PASSENGERS’ FLOW ANALYSIS AND SECURITY ISSUES IN AIRPORT TERMINALS USING MODELING & SIMULATION

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Airport terminal security, Modeling, Simulation, DOE, ANOVA.

ABSTRACT
The focus of this paper is to deal with passengers flow and security issues of an Italian airport terminal, the International airport of Lamezia Terme in Calabria (Italy). The objective is to analyze system performance under different scenarios through a simulation model implemented in Anylogic™. After the modeling phase, the simulation model has been validated comparing simulation results with real system results. The authors use the simulation model for investigating system behavior under the effect different scenarios obtaining varying critical input parameters. The passengers average wait time for reaching the gate area measures system performance.

INTRODUCTION
The importance of an airport is related to its interface function between land and air transportation. An airport is a complex system that dynamically interacts with entities operating in the same location. The airport terminal management is a quite complex task, the a-priori planning of resources allocation must be updated as the time goes by for taking into consideration the stochastic variables that affect terminal processes and activities (flow of people, flow of cargo, inter-arrival times, etc.). Such context has been remarkably complicated by security measures adopted after 11/9 terrorist attacks: a great number of security measures were adopted to avoid new terrorist actions in airport terminals (see Rossiter and Dresner, 2004). Without proper security measures, people could consider the air transportation system as unsafe and could refrain from traveling by aircraft (Branker, 2003).

There are also studies about the airport security; Candalino et al. (2004) study baggage screening strategies using artificial intelligence techniques. Babu et al. (2006) consider the security problem at a US airport. Olapiriyakul and Das (2007) analyze the problems related to the design and analysis of security screening and inspection system. Yfantis (1997) introduces a new baggage-tracking system for improving airport security. In this paper the authors propose a simulation model of the airport of Lamezia Terme (Calabria, Italy) for investigating system performance under the effects of different scenarios characterized by different resources allocation and availability.

THE AIRPORT TERMINAL
As before mentioned, the airport considered in this paper is the International Airport of Lamezia Terme in Calabria, Italy (see Figure 1).

Figure 1: The Airport Terminal of Lamezia Terme

It is the most important terminal of Calabria because of its geographic central position that guarantees connections between the south part of Italy and the most important Italian/International hubs (see Figure 2). The airport has a catchments area of 1200000 passengers per year and air traffic that in 2004 registered 14000 movements (landings and take-offs). The success and
the progressive development of the airport is due to the quality and functionality of the structure, characterized by high quality services (check-in area accessibility, check-in number, shops and baggage hall), by the efficiency of the airport/town connections operated with different transportation vehicles (taxi, cars rent, buses).

The passenger flow in the terminal can be subdivided in three sub-processes:
- departure;
- arrival;
- transfer.

The departure process starts when passengers enter the terminal and finish when they exit from the structure. The arrival process starts when passengers land in the airport and finishes when they exit from the terminal. The transfer process includes operations of the departure and arrival process: passengers are involved in the procedures related to the departure process (security controls) and in some procedures connected to the arrival process. Figure 3 reports the detailed flow chart of the arrival process.

The baggage flow in the airport terminal interests:
- baggage of departing passengers, which, after the check-in operations, are routed to aircrafts by trucks;
- baggage of landing passengers, which are moved from aircrafts to the baggage hall.

THE SIMULATION MODEL

An airport terminal simulation model should describe the system under study in details, but it can have some disadvantages (see Brunetta and Romanin–Jacur, 1999), due to model flexibility: a model implemented to satisfy specific requests could not be applied to solve problems of an airport terminal different from that considered.

On the contrary, a generalized flexible simulation model could be applied to analyze general problems of an airport terminal under different operative scenarios. The focus of this work is to implement a flexible simulation model of an airport terminal that can be easily modified to study any similar terminal.

The simulation model proposed in this paper reproduces all the most important processes and operations of the terminal: passengers, baggage and aircrafts flows. Flight departures and arrivals are scheduled according to the arrival/departure flight timetable of the terminal (see next section from input data analysis).

The model has been implemented using the commercial package Anylogic™ by XJ Technologies. Anylogic™ is a multi-paradigm simulation tool which can be adopted to implement discrete, continuous and hybrid systems, with a great flexibility and user-friendliness; moreover it is 100% Java based.

In particular, for reproducing each process and for increasing the flexibility of the model, different classes have been implemented using the objects of Anylogic™ Enterprise Library. In fact, in each class, it is possible to find objects like:

- queues and delays for entering entities (aircrafts, passengers, baggage);
- selectoutput objects to reproduce entities decision and flows in the model;
- conveyors to move entities along a particular path or to represent their delay time.

The most important classes are:

- Passengers Arrival Process, which generates passengers flowing in the model;
- CheckIn Line that represents the delay elapsed to cover the path to check-in points;
- CheckIn Process to recreate the check-in operations;
- Baggage Process which represents the checked-in baggage handling operations through the terminal;
• **Security Controls** which reproduces the security control points;
• **Passport Controls Operations**, which reflects all the operations related to the passports control process;
• **General Services** which represents all the other processes of the terminal (first aid station, lost & found, hairdresser, WC, etc.);
• **Exit Operations** which includes three different classes for modeling buses stop, car park and taxi service;
• **Baggage Operations** which reproduces all the operations involving baggage;
• **Gates Operations**, which reproduces all the operations for the departure process as well as the operations related to the aircraft boarding and getting off.

**Input Data**

In order to test the simulation model with scenarios similar to real system evolution, we must import all the data related to the departing/landing flights. The data have been organized in two Microsoft Excel spreadsheets: the first reporting the departing flights, the second one reporting the landing flights. Initially the data have been sorted according to different flight companies, then the spreadsheets have been modified for allowing the interface with Anylogic™ java routines. The initial sheet is reported in Figure 5.

**SIMULATION MODEL VERIFICATION AND VALIDATION**

Verification is the process of determining that a model implementation accurately represents the developer’s conceptual description and specifications. The simulation model verification has been made using the debugging technique. The model has been debugged, following an iterative procedure, for finding and eliminating all the bugs due to model translation (translation from the conceptual model to the Anylogic model, or, in other words, to the computerized model). Validation is the process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended use of the model. The data used for validating the simulation model regard national and international passengers flow in the period January 2005 – May 2006. Table 1 consists of such data subdivided per year and per type of passenger. The same data are also available, for the same period, for each origin/destination flight.

**Table 1: National/International passengers**

<table>
<thead>
<tr>
<th>PERIOD</th>
<th>NATIONAL</th>
<th>INTERNATIONAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>01/01/2005</td>
<td>925952</td>
<td>229342</td>
</tr>
<tr>
<td>31/12/2005</td>
<td></td>
<td></td>
</tr>
<tr>
<td>01/01/2006</td>
<td>439961</td>
<td>146262</td>
</tr>
<tr>
<td>31/05/2006</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL pax</td>
<td>1741517</td>
<td></td>
</tr>
</tbody>
</table>

The validation process is made up by three different steps:

- evaluation of the simulation run length;
- global simulation model validation based on the passengers flows in a period of 17 months;
- specific simulation model validation based on passengers flow on the most important Italian flight from and to Lamezia Terme airport.

**Simulation run length**

The simulation run length is usually the first step of the validation process. Such information is used for...
validation, design of experiments and simulation results analysis. We can say that the run length is the correct trade-off between results accuracy and time required for executing the simulation run. To evaluate the run length we use the Mean Square Pure Error analysis (MSPE) considering the number of inspected people per day. Figure 7 shows the experimental error of the number of inspected people per day versus time (expressed in days). After 130 days the value of the MSPE is small enough for assuring the goodness of the simulation model statistic results.

![Figure 7: MSPE Analysis](image)

**Validation**

As before mentioned the validation of the simulation model has been conducted at global and specific level. The global validation compares the real flow of passengers in the period January 2005 – May 2006 with the flow of passengers obtained by the model in the same period. The passengers are subdivided in national and international. Table 1 consists of validation results. The difference between real and model results for national flow of passengers is 5.37% whilst the difference for international passengers is 2.22%.

<table>
<thead>
<tr>
<th>Origin</th>
<th>Destination</th>
<th>Real</th>
<th>Model</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>L.Terme</td>
<td>Roma F.co</td>
<td>215239</td>
<td>203908</td>
<td>5.26 %</td>
</tr>
<tr>
<td>L.Terme</td>
<td>Milano Lin.</td>
<td>105320</td>
<td>99862</td>
<td>5.18 %</td>
</tr>
<tr>
<td>L.Terme</td>
<td>Milano Mal</td>
<td>104155</td>
<td>98101</td>
<td>5.81 %</td>
</tr>
<tr>
<td>L.Terme</td>
<td>Torino</td>
<td>38926</td>
<td>36966</td>
<td>5.04 %</td>
</tr>
<tr>
<td>L.Terme</td>
<td>Bologna</td>
<td>32322</td>
<td>34004</td>
<td>4.95 %</td>
</tr>
<tr>
<td>L.Terme</td>
<td>Venezia</td>
<td>22705</td>
<td>21301</td>
<td>6.18 %</td>
</tr>
<tr>
<td>Roma F.co</td>
<td>L.Terme</td>
<td>215520</td>
<td>204567</td>
<td>5.08 %</td>
</tr>
<tr>
<td>Milano Mal</td>
<td>L.Terme</td>
<td>110617</td>
<td>104900</td>
<td>5.17 %</td>
</tr>
<tr>
<td>Milano Lin.</td>
<td>L.Terme</td>
<td>97738</td>
<td>92701</td>
<td>5.15 %</td>
</tr>
<tr>
<td>Torino</td>
<td>L.Terme</td>
<td>38969</td>
<td>39870</td>
<td>2.26 %</td>
</tr>
<tr>
<td>Bologna</td>
<td>L.Terme</td>
<td>32925</td>
<td>31234</td>
<td>5.14 %</td>
</tr>
<tr>
<td>Venezia</td>
<td>L.Terme</td>
<td>22491</td>
<td>21410</td>
<td>4.81 %</td>
</tr>
</tbody>
</table>

The second validation process compares the real flow of passengers with the flow of passengers obtained by the model for the most important Italian routes. Such validation is useful for understanding if the model correctly subdivides the total flow of passenger among the different routes. Table 4 consists of the second validation results. The difference between the real system and the model is comparable with the previous case. The highest value is 6.18%, the lowest value is 2.26%.

<table>
<thead>
<tr>
<th>Origin</th>
<th>Destination</th>
<th>Real</th>
<th>Model</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1036927</td>
<td>988824</td>
<td>4.64 %</td>
</tr>
</tbody>
</table>

We concluded that, in its domain of application, the model implementation accurately represents the initial conceptual model (verification) and recreates with satisfactory accuracy the real system (validation).

**PRODUCTION RUNS DESIGN**

As mentioned into the introduction, in this paper we propose a simulation model of the airport of Lamezia Terme (Calabria, Italy) for investigating system performance under the effects of different scenarios characterized by different resources allocation and availability. We take into consideration the following factors as input parameters:

- passengers arrival time at the airport before the flight;
- check-in points available;
- security control lines available.

The variation of such parameters creates different operative scenarios characterized by different resources allocation and availability (we specifically refer to check in points and security control lines). Both of them affect the passengers’ average waiting time for reaching the gate area (performance index selected for our analysis). In addition, another important factor affecting
the performance index is the passengers arrival time at the airport before the flight.

For analyzing the impact of such factors on the performance index, we decided to use the Factorial Experimental Design. Table 5 consists of factors and levels used for the design of experiments.

Table 5: Factors and Levels

<table>
<thead>
<tr>
<th>Factor</th>
<th>ID</th>
<th>Level 1</th>
<th>Level 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time before flight (min.)</td>
<td>X1</td>
<td>-180 (-1)</td>
<td>-60 (+1)</td>
</tr>
<tr>
<td>Check-in points</td>
<td>X2</td>
<td>10 (-1)</td>
<td>15 (+1)</td>
</tr>
<tr>
<td>Security control lines</td>
<td>X3</td>
<td>2 (-1)</td>
<td>4 (+1)</td>
</tr>
</tbody>
</table>

Each factor has two levels: in particular, level 1 (-1) indicates the lowest value for the factor and level 2 (+1) indicates the greatest value. In order to test all the possible factors combinations, the total number of the simulation runs is 23. Each simulation run has been replicated 5 times, so the total number of replications is 40 (8x5 = 40). Each replication has a length of 130 days as evaluated by the Mean Square Pure Error analysis.

SIMULATION RESULTS ANALYSIS

The results of the simulation model have been analyzed by means of Analysis of Variance (ANOVA) and Residuals Analysis. The ANOVA partitions the total variability of the performance index (the passengers’ average waiting time for reaching the gate area) in different parts due to the influence of the factors reported in Table 5. Following this way, we can understand if factors affect the performance index, or, in other words, we can write an analytical relation (called meta-model of the simulation model) between the performance index and the factors. We hypothesize that such relation is a general linear statistic model. Let Y be the performance index and x_i be the factors, we can write:

\[ Y = \sum_{j=1}^{k} \beta_j x_j + \sum_{i<j} \beta_{ij} x_i x_j + \varepsilon \]  

\[ \text{k=3} \quad (1) \]

Table 6 consists of ANOVA results, obtained by using the software Minitab.

Table 6: ANOVA results

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Adj MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>X1</td>
<td>1</td>
<td>4764013</td>
<td>173.95</td>
<td>0</td>
</tr>
<tr>
<td>X2</td>
<td>1</td>
<td>6073484</td>
<td>221.76</td>
<td>0</td>
</tr>
<tr>
<td>X3</td>
<td>1</td>
<td>5929707</td>
<td>216.51</td>
<td>0</td>
</tr>
<tr>
<td>X1 * X2</td>
<td>1</td>
<td>4022157</td>
<td>146.86</td>
<td>0</td>
</tr>
<tr>
<td>X1 * X3</td>
<td>1</td>
<td>3733961</td>
<td>136.34</td>
<td>0</td>
</tr>
<tr>
<td>X2 * X3</td>
<td>1</td>
<td>3727133</td>
<td>136.09</td>
<td>0</td>
</tr>
<tr>
<td>X1 * X2 * X3</td>
<td>1</td>
<td>634614</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Error</td>
<td>24</td>
<td>634614</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>31</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

From the ANOVA theory, factors that have a significant impact on the passengers average wait time have a value of \( p \leq \alpha \), where \( \alpha \) is the confidence level (in our analysis \( \alpha = 0.05 \)) and \( p \) is the probability to accept the negative hypothesis (the factor has no impact on the performance index).

According to ANOVA results and to equation (1), graphically reported in figure 8, we can observe that:

- decreasing passengers time before flight from 180 to 60 minutes, the passengers’ average wait time for reaching the gate area increases up to 10 minutes (because of the greater number of people in check in and security control queues just before the flight);
- increasing check-in points from 10 to 15, we can obtain a reduction of the passengers’ average wait time from 7.5 to 2.5 min;
- increasing security control lines from 2 to 4, we have a reduction of the passengers’ average wait time from 7.5 to 2.5 min.

Figure 8: First order effects

The input output meta-model is reported in equation (2).

\[ Y = 14.72 + 7.20 \times x_1 + 2.76 \times x_2 + 2.72 \times x_3 - 2.87 \times x_1 x_2 + -2.67 \times x_1 x_3 - 0.90 \times x_2 x_3 \]  

\[ (2) \]

Equation 2 is the most important result of the analysis. In effect, the input output relation is a powerful tool that can be used for correctly designing passengers’ flow taking into consideration security issues.

The validity of the results, obtained thanks to ANOVA has been confirmed by residuals analysis. From the literature we know that the ANOVA starting hypotheses are: observations normally and independently distributed and observations with the same variance for each possible combination of the factors levels. Such hypotheses have been verified using the graphical tools, based on residuals analysis, reported in Figure 9.

From the Normal probability plot of the residuals, it is possible to observe that the residuals deviation from the normality is not severe, from the Residuals Versus the Fitted Values we can see that the hypothesis of equal variance can be accepted and, the hypothesis of
residuals distributed according to a normal distribution is confirmed by the Histogram of Residuals.

Figure 9: Residuals analysis

CONCLUSIONS

The simulation model recreates, with high flexibility, all the processes and operations of the International airport of Lamezia Terme in Calabria, Italy. The simulation model verification and validation (performed according to real data) shows the capability of the simulation system. The analysis carried out with the simulation model investigate the passengers’ average waiting time before reaching the gate area under the effect of different resources availability as well as in correspondence of different passengers’ behaviour. The input-output model, obtained by means of ANOVA, is a powerful tool for correctly designing passengers’ flow into the airport keeping into consideration security controls. In addition, the results confirm the model flexibility and its possible future applications for analyzing similar airport terminals.

REFERENCES


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