Proceedings of the 34th European Modeling & Simulation Symposium (EMSS), 012
19th International Multidisciplinary Modeling & Simulation Multiconference

ISSN 2724-0029 © 2022 The Authors.
doi: 10.46354/i3m.2022.emss.012

A novel validation approach for validating the simulation model of a passengers' airport terminal: case study Palma de Mallorca airport

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Abstract

In this paper we propose a novel approach for validating a simulation model for a passengers' airport terminal. The validation approach is based on a "historical data" and "model-to-model" validation approach, and the novelty is represented by the fact that the model used as comparison uses historical data from different data sources and technologies. The proposed validation approach , which is presented as part of the IMHOTEP project, implements various data fusion and data analytics methods to generate the passenger "Activity-Travel-Diary", which is the model that is then compared with the results from the simulation model. The data used for developing the "Activity-Travel-Diary" comes from different sources and technologies such as: passengers' data (personal mobile phone, apps), airport data (airport Wi-Fi, GPS, scanning facilities), and flight Information (flight schedules, gate allocation etc.). The simulation model is based on an agent-based simulation paradigm and includes all the passengers flows and operations within a terminal airport. The proposed validation approach is implemented in a real-life case study, Palma de Mallorca Airport. A statistical and visual validation process was conducted, showing that the simulation model was accurately representing the different areas of the airport terminal, when compared to the "Activity-Trave-Diary" model.

Keywords: validation approach, agent-based simulation, airport terminal

1. Introduction

One of the most critical tasks in developing a simulation model is to determine whether the model is an accurate representation of the actual system being studied. The success and the credibility of a simulation model depend on the quality of its model design and components and the accuracy of the results obtained from the simulation. Every simulation model must be verified and validated. Validation is the process of determining whether a simulation model is an accurate representation of the system being modelled (Zeigler at al., 2019). The ease or difficulty of the validation process depends on the complexity of the system being modelled and on whether a version of the system currently exists. The simulation model of a complex system can only approximate the actual system, no matter how much effort is spent on model building. In the literature we can find several studies about validation approaches and techniques. Relevant methods are classified in qualitative (graphical approach/face validation) and quantitative (statistical analysis) (Kleijnen, 1995; Ni et al., 2004). Among the statistical analysis methods, Rebba et al. (2006) mentioned the three most relevant: hypothesis, Bayesian, principal component analysis (PCA).Rehman and Pedersen (2012) investigated the factors for choosing the right validation method, and they identified the following: purpose; mathematical character; and time. Based on these factors they defined three validation categories: confirmative, where the model is confirmed by empirical observations; sub validation, which suits large models, where confirmative validation is conducted for each sub-model; and reference, which refers to theoretical experiments when observations are out of reach. Hora and Campos (2015) provided a guide for choosing which performance criteria to use for validating models. The performance criteria were based on features intended to be assessed like correlation, bias, variance, lag, information, and shape. The performance criteria evaluated were categorized as: Error measure, information theory, information criteria, parametric tests, non-parametric tests, distance-based measures, combined measures. Pace (2004) addressed the main challenges when conducting a validation study, which are inference (data), adaptation (M&S programming), aggregation (level of detail/resolution), human involvement/representation. Concerning inference, the main challenge pointed out in the study is to quantify the uncertainty of the real-world systems. In this context, data plays a critical role as the more data available the more adequate predictions can be made. Challenges with data validity are also highlighted in the work of Sargent (2013), where having appropriate, accurate and sufficient are seen to be the main concerns. The paper suggests the most relevant areas for dealing with data in a proper way are collecting and maintaining data; testing the data by using data relationship correctness techniques; and screening the data for outliers or identify if the outliers are correct.Xiang et. al. (2005), discussed how validation techniques used traditionally in industrial and system engineering fields can be adapted to agent-based simulation models. The paper focuses on the differences between validating discrete-event and agent-based simulation models. The results from their study confirmed model-to-model validation approach as an efficient one for agent-based simulation (ABS) models.

In this paper, we proposed a novel approach for validating a complex system such as the passenger flow at a terminal airport. The validation method builds on the historical data validation (Sargent, 2013), where part of the data is used to build the model and another part is used for validating it. The novel aspect of the validation process is that the data used for validating the model is based on the reconstruction of the passenger activity-travel-diary (ATD) from a combination of different big data and conventional sources, with the objective of obtaining an accurate and reliable passenger trajectory. This aspect reflects the challenges and concerns raised in Pace(2004) and Sargent (2013), focusing on data validity to overcome these challenges. Moreover, mode-to-model validation approach was implemented as in Xiang et al. (2005), where a validated ATD model is used as comparison for the simulation model.

The remaining of the paper is as follows: In Section 2, the passenger airport terminal operations and the simulation model will be described; in Section 3 the proposed validation methodology will be presented and in Section 4, the ATD will be explained; in Section 5 the preliminary results of the validation process based on a real airport (Palma de Mallorca, PMI) will be shown. Finally, In Section 6 conclusions and future developments will be mentioned.

2. The passengers' flow within the airport terminal

In line with the objectives of the simulation model, the level of abstraction required is passenger-specific, meaning that the model shall simulate each passenger's flow within the airport terminal. The model will also consider the terminal surface constraints and passenger interactions. We distinguish three passengers' flows: departure, arrival, and transfer. The conceptual model has been built based on these three flows, as they are depicted in the flowcharts of Figures 1, 2 and 3. The departure flow starts by passengers accessing the airport terminal from one of the entry points. Then it continues at the check-in desk, where passengers will obtain their boarding pass and/or will check their baggage. After that, the passengers go through the boarding pass scan and, according to the passengers' status (domestic or international), through the passport control and then trough the security control (security checkpoint). Once passed the security control, passengers will decide either to stop at the shopping/catering area or continue directly to the gate area, where they will wait before boarding (see Figure 1).

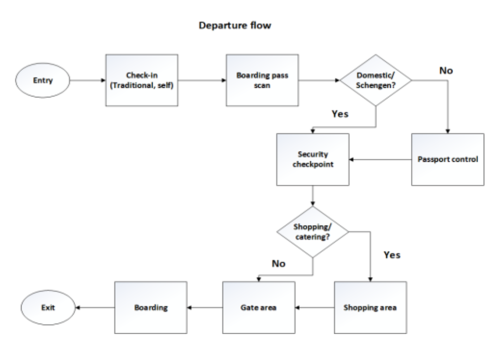

Figure 1. Departure flow

The arrival flow follows almost the opposite path compared to the departure one. The passengers access the terminal from one of the arrival gates and walk through the terminal until they reach the baggage claim area. According to the status of their flight, Schengen or non-Schengen, they will go through the passport control before reaching the baggage claim area. After having picked up their baggage, the passengers will end their itinerary by reaching one of the exit points of the terminal (see Figure 2). In this specific context we did not model any custom processes.

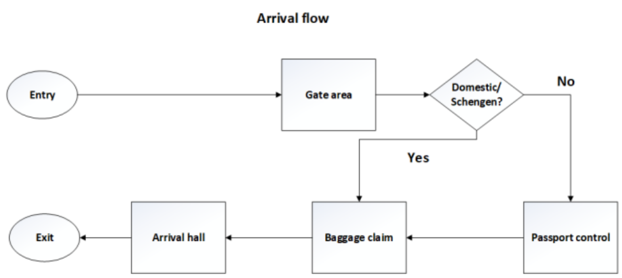

Figure 2. Arrival flow

The transfer flow occurs when passengers need to move from their arrival gate to their new departure gate without needing to access the check-in area. The starting point of the passenger's flow is at one of the arrival gates. Then, according to their status (Schengen or non-Schengen), it continues through the passport control. Passengers may spend their idle time in the shopping/catering area or go directly to the departure gate area before boarding the departure gate (see Figure 3). For some airports security processes are conducted when there are passengers travelling from/to international origins/destinations.

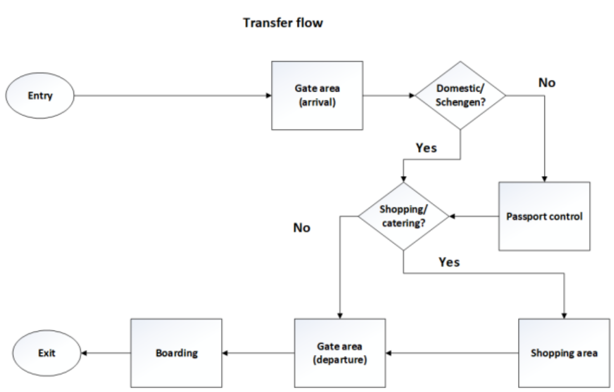

Figure 3. Transfer flow

2.1. The airport terminal simulation model

The airport terminal model is based on the agent-based simulation (ABS) paradigm. The application of ABS to study airport operation system can help better understand the travel behavior of passengers, especially how and why air travelers make decisions before a trip (pre-planned) and within a trip, and how does the system perform in such a circumstance (Federal Highway Administration, 2014). Through a dynamic ABS model, we can evaluate the inherent variability of the airport terminal system and evaluate the interactions between different agents (passengers) and the operational processes. ABS modelling provides a more detailed representation of the individual passenger trajectories, allowing the study of how the passengers move inside the airport, including discretionary activities (e.g., shopping), and the analysis of how the visited locations and the time spent at each of them varies with personal preferences, trip purposes, etc. The model conceptualization has been translated into a computer-based model by employing a dynamic passenger flow simulation software, CAST Terminal (ARC, 2021). The main operations included in the model are the following:

- Check-In counter operations
- Boarding pass scan operations
- Security operations
- Passport check operations
- Gate boarding operations

In figure 4 a top view of the check-in area from the simulation model is shown. For a more detailed explanation of the features of the simulation model, please refer to Mujica et al. (2021).

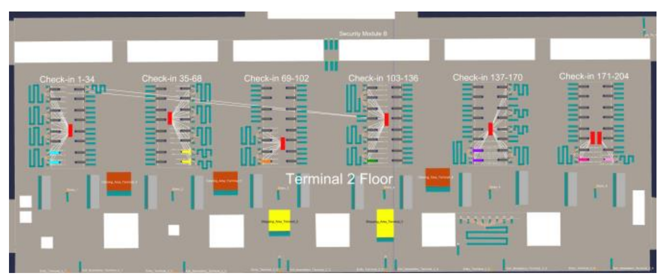

Figure 4. Top view of the check-in area

3. The validation methodology

In this section the step-by-step approach for validating the model is presented. The diagram of Figure 5 summarizes it.

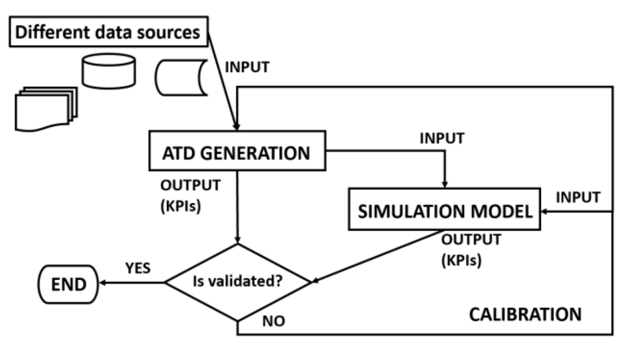

Figure 5. Validation methodology

At first, the ATD is generated, and the main KPIs extracted (throughput, occupancy, dwell times); then the simulation model, of which inputs are partially provided by the ATD (passengers' arrival at the terminal) is executed. The results from the two models are compared (visually and statistically) and then depending on the output, it is decided either to change some of the simulation model/ATD inputs (calibration) and re-execute them until a satisfactory outcome is reached, or to validate the model as it is.

In the next section, the development of the ATD is described.

4. The passenger Activity-Travel-Diary

The approach followed for reconstructing the ATD relies on the fusion of different data sources. The steps that have been followed to obtain the complete ATD are shown in Figure 6. The step that are implemented are listed as follows:

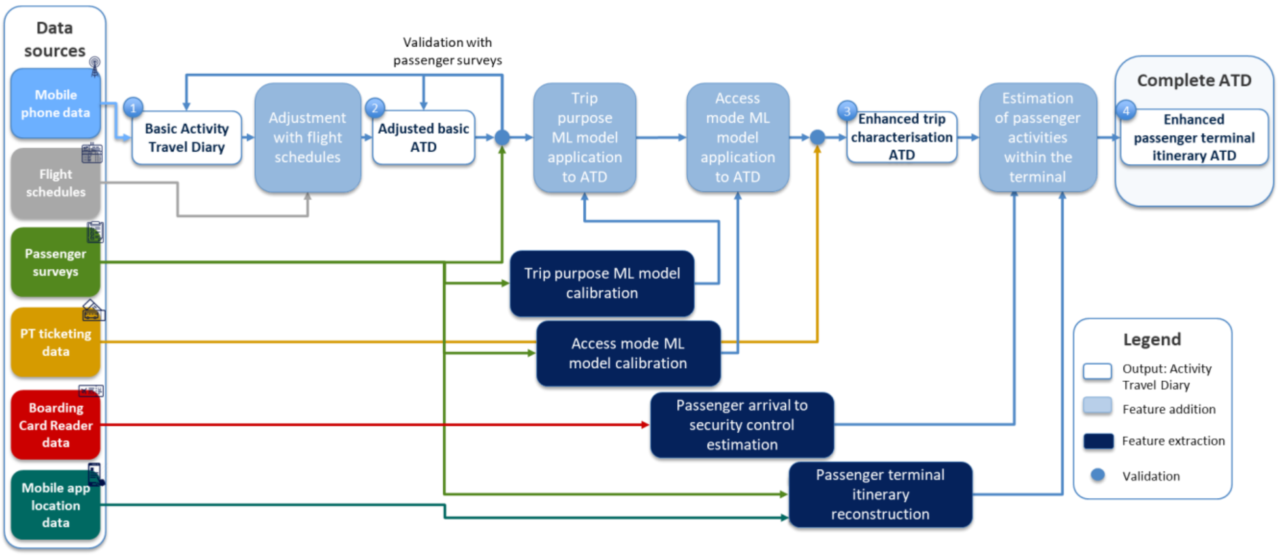

Figure 6. ATD reconstruction step-by-step methodology

1. Basic ATD, is built exploiting the proprietary algorithms of Nommon to extract activity-mobility patterns from anonymized mobile network data. These basic ATD include passengers' arrival time at the airport and approximate departure time, type of passenger (departure or arrival) and other personal passengers' information such as: age, gender, nationality etc. (see Burrieza-Galan et al. 2022 for more details on the generation of the basic ATD).
2. Adjusted basic ATD, the basic ATD obtained in the previous step is adjusted to the total number of passengers using the airport flight schedules and results are validated using the airport surveys.
3. Enhanced trip characterization ATD, information extracted from passenger surveys is used to calibrate machine learning models able to estimate the purpose (business or leisure) of the trips and the transport mode used by the passengers to access and egress the airport terminal (A. Gregg et al. 2022). Additionally, ticketing data available from public transport systems are used to validate and adjust the mode choice results.
4. Enhanced passenger terminal itinerary ATD, Finally, statistical matching techniques are used to reconstruct the passenger itinerary inside the airport using data from the boarding card reader (BCR) at the security control arrival and mobile app location data.

In the following subsections, the data used, and the data analytics approaches implemented for reconstructing the ATD are described from step 2 onwards.

4.1. Data sources

- Mobile network data (MND) from July and August 2019. This data includes network events (call detail record and network probe data), network topology (location of the network towers and antennas) and sociodemographic information (age, gender, nationality)
- Flight schedule and number of passengers for July and August 2019. Airport flight schedules including information on flight destination/origin, gate, scheduled time of departure/arrival (SDT/SDA), passengers per flight, etc.
- Passenger surveys conducted between 18th to 24th of July 2018. Surveys includes information on different trip characteristics (destination, purpose of the trip, duration of the stay, etc.) as well as sociodemographic details (age, gender, nationality, etc.)
- Boarding card reader (BCR) data from October 2019 to March 2020. BCR data captures the time

stamp and flight information of each passenger that scans his/her boarding pass at the boarding pass reader located before the security area.
- Mobile apps data from August 2019. Geolocated data generated when mobile phones make use of certain apps. Location data is based on GPS and/or Wi-Fi sensors, thus providing a more precise location than the mobile network data

4.2. Data analytics techniques

4.2.1. Adjusted basic ATD

This step takes as starting point the basic ATD extracted following the methodology presented in Burrieza-Galan et al. 2022. The passenger trips detected using MND just represent a sample of the total trips performed at PMI airport. Table 1 presents the sample size of passengers detected using MND for July and August 2019. Note that just regular and charter flights have been considered in this study, representing the 99.85% of the total passengers of the airport (cargo, ambulance and other residual categories have been discarded). The airport flight schedules are then used to adjust the detected trips to the total number of passengers using PMI. To do so, a statistical matching process has been performed in order to match each detected trip to an existing flight. Subsequently, the sample has been expanded based on the real number of passengers per flight. Additionally, a comparative analysis aimed at validating the results obtained from the mobile phone data analysis is conducted. The correlation between a set of indicators obtained from both mobile phone data and passenger surveys is evaluated with the objective of assess that the previous processes have been performed correctly.

Table 1. Number of passengers obtained from the flight schedule and from the mobile phone data

Month	Number of passengers from the flight schedule	Number of passengers from the mobile phone data	Sample size (%)
July	4199919	461802	10.99%
August	4275063	470471	11.01%

4.2.2. Enhanced trip characterization ATD

PMI passenger surveys are used to develop and calibrate a set of machine learning models able to estimate whether a passenger is travelling for business or leisure purposes and the transport mode used to access and egress the airport (see Gregg et al. 2022 for more details on the development of machine learning models).

4.2.3. Enhanced passenger terminal Itinerary

- ***Passenger arrival to security control estimation***

The objective of this step is to add to the Passenger ATD the passenger arrival time at the security control, more precisely to the BCR machines located at the beginning of the process. The proposed methodology is depicted in Figure 7.

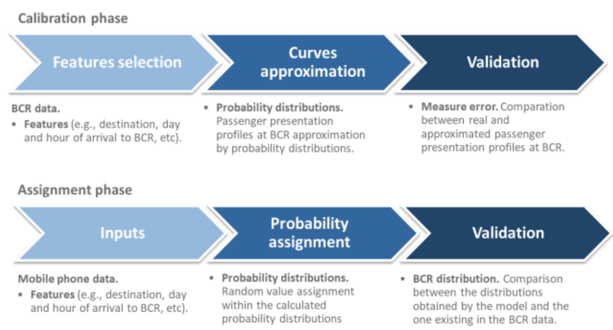

Figure 7. Enhanced passenger terminal Itinerary methodology

In an initial calibration phase, the BCR data provided by the airport has been used to extract the passengers' behavior regarding the time of arrival to the security control depending on relevant features (time of the day and passenger's final destination). Then, the passenger presentation at BCR has been approximated by gamma probability functions depending on the previous selected features. Figure 8 presents an example of the estimation obtained for Schengen flights in the period P3 (evening), compared to the real data obtained from the BCR dataset. Finally, in the assignment phase, the calculated probability functions are applied to the trips detected with mobile phone data according to their characteristics (final destination and time of the day) in order to estimate the passenger arrival to the security control.

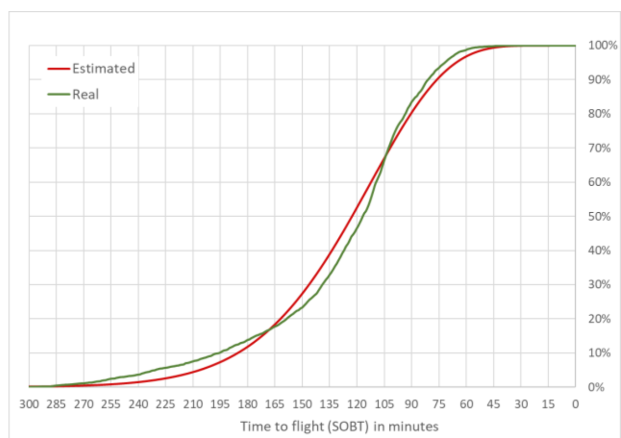

Figure 8. Comparison between the estimated (gamma function) and real (BCR data) passenger arrival at the security area

A last validation is performed in order to assure that the behavior observed on the BCR data has been correctly translated to the trips detected with mobile phone data. To do so, a comparative analysis between the passenger arrival profiles found in the BCR data and the ones inferred to the ATD is conducted.

- ***Reconstruction of the passenger terminal itinerary***

Geolocated mobile app data has been used to reconstruct the passengers' itinerary within the airport terminal. As the mobile app registers can be located anywhere inside the airport, feasible travel paths have to be defined so that the passengers are only able to travel along such paths. To do so, a set of study areas have been defined (parking, terminal, security control, commercial area and modules) and the airport area has been translated into a squared network. This network, connects every square with its neighbors, allowing the flow of people between one square and the surrounding squares. The airport defined areas as well as the squares network are presented in Figure 9.

Figure 9. PMI airport outline and grid

The construction of the airport travel paths is generated as follows:

- Assign the location data and timestamp taken from mobile phones and app to the previously defined network square.
- Connect each location point to the next register following the shortest paths.
- Calculate the timestamp in each square where the user is detected, assuming constant speed between two points.
- Connect the whole agent's trajectory.

Figure 10 shows an example of the extracted passenger trajectories.

Figure 10. Passenger trajectory example at PMI airport

Once the trajectories have been calculated, the passengers' stay times at the different airport areas are calculated and are used to estimate the stay time distribution in each area. These time distributions have been fitted into a gamma distribution and then used for the assignment of the passenger stay time to the previously calculated ATDs. The assignment is made based on the period of the day (peak/off-peak hours) and the module the passenger is accessing to (A, B, C or D). Figure 11 shows the comparison between the data extracted from the mobile apps data and the approximated curves about the stay times for the security area.

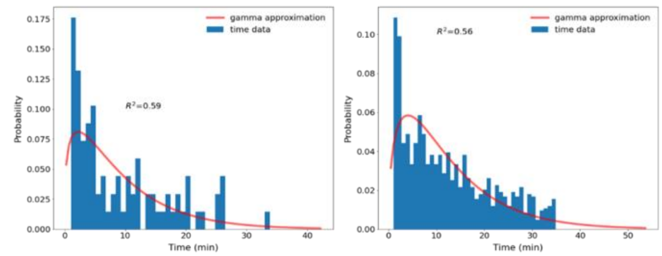

Figure 11. Security area stay times: approximation for off-peak (left) and peak hours (right).

Once the time distributions in the study areas are extracted, those times are applied to the ATDs, hence obtaining a complete passenger itinerary inside the airport terminal.

5. Statistical and visual analysis for the validation of the simulation model

In this section we will show some preliminary results of the validation process. We took as case study Palma de Mallorca airport, and we built the ATD and simulation models based on data from 2019. It is worth noting that the validation process, as shown in Figure 5, is a continuous process which involves the calibrations of the models. In this paper we will present only one step of the validation process as proof-of-concept for the validation methodology proposed.

The validation has been made via a statistical analysis (t-test) and by visually assessing the performance of the models. In this context we chose the throughput as the main KPI to evaluate. The statistical test chosen to run the validation is the t-Test, two-tail two-sample assuming equal variances, with a level of confidence of 95% (α= 0.05). We defined a null hypothesis H_0, that does not reject the validity of the model, in other words, it assumes that there is no significant difference between the means of the two data samples. While the hypothesis H_1 rejects the null hypothesis.

In Table 2 there is the outcome from the t-test for the average throughput in each area of the terminal.

Table 2. Validation results for each area of the airport terminal

Terminal area	Mean		P_0	t_0	$t_{\alpha/2}$
	ATD	Simulation			
Check-In Area	274.68	253.96	0.1526	1.432	1.964
Security Area	274.77	249.07	0.07	1.814	1.964
Commercial area	270.27	249.29	0.139	1.481	1.964
Passport area	76.88	70.4	0.2656	1.114	1.964
Module A	77.41	71.07	0.3717	0.893	1.964
Module B	4.52	5.03	0.6055	-0.516	1.964
Module C	117.45	107.98	0.2146	1.242	1.964
Module D	75.95	70.92	0.3618	0.912	1.964

Looking at the results, we can see that the calculated t_0 value is always less than the critical value $t_{\alpha/2}$ for each area, which means that the null hypothesis H_0 is not rejected. Looking at the mean values we can see that these values are similar for the ATD and simulation in each terminal area, confirming the validity of the simulation model. Moreover, we visually compared the throughput performance of the simulation model and the ATD for each terminal area as they are showed in Figures 12 to 15. Due to page limitations, only the graphs of the most relevant areas were shown. By looking at these graphs, it can be seen that, in every terminal area, the ATD (blue line) and the simulation model (red line) throughput are similar. This confirms the results generated by the t-test, however, the authors will further investigate more KPIs for a thorough validation of the model in future work.

Figure 12 and 13 , show the throughput of the check-in and security areas, which represent the first steps (sequential) of the passengers departure flow. In this figures, the throughput of both simulation and ATD is similar, only for the ATD being slightly higher. This is confirmed also by the comparison of the mean values in Table 2, however, the difference in mean is not significant.

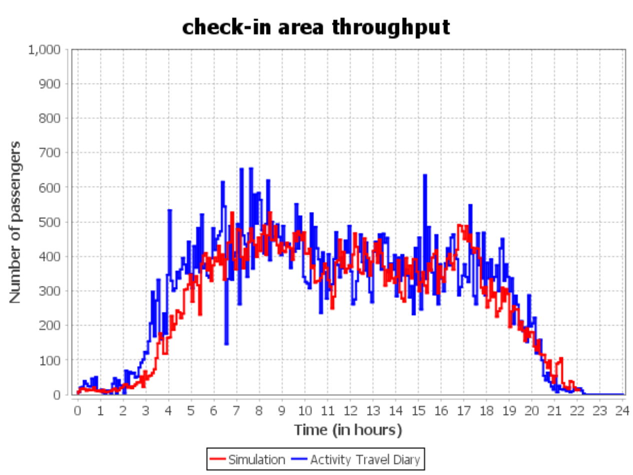

Figure 12. Check-in area throughput

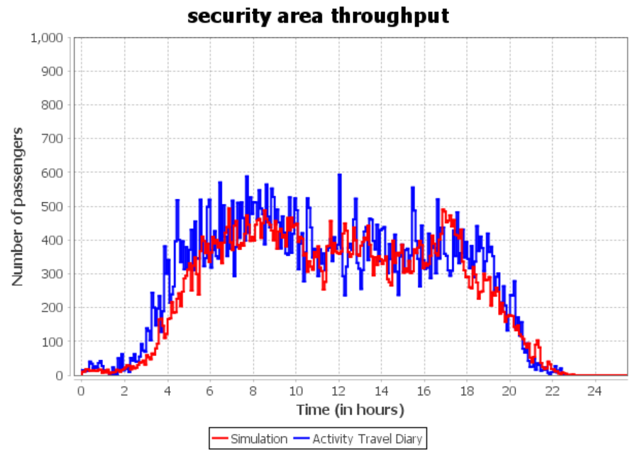

Figure 13. Security area throughput

Figures 14 and 15, show the throughput of two of the four modules where the gate areas are located. The module B, (see Figure 14), represent accurately the throughput compared to the ATD, revealing to be a good approximation of the real-life operations. It is worth noting that the access to the Module B is done directly from the Check-in area, as this module serves only inter-island and domestic flights, and they have a dedicated security area.

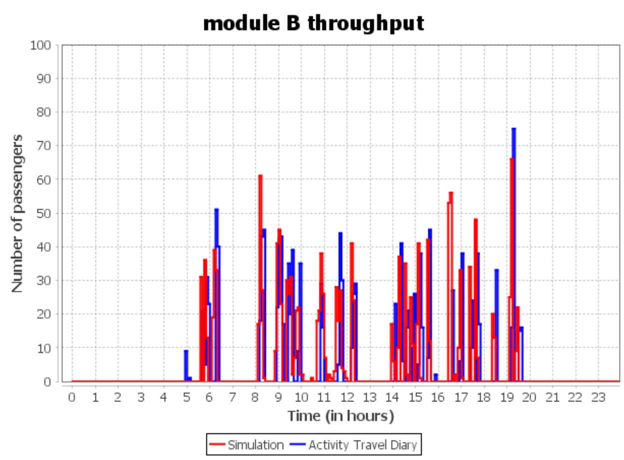

Figure 14. Module B throughput

In the throughput of Module C (see Figure 15), we can notice that there is a main difference in the first hours of the day (3-6 AM), being the simulation values shifted of one hour compared to the ATD one. However, the throughput values for both simulation and ATD have the same trends during the rest of the day, being the mean of the two very similar (see Table 2). As the Access to this Module is done through the man security area, and the commercial area, it is believed that this shift in throughput is given by the behavior of passengers within the commercial area, specifically, their preference to shop and to spend time in catering areas. This last point will be the focus of further research.

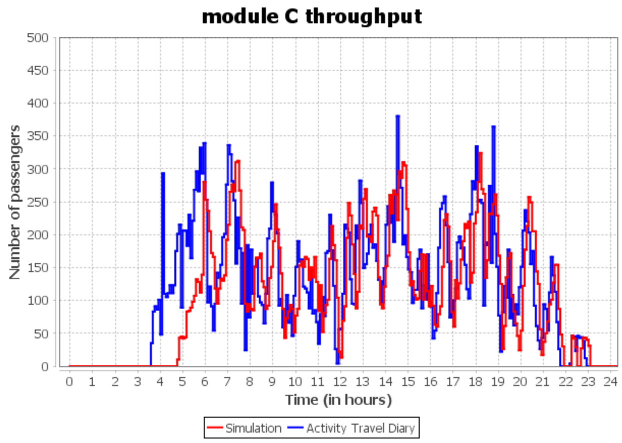

Figure 15. Module C throughput

6. Conclusions

In this paper a novel validation methodology was presented. This methodology is based on the use of different data fusion and data analytics methods that generate a more reliable benchmark for assessing the validity of the simulation model. The generation of the Activity-Travel-Diary, proved to be a good and reliable dataset for validating purposes. Moreover, some of the data generated from the ATD was used as input to the simulation model, proving to be a valuable information for the validation of the simulation model. The methodology presented can be used as a guideline for the validation of similar models, especially useful for integrating different data sources. The use of a case study proved the potential of this methodology, which, in turn, could be applied to similar systems. In this paper, only preliminary results were shown, therefore, future development will consider investigating more KPIs and conducting different statistical tests for the model validation.

Funding

This project has received funding from the SESAR/European Union's Horizon 2020 research and innovation program under grant agreement No 891287. The opinions expressed herein reflect the authors' view only. Under no circumstances shall the SESAR Joint Undertaking is responsible for any use that may be made of the information contained herein.

Acknowledgements

The authors would like to thank the Amsterdam University of Applied Sciences for the support in this research for disseminating the results of this work.

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