The Rise of the Smart Passenger I: Analysis of impact on Departing Passenger Flow in Airports

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***Abstract*—Airport infrastructure evolves alongside legacy systems and processes that limits the ability to fully realise the efficiency potential of costly renovations. Airports will continue to take advantage of current and future technologies. Nevertheless, for such systems to work as efficiently as possible, the passenger should play an active role. This paper analyzes the effect of a new type of emerging 'smart passenger', one that cooperates to be enabled to use the most efficient processes for a seamless experience. The technological and behavioural enhancements are assessed with the simulation of two case studies: London City and Palma de Mallorca airports. Results indicate that the introduction of this type of passenger brings benefit in terms of level of service indicators not only to this type of passenger but also to the traditional ones (business, visitor and leisure). However, the impact differs depending on the type of airport and the proportion of 'smart passengers'.**

***Keywords*—optimization, capacity, industry 4.0., simulation, aviation, transport**

I. Introduction

Technological evolution constantly challenges the design, management and operation of airport facilities. Electronic processing of passengers and bags has reduced processing time, queues and space requirements and even enabled some activities, such as check-in, to move off-terminal to a considerable extent [1]. However, these gains in efficiency contrast with the addition of processes and restrictions to ensure safety and security throughout the air journey [2], further increased by the focus on biosafety measures with the response to the COVID-19 pandemic [3,4]. Moreover, passenger experience is a result of the combined delivery of a variety of services by multiple stakeholders using different systems and usually following different objectives that consider quality of service from various perspectives. As a result, airport operators strive to put in place more advanced systems to make passenger processing as fast as possible without sacrificing on security and safety.

With the introduction of new technology within the realm of industry 4.0, like artificial intelligence (AI), machine learning (ML) and advanced sensor technology, aided by simulation and optimization techniques, new opportunities to make airport systems more efficient appear. This article analyses the impact that some technologies could have if the transparency is increased so that a more proactive 'smart passenger' could prepare to own more elements of the journey and take as much advantage as the system allows in terms of time savings and comfort. This type of passenger could have a smoother journey and enjoy a faster trajectory through the system that ultimately benefits all airport stakeholders (passengers, airport operator, airlines, retailers and ground handlers). This concept falls within the ambition of the IMHOTEP project where information from the system is propagated in a transparent manner across stakeholders to increase the awareness of the passengers [5]. The impact of enabling a number of well informed, *smart passengers* is evaluated by developing two case studies considering substantially different types of airports: London City (LCY), which is dedicated to serving a large proportion of business travelers on short-haul trips where efficiency is key to delivering its value proposition; and Palma de Mallorca (PMI), which serves mainly leisure passengers and where very high demand peaks strain infrastructure and processes. The extreme and opposite characteristics of these airports make the case studies relevant to study the potential implications at different categories of airports, at least in Europe.

II. State of the Art on Evaluation of New systems at Airports

In this section, an overview of the studies regarding passengers' profiling and the modeling of airport terminal operations using simulation techniques is presented. Regarding the latter aspect, the literature will focus on articles where policies and new technologies have been implemented.

A. *The emergence of the 'smart passenger'*

The analysis of the passenger journey through an airport system usually considers the existence of different *pain points*, such as check-in, luggage drop-off, security screening and migration control [6]. Pain points are normally associated to waiting times, queuing and anxiety, therefore impacting the overall passenger experience [7]. Technological advances designed to improve passenger experience in relation to security control are known as "biometric identification and registered passenger schemes" [2]. The combination of both enables passenger profiling to better allocate resources in relation to risk and represents a shift from the current 'one-size-fits-all' approach to airport security. Arguably, privacy concerns and the limited practical implementations of registered or trusted passenger schemes, diminishes the potential of new technologies to substantially enhance passenger experience. These pitfalls could be overcome with the use of a passenger-centric solution where individuals agree to release personal information when needed to facilitate their journey but remain in control and have ownership of their own data.

The World Economic Forum has identified four critical emerging technologies that would enable the implementation of their concept for a Known Traveller Digital Identity: a distributed ledger, cryptography, biometrics and mobile interfaces and devices [6]. These could ensure the connection between the physical and digital worlds to grant authorization to access personal information securely without relying on a single central authority. In fact, a passenger survey from SITA suggests wider support for technologies that enable digital identity management and shows a significant increase in the use of mobile devices for checking-in (13% of respondents), as well as of automated technologies for checking in (18%), self-bag drop (24%), identity control (38%), boarding (18%) and border control (24%) [8].

Increased implementation of these technologies should liberate passengers from country- or airport-specific programs of known passengers. In this sense, we propose a 'smart passenger' that has the ability to use specific processes or facilities to speed up the journey, regardless of travel purpose or ticket purchased. A 'smart passenger' is enabled by mobile technologies and biometric identification to travel through the airport terminal unencumbered by luggage, as both hand and hold luggage will be processed through the baggage handling system through self-bag-drop kiosks. Then, the 'smart passenger' will enjoy preferential or exclusive access for departure processes with the expectation (and sometimes certainty) that processing times will be much lower than for the rest of travellers. In this study, we assumed that the *smart passengers* would be a novel category of passengers; however, it could be case that in the future the categories will not be mutually exclusive (i.e. there could be a smart-business and smart-leisure ones).

B. Modeling airport terminal operations with simulation

Simulation techniques have been widely used for evaluating airport terminal performance. Some researchers tackle airport terminal individual operations or integrated approaches where the flow of passengers is modeled throughout all the different processes. Agent based models are commonly used for modeling the passenger flow within the terminal. These allow for the investigation of innovative concepts for passenger flow guidance within terminals [9] or the evaluation of handling processes, which would be useful for improving the efficient use of concessionary areas and passenger level of service [10]. Some studies [11] focused on the check-in operations, which used an agent-based model to obtain insights about the passenger flow behaviour and how to efficiently use ancillary facilities such as cafes or information kiosks. Crucially, they analyzed the effect of including additional attributes to the passengers in the model, but none of those characteristics are related to the use of specific technologies or processes.

A discrete event simulation model of the check-in area was developed to optimize the check-in counter utilization in order to provide a better level of service to the passengers [12]. The model was coupled with an evolutionary algorithm and it represents one of the first simulation-optimization approaches developed in the field. An analysis on the impact of different variables related to passenger or trip characteristics to determine their impact on processing times concludes that technological advancements could change the effect of the variables under analysis, and therefore further research is needed [13]. To simulate passenger boarding activities in the aircraft cabin an environment is implemented using a stochastic transition model via the cellular automata approach [14]. This approach not only allowed to investigate essential optimization approaches, but also to derive solutions taking into account COVID-19 requirements [4]. Security screening operations were the focus of other authors as well, who used a discrete-event oriented approach with the objective of improving level of service indicators such as queue length, queuing times and throughput [15,16]. In the latter, different policies regarding the security line utilization based on passengers' status and use of new technology were implemented.

The current study builds upon the latter work to propose policies based on passenger profiles and the use of new technologies for improving the efficiency of operations. The main difference is methodological, as this paper incorporates a dynamic agent-based simulation model in order to include the interactions between passengers and between passengers and physical facilities. Moreover, this study extends the evaluation of the security area by including also the check-in process in the departure trajectory of passengers (similar to the approach followed by [17]). By identifying the dependencies of these processes from the perspective of the passenger flow, this research aims at unlocking the potential capacity of an airport terminal depending on the types of passengers that use it.

III. Methodology

Aviation systems have different processes that can be studied by using different levels of abstraction, such as high-level strategic analysis, to highly detailed passenger-level operations. A multi-layered methodology has been explored before with good results [18]–[20]. The current case focuses on passenger trajectories within the airport terminals and their interaction with the environment. In the models for the case studies, the network of locations overlays a layout of the terminal, generating high-detailed models where the different performance indicators related to the passenger journey can be evaluated and the dependencies of the different processes identified.

As Figure 1 illustrates, after determining the objective, and verifying and validating (V&V) the models; different scenarios can be devised considering the novel characteristics of the flowing entity (passenger) or the system (airport terminal buildings). In our case it will be a combination of both. The

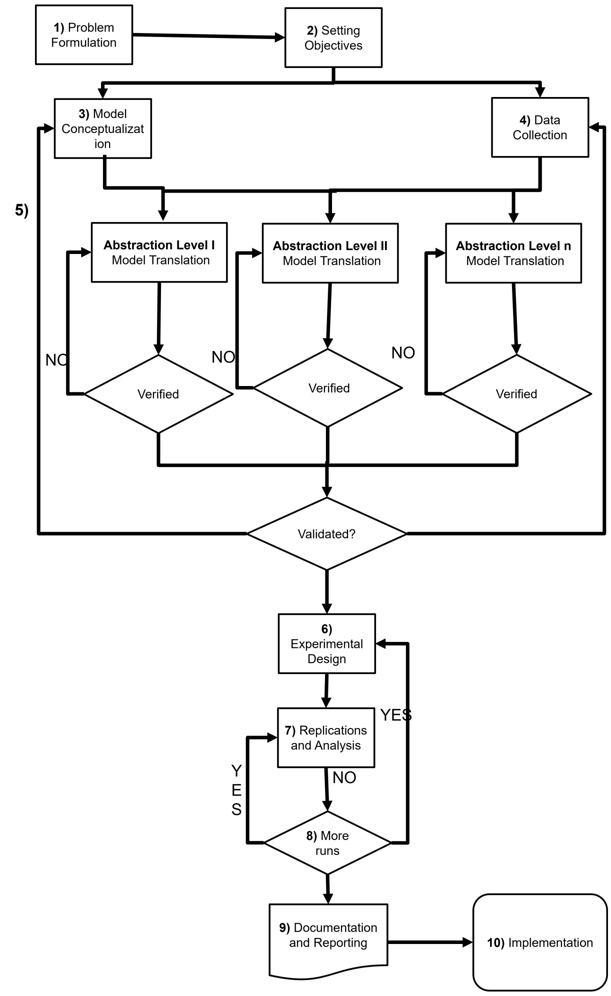

Figure 1. Multi-layered simulation methodology

passenger has novel characteristics and the system should be modified considering the latest technology that allow a smoother flow of passengers within the terminal. The airport models developed for the IMHOTEP Project [5] are used for the V&V step. These models have been verified and validated under the project scope and provide exemplary cases of very diverse types of airports. The evaluation on those two cases provides insight about the benefit and/or impact for the airports that fall within the categories of mostly-business and mostly-leisure airports and can provide direction on which levers to use when improving airport performance depending on its user profile.

A. Simulating the 'smart passenger'

This section defines the 'smart passenger' profile which will be implemented in the simulation environment, including their main characteristics in terms of travelling behavior. The *smart passengers* are conceived as passengers who, regardless of their travel purpose, want to make the most out of their dwelling time within the terminal by avoiding unnecessary idle time queuing at the airport facilities (i.e., check-in, security); instead, spending more valuable time at recreational facilities, such as restaurants, shops, or airline/airport lounges (cf. [21]). In addition, these passengers are very well informed and therefore control the course of their journeys independently and dynamically (cf. self-connecting passengers) [22]. To achieve this, the *smart passengers* obtain their boarding pass online and use self drop baggage facilities for checking their hold and cabin baggage. In this way, they will be bag-free for the rest of the dwelling time within the airport terminal. Moving within the terminal bag-free will allow them to move quickly (higher walking speed than average passenger with bag), and to have a quicker security screening process, as they do not need to scan any bags. Table I compares the characteristics of the *smart passengers* with those of the other three passengers profiles that have been identified in this work, namely 'business', 'visitors', and 'leisure'. These categories were identified in the analysis of passenger surveys performed in the IMHOTEP project.

TABLE I. PASSENGERS PROFILE CHARACTERISTICS

Passenger profile	Groups	Walking speed (m/s)	Bags to check in	Items for security screening	Propensity to shop/eat
Business	no	1.5	0	1	low
Visitor	yes (1-2)	1	1-2	1	low
Leisure	yes (1-4)	1	1-4	1	low
Smart	no	1.5	1-2	0	high

Table I shows that *smart passengers* are similar to business passengers; but business passengers do not carry any checked baggage, and therefore, they skip the check-in process and the baggage claiming process once they reach destination. However, business passengers carry a cabin bag during their time spent within the terminal, making the security screening process more time- consuming. Smart passengers, as already mentioned, focus on maximizing the dwelling time within the terminal in the departing journey by being bag-free. Visitor passengers are a category of passengers who travel with the purpose of visiting family and friends. They are similar to the leisure passengers as they share similar characteristics such as traveling in groups and checking in their bags at the check-in counter. However, leisure passengers generally travel in bigger groups (families) and therefore carry more bags. Due to the limitation of time, the propensity to consume within the terminal is lower than the one for the *smart passengers*.

On the airport side, a change in the facilities technology and processes policies can incentivize the 'smart' behavior of passengers, for instance by implementing self kiosk baggage drop and millimetre-wave body scanners at the security screening process [23]. The latter could drastically decrease the security control processing time as the *smart passengers*, who do not carry any cabin bag, will not need to use trays for scanning their belongings, and could just go directly through the body scanner. This solution cannot be implemented for the other passengers profiles as they will need to scan their cabin baggage. Figure 2 depicts the departure passengers' itinerary within the terminal according to their profile.

The flowchart of Figure 2 shows how *smart passengers*

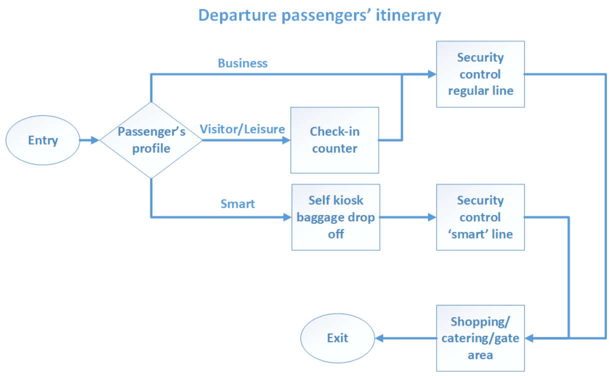

Figure 2. Departure passengers' itinerary within the terminal based on the passengers' profile

have dedicated self-service kiosk for the baggage drop off and dedicated lines for the security process; this can incentivize the 'smart' behavior and improve both airport performance and passengers' travel experience. The models in this study consider different processing times for each of the processes modeled (check-in and security screening) based on the types of passengers. Table II summarizes the processing times applied to this study for each of the passenger profiles. These processing times have been defined based on observations of actual processing times at the case study airports.

TABLE II. PROCESSING TIMES ACCORDING TO PASSENGER PROFILES

	Distribution of processing times (s)	
Passenger profile	(Self) Check-in	Security screening
Business	0	uniform(30,32)
Visitor	1 bag: uniform(70,90)	uniform(50,51)
	2 bags: uniform(90,110)	
Leisure	1 bag: uniform(70,90)	uniform(50,52)
	2 bags: uniform(90,110)	
	3 bags: uniform(110,130)	
	4 bags: uniform(130,150)	
Smart	1 bag: uniform(35,45)	uniform(14,16)
	2 bags: uniform(45,55)	

IV. EXPERIMENTAL DESIGN AND RESULTS

Different scenarios are used to evaluate how the implementation of the *smart passengers* and related technologies impact on airport performance. These scenarios were based on the proportion of *smart passengers* out of the total travelers, and the new technologies implemented in the check-in and security screening areas. The focus is on the departure processes, with emphasis in the check-in and security screening areas, which are known to be the most problematic areas to manage [16,24]. Airport performance is monitored in terms of queue length and queuing time while increasing the percentage of *smart passengers* for each scenario, as summarized in Table III.

In addition, two case studies were considered to make a thorough analysis of the impact of the *smart passengers* to airport performance. They refer to two airport terminals having different characteristics (LCY and PMI), both in terms of passenger profiles and terminal layouts. In the following sections the two case studies will be described together with

TABLE III. SCENARIOS EXPERIMENTED

Scenario	Share of *smart passengers*
Base case	0%
Scenario 1 (S1)	10%
Scenario 2 (S2)	20%
Scenario 3 (S3)	30%

the analysis of the results which present the impact for the regular passengers (business, visitor and leisure categories) and the emerging *smart passenger*. As the smart passengers require the use of dedicated facilities (check-in and security), the results compare the performance of the facilities used by them with the the rest of the (regular) passengers.

Following the simulation methodology, several replications ran for each scenario in order to get representative results. Therefore, the results include the median, 95% percentile and maximum values. Due to computational power and software limitations, the simulations only covered the peak hours during part of a typical busy day (considering pre-Covid-19 pandemic levels) as to evaluate the system in the most stressed configuration.

A. *Case study 1: Leisure-oriented airport*

The Case study 1 (PMI), is an airport which serves mostly leisure passengers. Some of the main characteristics of these passengers are that they often travel in groups, carry multiple baggage and often arrive at the airport based on tour operators schedules. The airport is a large-size airport that carries around 25 million passengers per year, therefore, the terminal features large areas for check-in, security screening and gates. Moreover, in this airport the shopping/catering areas occupy a large area of the terminal. Table IV shows the passenger profile shares among the different scenarios, while Table V gives an overview of the terminal facilities.

TABLE IV. CASE STUDY 1 PASSENGER PROFILES

Passenger profile	Base case	S1	S2	S3
Business	10%	9%	8%	7%
Visitor	15%	13%	12%	10%
Leisure	75%	68%	60%	53%
Smart	0%	10%	20%	30%

TABLE V. CASE STUDY 1 FACILITIES

Facility	Amount
Check-in counters	204
Boarding pass readers	40
Security lines	19
Gates	75

Physically, the airport has 204 check-in desks available; however, not all of them are in use simultaneously, as they are assigned to ground handlers who in turn assign them to specific flights. Table VI shows the amount of check-in counters used for each ground handler, and the total amount of check-in counters used. As it can be noticed, 80 counters out of 204 are used, leaving room for a better utilization. For this case study, it was assumed that each ground handler would add two more check-in counters and turn them into self baggage drop-off to be used by *smart passengers* only. Regarding security screening, it was assumed that four security lines (out of the 19 available) would be dedicated to *smart passengers*, and would use different technology for body scanning to enable walk-through security screening, leading to a drastic decrease in the processing time as shown in Table II. It is assumed that dedicating 20% of the security capacity to *smart passengers* was a reasonable assumption, but this can be tested in future work with a sensitivity analysis.

TABLE VI. CHECK-IN COUNTER ALLOCATION

Ground handler	Check-in counters used
GH 1	16
GH 2	16
GH 3	8
GH 4	16
GH 5	18
GH 6	4
GH 7	2
Total	80

The case study was run simulating the time-window from 4:00 AM to 10:00 AM which represents the busiest hours of the day, having in total 101 departures and 16,560 passengers expected to transit in the terminal; the traffic was based on real data.

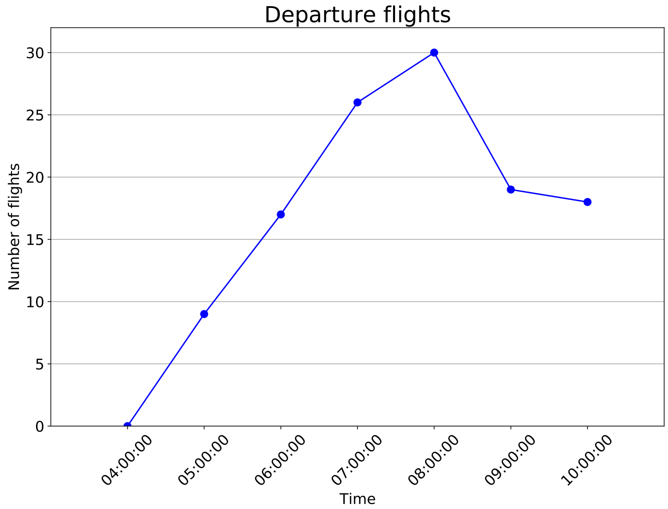

Figure 3. Departure flights over the day (case study 1)

1) Case study 1: Experimental results: In this section we illustrate the results provided by evaluating the different scenarios, focusing on the check-in area and the security area. These graphs present the distinction between passengers' profiles, in this case *smart* and *regular* (business, visitor and leisure). Figure 4 shows the queue length at the check in area, here we notice that the queue length for the *regular passengers* improves by introducing the *smart passengers*, on the other hand, the *smart passengers* queue length has a sharp increase in S2 and S3 when we increase their percentage by 20% and 30%, respectively. In these two scenarios, we observe that the 95% percentile of the *smart passengers* is higher than the one of the *regular* ones. This situation is not ideal, as it would negatively affect the benefit of being a *smart passengers*. This phenomenon is confirmed in Figure 5, which shows that the queuing time for *smart passengers* grows until it exceeds the queuing time of *regular passengers* in S3. The best scenario for *smart passengers* is found in S1, while for *regular passengers* is S3. However, a trade-off can be found in S2, where the queuing time has lowered for the *regular passengers*, while the *smart passengers* can still benefit from a lower queuing time compared to the *regular* ones. This trend reveals that, as the percentage of *smart passengers* increases, the capacity for them is limited, with the consequence of longer queues in check-in. A similar phenomena has been identified in a previous study [16].

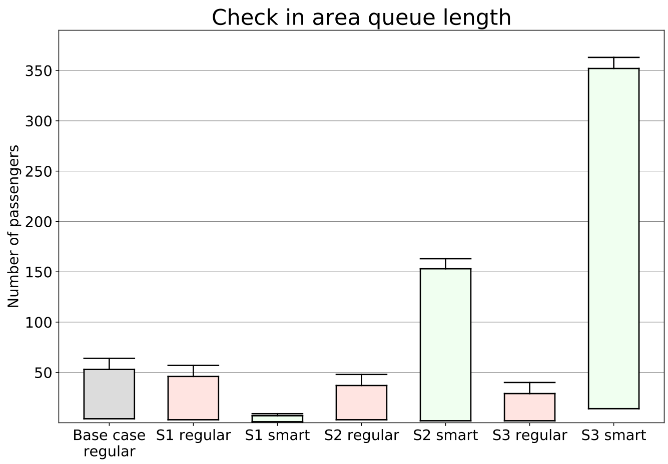

Figure 4. Queue length at the check-in area (case study 1)

Figure 5. Queuing time at the check-in area (case study 1)

In Figures 6 and 7, the security area queue length and queuing time values are depicted. Both graphs show low values of queue length and queuing time, suggesting that, for this specific airport, with this specific traffic and resources, the security area would not be a bottleneck for the system. Scenarios S1, S2 and S3 improve the queue length performance for the *regular passengers* when compared to the 'base case'; however, for all scenarios these values are already low. The *smart passengers* do not present any significant queue length or queuing time for all scenarios, this suggests that the implementation of the *smart passengers* category is not significant for the security area.

Results show that by including specific policies for the *smart passengers* impacts mostly performance of the check-in area, while the security area does not seem to be the affected by it. Furthermore, we identified interesting behaviour. In check-in area *smart passengers*'s indicators degrade as the percentage increases suggesting that the facilities are reaching their capacity. For the *regular* ones, as more *smart passengers* use the facilities, the performance of *regular passengers* is improved. Since the values for *smart passengers* are high, it would be necessary to increase the facilities for them or investigate different policies.

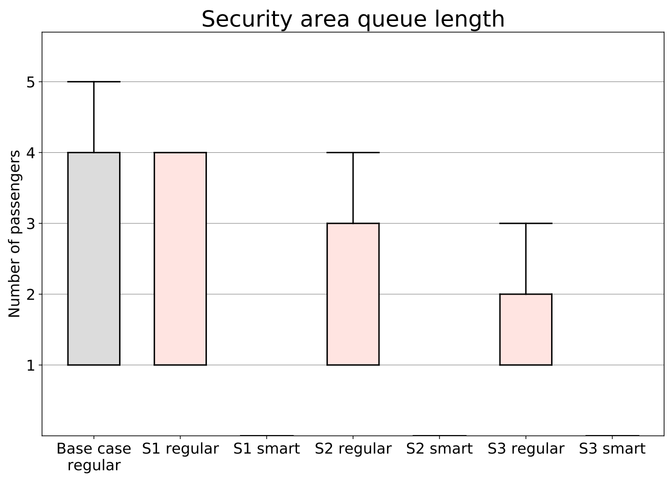

Figure 6. Queue length at the security area (case study 1)

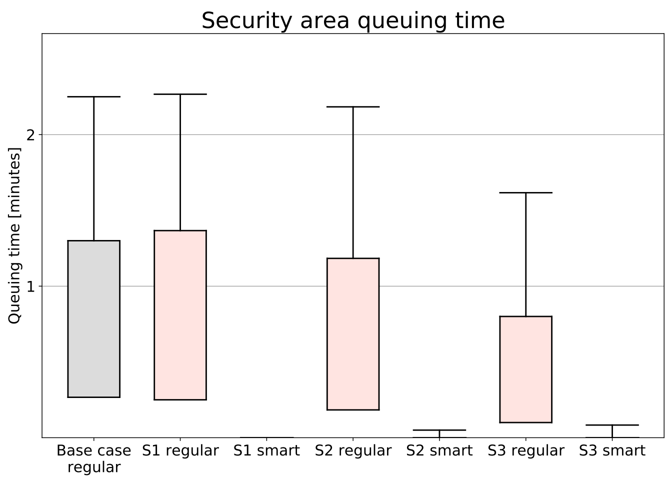

Figure 7. Queuing time at the security area (case study 1)

B. *Case study 2: Business-oriented airport*

Case study 2 considers LCY, an airport largely oriented to business travelers, although used by leisure passengers as well. The business proposition of the airport promotes short periods between the terminal access and aircraft entry. Therefore, fast processing times and low queuing times at the terminal facilities are required. Business passengers are primarily experienced in traveling by air and know the necessary terminal procedures, which leads to relatively lower processing times. These passengers travel mainly with hand luggage, which reduces the check-in time significantly. Table VII exhibits the distribution of passenger profiles. Visitors (passengers visiting friends and relatives) are not considered in case study 2 given the focus on business passengers in the airport's market proposition. The airport is designed compactly to allow short distances between the individual facilities. The number of existing airport facilities are shown in Table VIII.

TABLE VII. CASE STUDY 2 PASSENGER PROFILES

Passenger profile	base case	S1	S2	S3
Business	57%	52%	47%	42%
Visitor	0%	0%	0%	0%
Leisure	43%	38%	33%	28%
Smart	0%	10%	20%	30%

TABLE VIII. CASE STUDY 2 FACILITIES

Facility	Amount
Check-in counters	19
Boarding pass readers	8
Security lines	6
Gates	15

The business-oriented airport focus on the use of electronic, digital, and self-service facilities. The majority of check-in and boarding pass control procedures are performed using self-service kiosks. The check-in desks are primarily available for business travelers and families with infants or small children. During peak periods, the use of check-in facilities at manned and unmanned counters is coordinated by the airport to avoid long waits and queues. The security control is divided in to adjacent areas. The simulation is performed for the busy period between 2:00 PM and 7:00 PM based on a real flight plan, with a demand peak in the second half of this period. The number of departure flights is shown in Fig. 8.

1) Case study 2: Experiment results: Due to the high rate of passengers using a self-service check-in facility, the resulting waiting times and queue length in the base case are significantly lower compared to Case study 1. Less than half of the passengers did not have to wait for check-in, and the average 95% percentile equals approximately 2 minutes. The check-in processes at the business airport are not congested, which results in only small and insignificant improvements by an increasing rate of smart passengers. Since mainly flight experienced business passengers with fewer bags use the airport, the processing times are lower than for the leisure passengers that dominate in Case study 1.

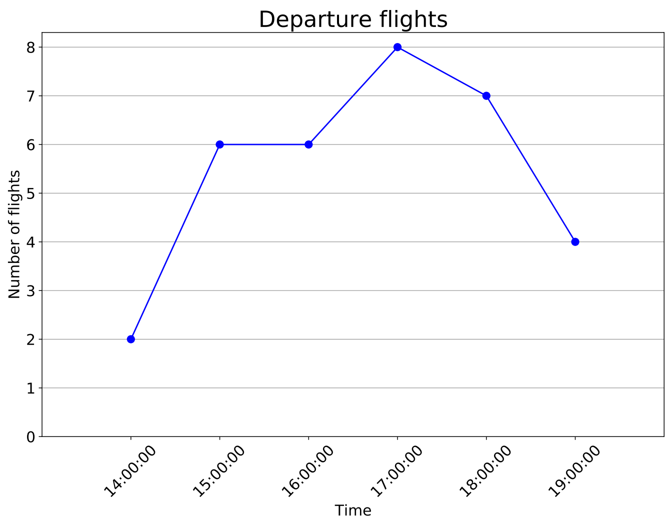

Figure 8. Departure flights over the day (Case study 2)

Fig. 9 exhibits characteristic security area values for all scenarios divided into regular and smart passengers. The median value for the base case shows a low queue length of 10 waiting passengers. However, the 95% percentile and the maximum are significantly higher than the median. This results from a traffic peak during the observed period and the occurring high demand, which exceeds the available capacity at the security facilities. The fast check-in procedure results in a high throughput leading to quick access to the security area. In the scenario considering the introduction of the *smart passengers* (S1), one security lane is dedicated for this passenger type. The regular passengers are using the 5 remaining facilities. Since the share of smart passengers in the first scenario is only 10%, no queue is observed, and the *smart passenger* security lane remains unused most of the time. For the regular passenger, the waiting times are increasing compared to the base case due to the reduction in available capacity for this passenger type. Scenarios S2 and S3 exhibit a shift in queue length figures for the regular passengers as in the previous case study. In particular, the 95% and the maximum parameters decrease by over 60% (S2) resp. 80% (S3) when the proportion of smart passengers is increased. The queue length for smart passengers increases but is still negligible. The median values remain stable in all three scenarios.

A similar result trend can be observed for the waiting time of regular passengers in the security lanes shown in Fig. 10 since queue length and waiting time correlate to each other. It is important to note that as the percentage of *smart passengers* increases, the performance values for the regular ones improve, and the dispersion of values is also reduced, meaning that a better level of service is achieved to all the passengers when more *smart passengers* use the terminal. These results are similar to the ones of the previous case study 1.

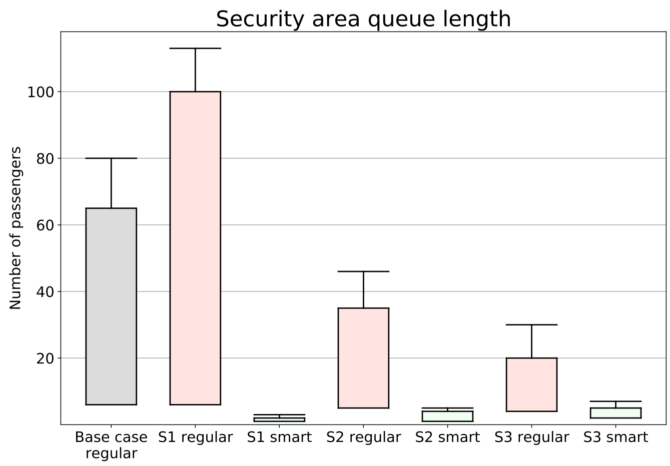

Figure 9. Queue length at the security area (case study 2)

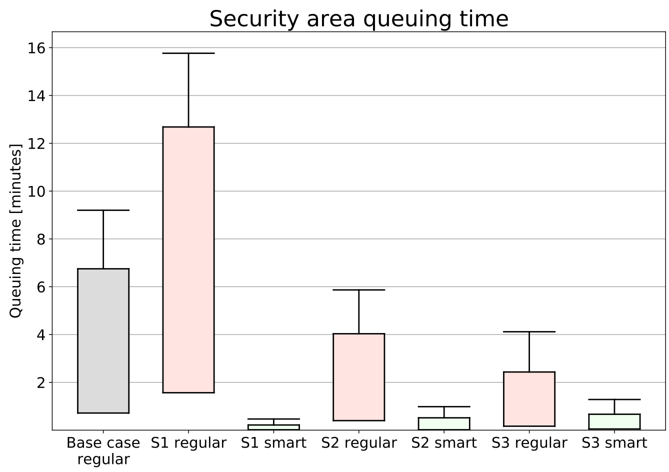

Figure 10. Queuing time at the security area (case study 2)

V. Conclusions and Future Work

This research presented the analysis of introducing a new category of passengers (the 'smart passenger'). These passengers takes more control over its journey with the objective of overcoming in a short time the pain points all passengers face in a terminal for enjoying the non-aeronautical facilities available. By using simulation, the notion of this new passenger type was tested in two airports with very different characteristics (Palma de Mallorca and London City). The simulation of the passenger journey in those airports revealed the potential impact these new passengers might have in the future together with knock-on effects in the system. For a leisure-oriented airport (Case 1), characterized by high peak traffic, the introduction of the *smart passengers* brings benefit both for them and for the regular travelers in the areas analyzed. Problems of capacity appear to *smart passengers* when their proportion grows, an effect already identified in a previous study [16], revealing that there are tipping points when it is necessary to adapt the system for the increasing demand of *smart passengers*. For a business-oriented airport (Case 2) with a high percentage of self-service check-in and digitally-assisted processes, the introduction of *smart passengers* is also positive. However, when the amount of *smart passengers* is low as in scenario S1, the regular passengers suffer from the reduction in capacity for processing them with the consequence of a bigger dispersion in the performance values compared to the base case. Remarkably, when the amount of *smart passengers* increases, the whole system gets the benefit. It is revealed by the reduction of mean and dispersion values in the performance for regular passengers and smart ones bringing an overall better level of service for all the passengers in the terminal. This results suggest that technology together with the incentives for *smart passengers* in terminals would unlock valuable capacity, which in turn would affect positively all the passengers (smart and traditional).

This study opens new research lines which will be explored by the authors in the future. For instance, given that resource management is important, a sensitivity analysis could help identifying what would be the right amount of resources (e.g.security lines or counters) dedicated to the *smart passengers*. Furthermore, as it is documented that variability plays an important role in dynamic systems, an analysis of variance to identify which elements contribute the most to the variability of the system could provide managerial insight. The option of flexible (shared) lines when the amount of *smart passengers* is low, as well as other interesting concepts like virtual queuing or pre-ordered services can also be evaluated. Furthermore, the results of the IMHOTEP Project and survey data available on line could improve the accuracy for the parameters that simulate behaviour. Last but not least other policies will be evaluated like virtual queuing and new designs of airport terminals considering the potential behaviour identified.

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