twin-engine jet airliner (applicable to 777 and 767 series), and recording durations (see Table 1).

The data collected does not necessarily reflect any particular firm, airport or airline operations. It is assumed that each activity has all the resources available at the beginning, including labour, equipment, and materials.

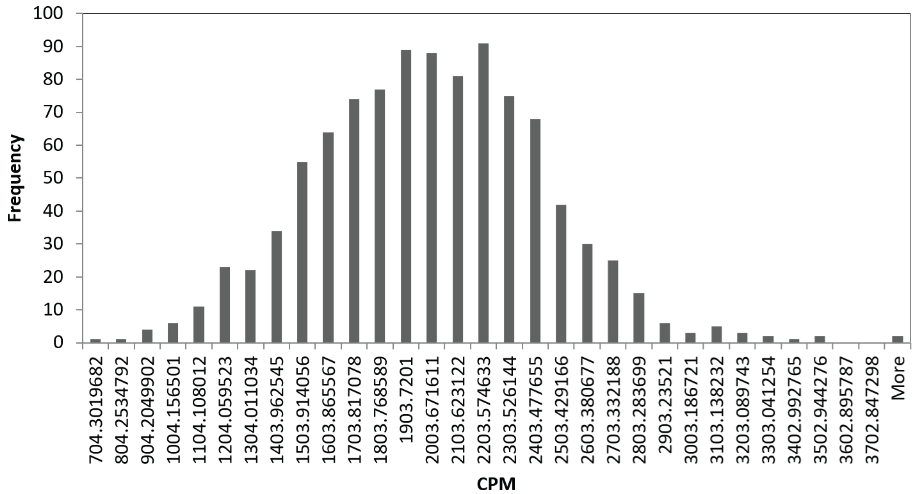
The Monte Carlo simulation output with 95% confidence level for $n = 1000$ trials, indicates that the mean CPM duration is between 1950.55 $\pm$ 27.34. Table 2 tabulates the simulation experiments.

Figure 4 shows the distribution of the CPM values as a histogram. It is easy to observe that the CPM values have a symmetric distribution which the mean is approximately equal to the median.

Table 2. The Monte Carlo simulation of the CPM duration

Minimum	Maximum	σ	$\overline{x}$	Median	Mode
704.30	3802.80	441.05	1950.55	1948.12	1637.16

Figure 4. The distribution of CPM values



CONCLUSION

In this paper, scheduling aircraft ground handling operations with uncertain durations using the critical path analysis and Monte Carlo simulation has been considered with the aim of improving aircraft ground services during the turnaround in general, and equipment availability, and the crew assignment in particular. Having accurately estimating of aircraft turnaround time considering its type and load, the recourses would be assigned to the ground operations more efficiently, reducing the idle times, and improving the ground support equipment availability at the airport ramp. A case study of a long-range wide-body twin-engine jet aircraft has been discussed. The proposed critical path analysis has the potential for application to other similar ground handling operations, such as the aircraft departures, the aircraft tow operations, and the aircraft cabin service and cleaning operations. A major challenge would be also to determine how the resources should be allocated to each operation.

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