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An integrated software platform for airport queues prediction with application to resources management

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ABSTRACT

Currently, one of the main issue for both Airport Operators and Passengers is to provide a quick access to the Airport facilities and to prevent congestion during peak periods. Towards this end, this paper proposes an integrated service software platform, that aims at enhancing both the airport management efficiency and the travel experience. Through the use of an analytical approach based on the queueing theory, the proposed platform is able to carefully forecast the waiting time at the security desks as well the required the number of active Security Control Counters, in order to improve the overall efficiency. The accuracy of the obtained analytical predictions has been validated by comparisons with real data obtained from a measuring campaign carried out in an airport environment. Based on the obtained results, the proposed platform can be considered as a practical support to achieve an efficient resource airport management and to improve the passengers Quality of Experience.

1. Introduction

Nowadays, an airport represents one of the largest and most technologically advanced man-made system. Furthermore, the economic relevance of international air transportation is becoming increasingly important in response to the growth of the market demand. One of the main aspects to be addressed in designing an efficient airport system is to assure to customers (usually referred to as *passengers*) a fast access to the facilities, with the aim at mitigating congestion during peak periods. Towards this end, (i) check-in and (ii) security screening procedures represent critical activities both from the airport operators and passengers point of view Gillen and Morrison (2015).

Online check-in, joined with self service kiosks, represents an effective approach to reduce the peak check-in waiting time Ma et al. (2011). Conversely, there are no out-off-the-shelf optimal solutions for security controls, which are typically implemented through: walk-through metal detector, hand-held metal detector, body scanner, dogs and manual inspections. Hence, in order to prevent that a long waiting time at the security desk could have a negative effect on the passengers' satisfaction Kirschenbaum (2013), Airport Operators (AOs) are requested to identify efficient techniques and systems.

This paper deals with the proposal of an integrated service platform to (i) efficiently manage the airport resource and (ii) maximize the passengers satisfaction, as explained in Fig. 1. The platform architecture is modular and integrates several components, among which:

- **Operational Control Center** (OCC) is in charge of *collecting* data by different Airport systems and performing the *data aggregation* with its exchanging in an automated way. Information is provided to both Airport Operator and Passenger via a Graphical User Interface (GUI) with different access levels;
- **Queueing Control Module** (QCM) which applies queueing theory approaches to *predict* the time to be spent waiting in line at the security control system on the basis of additional information provided by external modules. The QCM data can be also sent to the OCC in order to perform decision support process.
- **Resource Management System** (RMS) is in charge of the *monitoring* and optimizing resources assignment according to predefined policies; it accepts as input the information related to the resources status, including queue data.

The focus here is on the design of the QCM by proposing a suitable queueing analytical approach. Additional information, originating from the OCC and RMS, could be provided to the decision support process in order to improve the estimation accuracy of the waiting time at the security control lane, making it close to the actual value. Towards this end, two suitable parameters, named *queue disposal time* and *actual queue waiting time* are introduced. Specifically, we adopted an advanced queueing theory approach Kleinrock (1975), in order to obtain waiting time predictions as close as possible to the real values. The accuracy of our approach will be validated by providing comparisons between analytical predictions and actual values.

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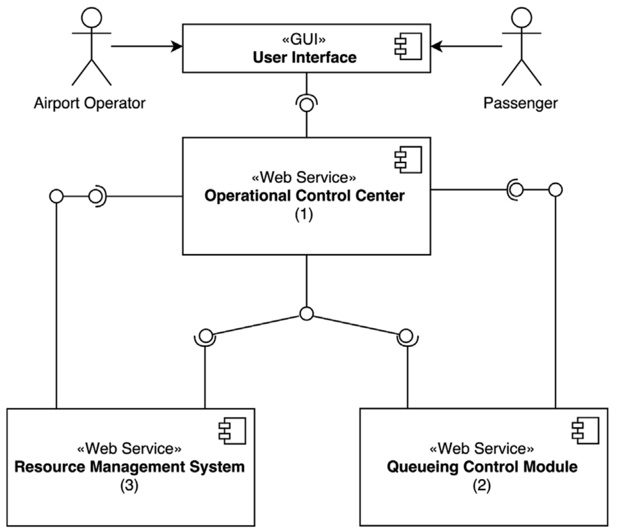

Fig. 1. The figure depicts the way components are logically connected. The system provides customize User Interfaces according to access levels. All components are implemented as Web Services. The OCC (1) module has in charge the decision process. It collects data from airport systems and shares them with the other modules. The QCM (2) receives the queue data in order to forecast the parameters of interest. The predictions are sent to OCC that uses the RMS (3) to control and optimize the resources assignment.

2. Related works

Queuing theory based methods have been widely investigated and applied in several scientific fields, as operation research and computer networks. Recently, queuing theory has been successfully adopted to address several airports features. The vast majority of the scientific literature uses queueing theory as a modeling method by limiting to Poisson arrival distribution. In particular, the $M/M/c$ queue model has been widely applied in characterizing the check-in process Bevilacqua and Ciarapica (2010); Kierzkowski and Kisiel (2015) as well as the passengers security screening process Gilliam (1979). An interesting case study is represented by the Monastir Habib Bourguiba International Airport Mehri et al. (2008), for which a $M/M/c$ model was considered Kierzkowski and Kisiel (2015). Nevertheless, after 9/11 and terrorist threats, the increasing complexity of the airport management makes the $M/M/c$ approach oversimplified, and it is not appropriate in providing accurate predictions in several practical situations, due to the lack of the memoryless property regarding the passengers arrival process Schultz et al. (2010); Paxson and Floyd (1995).

Unfortunately, the application of advanced queueing theory methods to support an efficient security control service planning and management, involves practical considerations and specific additional efforts, that sometimes makes it extremely complex, due to the presence of multiple servers and non trivial passengers arrival processes. This at first sight seems to favor simulation based methods van Dijk (2002); actually, the adoption of computer simulation methods present numerous drawbacks, e.g., they require big data input and an in-depth analysis of the passengers arrival process Robertson et al. (2002), including sociological aspects. Briefly, the simulation techniques, though attractive, are suited only if the equivalent analytic approach complexity is not affordable to be adopted.

The aim of this paper is to propose a low complexity queueing theory based method capable of correctly predicting several *service indexes* related to the airport security checkpoint, and, hence, representing a suitable alternative to any simulation based approach. As first result of our analysis, we show that the passengers arrival process related to a data collection campaign cannot be considered as memoryless. As a consequence, the more general $G/M/c$ queueing model has to be considered. Hence, with the aim of overcoming complexity impairments without loosing the analytic predictions accuracy, we propose here to adopt an equivalent $G/M/1$ model, where the server works c time faster than in the $G/M/c$ case. Comparisons between the obtained analytical predictions and actual data will be provided in order to validate the goodness of our assumption.

3. Queueing system model

At the airport security checkpoint, customers (i.e., passengers), after a successful ID and boarding pass checking, also performed in parallel lines, join an unique *input line*, before accessing the parallel Security Control Counters (SCCs), i.e., body scan and X-ray scan servers. It is worth noting that the arrivals flows, from individual ID and boarding pass checking lines, merge together to became an unique flow at the *input line*. Customers departure from the *input line*, according to the First Come First Served (FCFS) policy to joint a small queue to access the SCC service after arranging the baggage control. For the overall arrival process at the *input line*, we assume that the customers interarrival times have a general distribution and denote with $\mathscr{A}(t)$ the associated generic probability density function (pdf), characterized later in Sec. 4.2 by means of a suited statistic fitting.

Likewise, we assume the customers service time at a SCC as the time elapsed from the departure instant of a queued customer from the input line to the instant of security control completion (i.e., departure from the system). Customers are served on an individual basis, according to the arrival order (FCFS policy). Moreover, the service time of a given customer generally does not influence the service time of whichever customer: this highlights a sort of memoryless property. As a consequence, the passenger service process can be modeled as a stationary *exponentially* distributed process Ω, defined as:

$$\{\Omega(t)\colon t \ge 0\} \tag{1}$$

where $\Omega\sim$ Exponential(μ), with μ the mean service time and $\lambda \doteq 1/\mu$ the resulting mean service rate.

3.1. Analytical model

From the above considerations, it follows that the security checkpoint can be modeled as a $G/M/c$ queueing system with c independent servers (i.e., SCCs) that work in parallel. The passengers are waiting in line (queue) to access the first available server according to the FCFS policy. It is well known from the standard queueing theory, that the complete analysis of a $G/M/c$ queueing system is too complex to be carried out in a closed form. Hence, with the aim at maintaining the attractive features of analytical approaches with respect to the simulation alternatives, we have resorted here to the simplifying assumption of analyzing a $G/M/1$ system, named hereafter as *equivalent* $G/M/1$ system, where the server is c time faster with respect to any server of the $G/M/c$ case Whitt (2002). With the aim at justifying the accuracy of our assumption, we stress that it is well known from the standard queueing theory that a $G/M/c$ and a c time faster $G/M/1$ systems have the same behavior for what concerns the prediction of the time needed for a given passenger to reach the head of the arrival queue when all the servers are busy, that is the case study of interested here. Note (see Algorithm 1) that whenever a passenger asks to the platform to evaluate the expected waiting time when one of more servers are idle the answer is conventionally set to 0.

As known from standard queueing theory, the imbedded Markov chain approach can be adopted to analyze this equivalent $G/M/1$ queueing system Kleinrock (1975); Kendall (1953). The accuracy of our method will be validated in Section 5 by comparing the obtained analytical predictions with actual data. In our case, the imbedded points are represented by the passengers arrival instants at the input line. As a consequence, by observing the queue *state* (i.e., the number of passengers in the input line) at the time instant in which a passenger enters the queue, the Markov property is satisfied and the queue length evolution can be described through the Lindley's recursion equation