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A Discrete Event Simulation Model for Inbound Baggage Handling

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Abstract

Inbound baggage handling represents a crucial process among airport terminal's activities as it affects directly airport performance and passengers' service quality perception. It is important to make the inbound process as efficient as possible and to explore solutions to enhance the performance of the system, thus reducing passengers' waiting time at baggage carousels. The aim of this paper is to present a detailed discrete event model of inbound baggage handling at a large regional Italian airport. The simulation model allows to fully understand the whole process and to identify bottlenecks and critical operations. The model is validated by comparing the simulation results with real data.

Keywords: baggage handling; airport; discrete event simulation; airside operations.

1. Introduction, background and methodological approach

Baggage handling represents a crucial process among airport terminal's activities as it affects directly airport performance: badly managed baggage handling may cause serious passengers dissatisfaction as well as airline disappointment, because damaged, delayed and lost luggage also damage the airline's public image (Cavada et al., 2017). Besides, inefficient baggage handling may cause turnaround delays resulting in considerable additional operating expenses for the airport. Serious problems might arise especially during peak periods when a large amount of baggage must be contemporarily processed, sometimes beyond the system capacity. Moreover, because of the dramatic growth of air passenger traffic and the consequent increase in luggage throughput (Danesi et al., 2017),

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Baggage Handling Systems (BHS) are often overloaded, demanding for infrastructure expansion of terminal facilities and, thus, remarkable costs.

Baggage handling is the process that goes from the moment passengers drop their luggage at check-in desks until they collect them back in the baggage claim area of the destination airport. In the meantime, three major sub-processes take place (Ashford et al., 1997): transport from the check-in area to departure gates (outbound baggage), displacement from one gate to another (transfer baggage) and transport from aircraft to the baggage-claim area (inbound baggage). The whole process is shown in Figure 1.

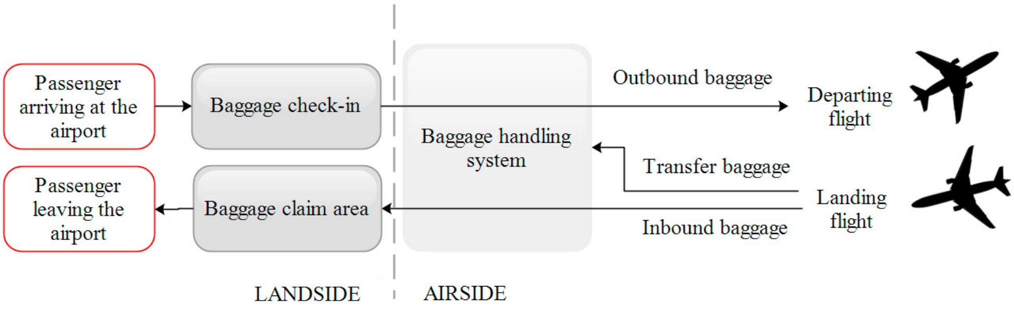

Figure 1. Outbound, Transfer and Inbound baggage handling processes.

Outbound baggage handling includes all operations necessary to transport departing baggage from check-in desks to a departing flight. IATA Resolution 753 on baggage tracking - effective since June 2018 – forces airlines/handling agencies to track each baggage at four key points along the journey (check-in, load, transfer, arrival) and share the tracking information with code-sharers to reduce baggage mishandling. While passengers undertake their path through security control to the gate and onboard the flight, each baggage checked is assigned an identifying bar code which includes information about the flight (i.e. its itinerary), then it is placed on the check-in conveyor belt and routed to its destination accordingly to the barcode. Similarly, transfer baggage unloaded from an arriving flight are placed on the conveyor belt and sent to their assigned output station, from where they are re-loaded on the departing aircraft. Security screening is performed in order to make sure that prohibited items are not loaded onto the aircraft: the baggage goes through the x-ray machine and, if any potential threat is identified, the bag is sent to a successive security screening level; otherwise, it is delivered to the associated output pier from which it is loaded on the corresponding departing flight. Upon arrival at destination airport, inbound luggage is unloaded and transported to the baggage claim area, where it is reunited with its owner. Inbound baggage processing is crucial as it represents the final step in passengers' journey and thus the last wait they have to face. According to a recent survey (SITA, 2017), bag collection is the step in which passengers perceive waiting time most negatively among all stages of the trip. SITA survey reveals that the majority of passengers are satisfied with waiting times shorter than 10 minutes, while Correia and Wirasinghe (2010) revealed that passengers are disappointed if waiting time exceeds 20 minutes. Passengers' waiting time importance at baggage claim carousels is confirmed also by the survey conducted at Calgary International Airport (Martel and Seneviratne, 1995).

While infrastructural resources are planned and operated by airport operators, ground handling as well as check-in services and baggage handling are performed by handling agency's or sub-contractor's operators, which are in charge of baggage handling as well as aircraft loading and unloading. Finally, decisions from air traffic control affect the flights' arrival and departure times.

An efficient baggage handling may encourage both passengers to reuse the airport in the future and new airlines to serve the terminal. An enhanced BHS could also lead to use resources as efficiently as possible and thus contain labor costs. Therefore, solutions to enhance BHS's efficiency and operational performance are of great concern to airport operators. Toward this goal, it is crucial to deeply investigate each step of the inbound handling process, in order to identify bottlenecks and services which can be optimized.

In the last decades, quite some work by the research community has been dedicated to optimizing baggage handling processes at airports. In particular, a number of studies focus on outbound baggage and they are mainly deterministic optimization models. Among these, Abdelghany et al. (2006) investigate the problem of scheduling outbound luggage for a major US-carrier at one of its hubs. Frey et al. (2010) analyze the same issue at international airports, proposing a heuristic decomposition to model the problem. Similarly, Barth and Pisinger (2012) address the same problem of assigning baggage stations to outgoing flights and test their solution on real world data from Frankfurt Airport. Quite different is the study conducted by Savrasovs et al. (2010), in which a discrete-event simulation model of Riga's outbound baggage handling system is simulated with ExtendSim.

Transfer baggage handling is a crucial activity, as mishandling leads to considerable costs for airports (SITA, 2017). However, only few works addressing this problem can be found in literature. For example, Barth (2012) modeled transfer baggage handling system at Frankfurt Airport taking into account uncertainty in input data.

As far as inbound baggage is concerned, mostly deterministic queuing models were developed to predict the arrival of both passengers and bags to the baggage claim area. In Horonjeff (1969) and Browne et al. (1970) works passengers and baggage arrivals are considered as independent events and the both queues are computed. Several recent works tackled the problem of assigning incoming baggage to carousels (Delonge, 2012). For example, Frey et al. (2017) propose a mathematical model to optimize inbound baggage handling process and tested it at Munich's Franz and Josef Strauss Airport, showing a reduction of 11% for passengers' waiting times and of 38% of baggage peaks at the carousel. However, inbound handling simulation has been performed only in a very limited number of works. A computer simulation of airport baggage operations at Terminal 5 of London Heathrow airport has been presented in McKenzie (2003). Brunetta et al. (1999) presented a model implemented in SIMSCRIPT for the evaluation of an airport terminal including BHS facilities. Cavada et al. (2017) built an integrated simulation model of the whole baggage handling system of Santiago International Airport in Chile, which includes also the inbound process.

The aim of this work is to build a discrete event simulation model of the inbound baggage handling process for both domestic and international arrivals. The model allows to analyse the basic system operations under normal conditions and to determine some performance indicators, e.g. the total processing time. The model is then validated with observed data within the same period of analysis allowing to (i) identify discrepancies between simulated and observed scenario, (ii) investigate the causes, and (iii) identify potential bottlenecks and their impact on the system. Moreover, by changing variables in the simulation (i.e. adding traffic or shifting activities forward or backwards), it is possible to predict the behavior of the system under alternative conditions.

The methodology adopted to build this study is focused on the description of baggage inbound handling process and its representation into a simulation model thanks to Arena, a discrete event simulation software developed by Rockwell Automation. The entities processed are bags stored inside the aircraft holds while the resources processing the entities are (1) Ramp team (operators in charge of ground handling operations for a specific airline), (2) Driver of the baggage tractor, and (3) Delivery conveyor belt (it is modelled as a resource in order to obtain statistics about the baggage processing). Bags enter the system in correspondence of the aircraft on-block time. The number of baggage and passengers for each flight simulated are stored in the airport's database. Then, entities are assigned a series of attributes such as the percentage of crew luggage or the percentage of business/first class passengers with bag (whose delivery is prioritized) on the total. The number of crew bags for each flight is computed considering one crew member for every 50 passengers on-board. Where airline policies foresee crew baggage to be delivered immediately at the stand, these entities immediately exit the system. Once the unloading operation is completed, baggage follows two different paths depending on the origin of the flight (Schengen or non-Schengen). As for non-Schengen baggage, if in-bound security control is performed (i.e. baggage on flights carrying authority figures or originating from countries under surveillance for security reasons are scanned under the x-ray machine as it happens for baggage in departure), this operation is modelled with an additional delay of 30 minutes prior the baggage is delivered to non-Schengen baggage claim carousels. The moment when the last baggage comes returned to the respective owner constitutes the end of the whole baggage delivery process. To this purpose, a data collection campaign has been carried out directly on the field at an Italian large-regional airport (Bologna "G. Marconi Airport") during the winter operation schedule, with particular reference to the Christmas holiday period where a relevant peak of traffic is concentrated. Data collected serve both as input data for the model and as baseline to validate the output.

The remaining of the paper is structured as follows. In Section 2, a detailed overview of the baggage handling process is provided and the representative parameters are set and listed. Section 3 describes the architecture of the simulation model and how it is fit to the case study of Bologna Airport. Results are shown and discussed in Section 4. Section 5 concludes the paper with a short summary of the results and outlook for future research.

The work has a twofold relevance: (1) to help the airport operator to obtain better control of baggage handling, understanding the intrinsic processes and highlighting critical processes; (2) to allow to test alternative scenarios to obtain a more robust and efficient planning, optimizing processes and increase passengers' satisfaction, while avoiding expensive infrastructural works.

2. Inbound baggage handling: description of the process

In the following, a detailed description of the inbound baggage handling is provided, from the airplane's arrival to the baggage claim area. The inbound baggage handling process starts when the aircraft reaches the parking stand after landing and the chocks are set: this moment is denoted as *on-block time* (*BT*). The parking position can be either located in front of the terminal or on a remote position on the apron. Stand allocation, which is responsibility of the airport operator, represents the initial operation of the process of baggage delivery and it plays a crucial role from an operational point of view. After chocks are placed, passengers disembarking operations begins and simultaneously cargo and baggage are unloaded. Passengers and bags proceed along different paths, which will converge in the baggage claim area (see Figure 2). In this area baggage claim carousels, which represent the final point of passengers and bags paths, are grouped and some displays indicate which carousel is assigned to each arriving flight. The assignment of baggage claim carousels to each flight is, as in the case of stand allocation, airport operator's responsibility. Passengers walk to the baggage claim carousel assigned to their flight through a predefined route which depends on the parking position and on the origin of the flight: while domestic passengers can go directly to the baggage claim area, those from international flights must undergo passport controls. Once at carousels, they wait until they can collect their bags and leave the terminal. Figure 2 below shows the baggage inbound process from the airplane to the baggage claim carousel, with the graphical indication of the actors involved. The activities performed by the handling personnel, as shown in the figure, are central in the whole process, as eventual delays are in fact directly attributable to them.

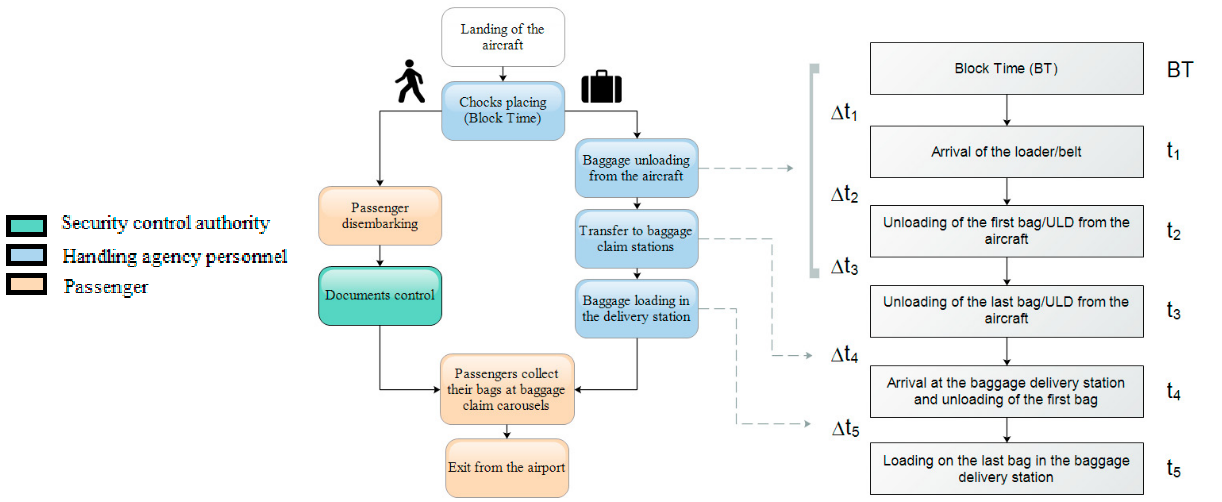

Figure 2. Inbound baggage handling process.

In the first phase, bags are unloaded from the aircraft. Depending on the airline and type of aircraft, bags may be stored without or with containers. Storing baggage without containers is known as "*bulk loading*" and this happens mainly for regional jets and older aircraft. Bags are unloaded individually by ramp agents with the aid of belt-loaders eventually equipped with a Rollertrack Conveyor device to reduce efforts from the ramp agents inside the aircraft hold and speed up the process. The loader is positioned at the door sill of the aircraft hold and inclined by means of a pneumatic system to reach the hold which is usually situated at a height between 1 and 2.8 m from the ground. Loose baggage are then put in open containers (also known as carts or loose baggage dollies) and transported to the belts. Instead, for bigger and newer aircraft, baggage is mostly stowed in containers called Unit Load Devices (*ULD*). The use of *ULD*s allows to load large volumes into a single unit, accelerating the unloading processes. Furthermore, each unit is assigned a code that identifies its content. *ULD*s are unloaded from the airplane and placed on dollies, which are standard sized flatbed trolleys or platform equipped with wheels and roller bars. In both cases, after the belt/loader is placed under the hold and doors are opened (t_1), the first bag/ULD is unloaded at t_2. The first phase ends when the last bag is put on dollies/containers (t_3). Then, containers are carried by a baggage tractor to the baggage claim facility, where employees load the bags on the conveyor belt. A baggage tractor can transport a variable number of containers, defined by the airport operator. Depending on the number of bags / containers to be transported, several trips might be necessary. Once arrived at the baggage delivery station, the driver of the vehicle starts unloading bags (t_4) which are delivered to passengers in the baggage claim area. The completion time of the unloading phase t_5 marks the end of the inbound handling process (*Last Bag time, LB*). The carousel's layout differs among airports (Ghobrial et al., 1982) and its capacity is the maximum number of bags which can be contemporarily placed on the conveyor belt.

It is thus possible to subdivide the whole process between BT and LB in five intervals, as shown in Figure 2 :the first three are related to ramp operations, while the remaining relate to the transfer and the subsequent discharge on the tapes. The $\Delta t_1 = t_1 - BT$ is the time between the *Block Time* and the positioning of the loader/belt and it depends on the efficiency of the ramp team. Once the loader/belt has been placed under the aircraft's hold, the successive time interval $\Delta t_2 = t_1 - t_2$ is the time needed to open the door, enter the hold and begin the unloading of the aircraft. Depending on whether the bags are palletised or bulk, the handlers predispose different operative means which generate variable values of Δt_2. The $\Delta t_3 = t_3 - t_2$ depends on the number of incoming baggage. It must be highlighted that resources handled for the unloading operations are not constant in number as the same handling company organizes different teams depending on the airline to serve. After completing the operations on the apron, the $\Delta t_4 = t_4 - t_3$ is the transfer time to the delivery stations. The main variable influencing this time interval is the position of the stand and the only resource used is the tractor driver which then performs the unloading of baggage, whose duration is defined by $\Delta t_5 = t_5 - t_4$.

In the following section, the case study at a large-regional airport is introduced and the model architecture deployed.

3. Discrete event simulation model

3.1. Case study: Bologna Marconi Airport

Bologna "G. Marconi" Airport is one of the major airports in Italy in terms of international destinations served; the runway has progressively been enhanced up to the current length of 2,800 m. 2017 was a record year, with 8,198,156 passengers and a growth of 6.73% compared to the previous year (Bologna Marconi Airport, 2018).

According to the origin of the flight, there are 6 Schengen delivery stations (S in Figure 3) and 5 non-Schengen belts located at end of the arrival branch (stations from 7 to 11, NS in Figure 3). These delivery stations are of the direct type and equipped with traditional carousel delivery belts. At Bologna Airport, ground handling services are provided by three different companies: GH Italia, Aviation Services and Aviapartner.

Figure 3. Location of baggage delivery stations at Bologna Marconi Airport

The process of returning baggage has been described in Section 2. However, two slight differences must be highlighted: as for Schengen belts, the baggage tractor's driver is not aware in advance of which delivery station is assigned to its flight; therefore, he has to reach a screen located in the delivery area (within the time interval Δt_{4S}) to visually collect this information prior starting the un-loading phase. To this purpose, we add a time t_6 to the model and the time interval Δt_6 is the time needed to cover the path from the monitor to the assigned belt. As for non-Schengen flights, the stations develop linearly and the operator proceeds straight until he reaches the assigned belt, which he knows in advance.

In both cases, after reaching the delivery station and before unloading the first bag, the tractor's driver presses a green button which opens the delivery station and starts the conveyor. After unloading the last bag, a red button is pressed to terminate the operation. The times in which the green and red button are pressed, which correspond respectively to t_4 and t_5, are stored in the Business Intelligence database of the airport, as well as the Block Time *BT*.

3.2. Implementation

The baggage handling process simulation is performed using the commercial software Arena. The simulation refers to several days, in particular to the winter peak period spanning from December 23, 2017 to January 7, 2018. For each day, both Schengen and non-Schengen scheduled arrivals are simulated during two peak periods: in the morning between 10:00 and 12:00 AM and in the evening between 19:00 and 24:00.

According to the airside configuration presented in section 3.1, Schengen flights' baggage are assigned to delivery stations 1-6: a belt is considered occupied if even one entity is being processed and another delivery station is chosen; in addition, palletized baggage cannot be assigned to belts 1-2-5-6, so ULDs are unloaded only on belts 3 and 4, depending on the availability. As for non-Schengen baggage, after the random security control has been performed, the allocation to baggage claim carousels 7-11 depends again on the availability of the resource and the size of the aircraft, with bigger aircraft's baggage unloaded either onto conveyor belts 8, 9 or, if they are both occupied, 10.

Figure 4 below summarizes the logic of the model and the succession of the baggage handling activities through a flow chart.

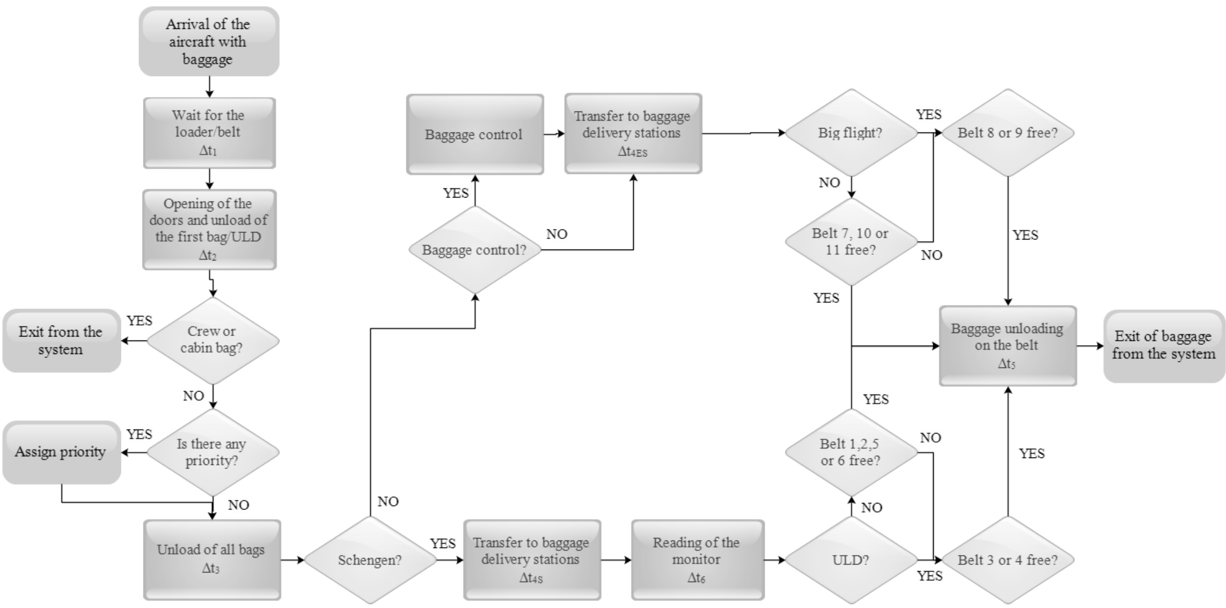

Figure 4. Logic of the model.

4. Data collection and results

4.1. Data collection

In order to gather input data for the model, a field investigation was carried out for all flights landing between 10:00 and 12:00 AM and between 19:00 and 24:00 PM from November 2017 to February 2018. A sample of 57 flights and the corresponding baggage delivery operations have been analyzed. The sample includes flights with different origins – Schengen or non-Schengen - and type of luggage storage, i.e. *ULD* or bulk luggage. 47% of the flights are classified as Schengen and in the 32% of the cases baggage was stored into ULDs. As far as airline typology, only scheduled network carriers flights have been taken into account; no charter flights took place in the time period inspected, while Low Cost flights were neglected due to the low and floating number of baggage carried which would have affected the model output. As a result of the field investigation, extremely specific data have been collected, which would be otherwise difficult to determine without the help of automatic specific devices and high installation costs.

For each sampled flight, operations have been analyzed and the time intervals described in Section 2 have been measured and recorded, namely Δt_1, Δt_2, Δt_3, Δt_{4ES} for non-Schengen and Δt_1, Δt_2, Δt_3, Δt_{4S}, Δt_6 for Schengen flights. Δt_5 is known as t_4 and t_5 are stored in the airport's database. The intervals are measured in minutes and, for each sample, a specification is added regarding the use of *ULD*s or less.

As input of the simulation, Arena requires to specify the statistical distribution of processes' times. The data obtained by the field investigation are analyzed by means of inferential statistic tools in order to derive the underlying probability density function which better describes each sampled time interval. For each interval Δt, the maximum and minimum sampled values are computed. Then, the duration of each process, considered from $t = 0$ up to the maximum, is subdivided into a succession of time intervals (time blocks). According to the theory of frequency analysis, the discrete time distribution is obtained by computing the number of samples belonging to each time block. From the discrete earliness arrival data, the underlying probability density is identified by testing probability density functions and identifying the best one by the Chi-Squared ($\chi 2$) test. Figure 5 shows, for time intervals Δt_1 and Δt_2, the probability distributions tested and, in red, the one which better fits the frequencies. A remark must be made regarding the distribution related to Δt_3 in the case of bulk baggage, because the sampled frequency distribution presents a double peak. After some attempts, two different distributions are assumed, the first one for flights with up to 80 pieces of luggage and the second one for those with a higher number of bags. The probability distributions obtained for each time interval are presented in Table 1, as well as the average and, if computable, the standard deviation.

Moreover, some additional information is necessary to build the model, including the number of resources provided by ground handlers – in terms of operators – and the modality of handling crew and cabin bags (i.e. not checked but loaded in the hold directly at the gate). In order to gather the missing data, a questionnaire is given to handlers to derive information on (i) ULD usage, (ii) number of operators, (iii) handling of crew baggage, and (iv) the presence and percentage of priority bags. These pieces of information are used as input of the simulation model. In the next Section 4.2, the results of the simulation are shown.

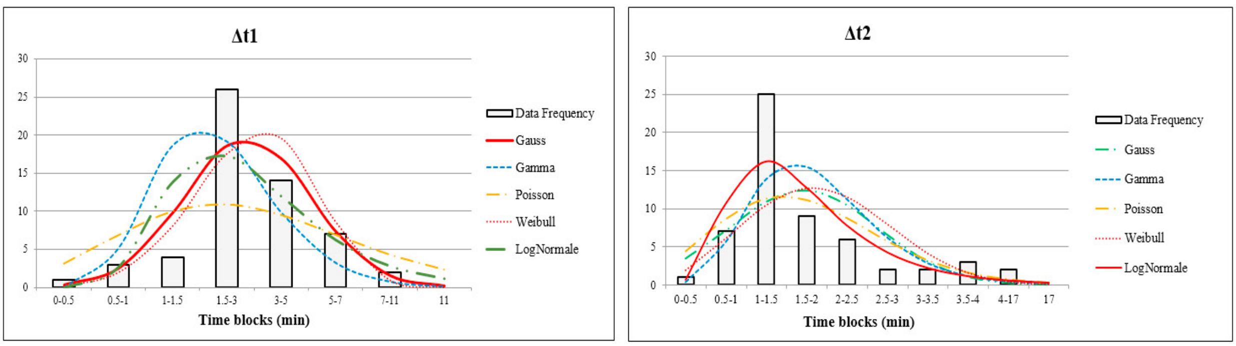

Figure 5. Δt1 and Δt2 discrete distribution and tested probability density functions.

Table 1. Probability density functions representing each time interval.

Time interval	Probability density function	Average (min)	Standard deviation (min)
Δt1	Gauss	3,167	2,1
Δt2	LogNormale	0,29 (Log)	0,34242 (Log)
Δt3 ULD	Gauss	8,517	3,667
Δt3 NT < 80 bag	Gauss	4,75	1,383
Δt3 NT > 80 bag	Gauss	11,2627	2,9833
Δt4 *non-Schengen*	Gauss	2,2	1,5
Δt4 *Schengen*	Laplace	1,583	\
Δt5	Gauss	0,91667	0,4

4.2. Results

As specified previously, the simulation refers to the period from December 23, 2017 to February 7, 2018. During this peak period, not only the number of movements is higher than average, but also flights have an increased baggage over passenger ratio, especially those to/from tourist destinations. A relevant number of iterations has been set in order to minimize standard deviation and obtain values as realistic as possible. Table 2 presents the values of the standard deviation, both in absolute value and as a percentage with respect to the average, obtained from the simulation for different number of replications. It is possible to see that with a number of replications equal to 200 the discrepancy is very small.

Table 2. Standard deviation as a function of the number of replications of the simulation

Number of replications	1	5	10	15	30	50	70	100	200
Standard deviation	\	4,53	2,3	1,95	1,82	2,18	1,66	1,42	0,93
%	-21,23	-4,22	-3,68	+0,36	+1,5	-2,33	-0,92	+2,6	-1,32

Simulation results constitute a useful tool to understand the correct development of the process. The comparison between the observed reality and the simulation is based on LB time, which represents the end of the inbound baggage handling process. This value is stored in the airport's database and it is compared to the one obtained by Arena. The histograms in Figure 6 show the comparison between the observed and the simulated value, averaged over flights of the same airline, differentiated according to the origin and referring to a value of replications amounting to 200.

The simulation on Arena leads to excellent results for almost all airlines, as differences between the observed and simulated valued are quite small (3 – 7 %). However, in a few cases results are slightly worse as the simulated model seems to underestimate the total time. This discrepancy is especially evident in two cases (Lufthansa and Tap Portugal for Schengen flights and Royal Air Maroc for non-Schengen flights), where the difference between the simulated and observed values is equal to 7.5 minutes in the first case and around 3.5 minutes in the other two cases. To our knowledge, these discrepancies are neither an anomaly of the model (which have been dealt with by changing lightly the model architecture as reported in section 3.1) nor seem due to a bottleneck located somewhere along the baggage handling process; otherwise, also the remaining data would have been affected by similar flaws. By deepening the analysis to the airport traffic schedule during the time period and the hours inspected, it is possible to guess that the discrepancy on Lufthansa data might be partially ascribable to the relevant traffic arriving and departing from BLQ airport during the morning peak (of which LH is the only airline inspected, being the other airlines involved Low Cost and minor Network carriers), to variability of baggage flows and the management of personnel rota and recreation breaks. As for the Royal Air Maroc flight, the most likely reason for deviation shall be a higher than simulated number of random incoming baggage security control. In both cases, the variables here mentioned – which have not been simulated - have enlarged the observed value with respect to the model output. Finally, additional uncertainty can be linked to the limited dimension of the sample.

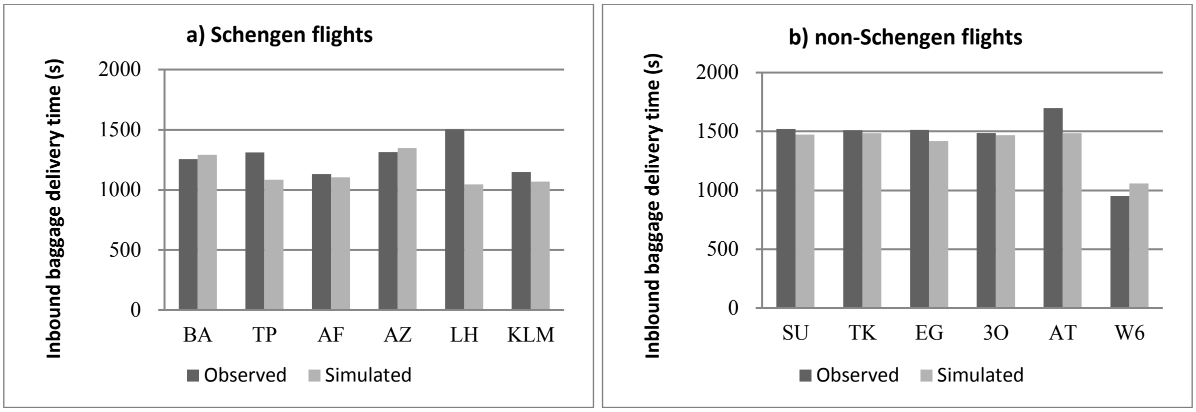

Figure 6. Comparison between observed and simulated process time for Schengen (a) and non-Schengen flights (b). BA = British Airlines, TP = Tap Portugal, AF = Air France, AZ = Alitalia, LH = Lufthansa, KLM = KLM Royal Dutch Airlines; SU = Aeroflot, TK = Turkish Airlines, EG = Ernest Airlines, 3O = Air Arabia Maroc, AT = Royal Air Maroc, W6 = Wizzair.

5. Conclusions

As baggage handling is the most crucial step at the end of the flight and as studies have demonstrated high levels of annoyance among passengers due to delays, authors have developed this discrete event simulation model for inbound baggage handling which has been then tested at a large regional Italian airport. This contribution adds to the literature on the topic which to our knowledge has not yet covered in depth this aspect. The significant aspect of this work, apart from the proved ability to synthetize the whole logistic supply chain within the model, consists in the quality of results obtained which are adherent to real performances despite the limited size of the sample. The baggage handling process has been split into different time intervals, for which discrete distribution and probability density functions have been computed, also with reference to particular conditions such as the use of ULD and infrastructural distribution of facilities alongside the terminal. These boundaries have been dealt with by slightly modifying the model's architecture to fit the layout of the case study airport. These modification, although, have not altered the transferability of the model, since baggage handling is a standardized activity regardless the technological tools adopted.

BHS at Bologna Airport is centralized, new and highly performing (3,600 bags/hour at its full capacity), which has concurred to increase both the passenger satisfaction index and ASQ (Airport Service Quality) rating over years. The performance in both outbound and inbound operations is expected to be further enhanced once the new terminal is operative.

Local discrepancies between model output and real data have been detected; while in the case of non-Schengen flights random inbound baggage screening activities can play a key role, in the case of Schengen activities the reason might be the presence of daily peaks of traffic which are even more exacerbated within the period of winter season inspected in this case study. In this last case, the cooperation between handling agencies and airport operator is fundamental to guarantee that the effects on airport operation are as limited as possible (i.e. by foreseeing overtime for handling agencies' personnel and evaluating the buyout of additional ramp vehicles and tractors) in compliance to Airport Regulation.

Aside peak operation events, this model can be adopted to simulate alternative scenarios in different moments of the day – to allow dynamic allocation of resources and personnel – and operating conditions (i.e. system malfunction, recovery from failures, overload or unforeseeable peak events due to flights diverted from other airports for various reasons) which might severely impact on the system's performance. Finally, as airport traffic is forecasted to increase over time, the model might also be used to simulate the performance of the system in response to crescent inbound flows over time and to tackle in advance flows before operative delays become too apparent. The importance of effective simulation and provisional tools at airports and the close cooperation in data sharing between airport operators, handling agencies and airlines to guarantee the passengers a seamless travel experience are here rebated.

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