AIRPORT TERMINALS' PERFORMANCE ANALYSIS: A CASE STUDY

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ABSTRACT
The paper presents a simulation model of an Italian airport terminal, the International Airport of Lamezia Terme in Calabria (Italy). The software tool adopted for the simulation model implementation is Anylogic™ by *XJ Technologies*. After the modeling phase, the simulation model has been validated comparing simulation results with real system results. The performance measure chosen for testing system behavior under different operative scenarios is a mean utilization index of the terminal. The output data of the simulation model are then analyzed by means of ANOVA in order to understand how some critical input parameters (number of security check lines, of passport controls and check-ins) affect system performance.

Keywords: Airport terminal performance, capacity factor, DOE, ANOVA

1. INTRODUCTION

Airport terminals (*ATs*) represent a wide area for applying simulation approaches and techniques in order to test systems' performance under different operative scenarios and to evaluate their structural flexibility, see Verbraeck and Valentin (2002).

In particular, airports have a great relevance because of their key-role as an interface between land and air transportation. Moreover, the importance of airports is related to processes and activities of entities which operate in the same location.

According to Tosic (1992) airport terminals' Modeling and Simulation (*M&S*) has advanced significantly. As reported in Brunetta et al. (1999), models implemented provide enhancements in terms of detail, fidelity and user friendliness. As a consequence, their use as decision support tool in airport terminals' design and management is continuously growing. The airport terminals simulation models can be subdivided into:

- *strategic models* which sacrifice the level of detail for increasing simulation speed and flexibility;
- *tactical models* which are characterized by high detail levels in data management and system representation.

The importance of ATs simulation became more and more important after 11/9 terrorist attacks: in effect, after these attacks security becomes one of the most critical issue of the aviation sector. As reported in Rossiter and Dresner (2004) several security measures have been adopted for avoiding new terrorist actions. According to Glasser et al. (2006), several protective measures have been introduced in order to face each type of problem. Fayez et al. (2008) introduce a decision support tool for supporting airport planners and decision makers in the evaluation of the impact of the changing security regulations and how their application in the airport structure impacts on passengers' service level. The security measures are applied in different fields like security controls and screening procedures for airport passengers, baggage and cabin baggage.

Concerning airport terminals M&S, several studies have been carried out. Sherali et al. (1992) propose new approaches for increasing AT performance and improving its capacity, focusing on increasing the operational use of runways. Snowdon et al. (2000) implement a simulation tool in order to help airlines and airports in using advanced technologies to improve passengers' service level. Other research studies are related to M&S of passengers and baggage flow in airport terminals (Brunetta and Romanin-Jacur, 1999), and innovative solutions for supporting future airport developments (Gatersleben and Van Der Wej, 1999).

The focus of this paper is to present a simulation model of an Italian airport terminal implemented for testing system behavior under different operative scenarios. Section 2 reports the description of the airport terminal being considered; in Section 3, the authors present the simulation model implementation. Section 4 proposes simulation results and analysis while conclusions summarize critical issues and results of the paper.

2. THE AIRPORT TERMINAL DESCRIPTION

The airport terminal analyzed in this research work is the International Airport of Lamezia Terme located in Calabria, (south part of Italy) see Figure 1.

Figure 1: The Airport Terminal of Lamezia Terme

This airport terminal has a key-role in the economic scenery of the region. In fact, it connects Calabria with many national and international cities, through scheduled and charter flights. Built in 1976, during the last years, the International Airport of Lamezia Terme has undergone several changes related to its management and structure, causing as primary consequence the increase of the passengers' number per year. The 2006 represents a record-year for the airport because of the increase in the commercial aviation passengers and flights' number due to quality and functionality of the structure and its services as well as the efficiency of the airport/town connections.

3. THE AIRPORT SIMULATION MODEL

According to Jim and Chang (1998) there is an imbalance in passenger terminal, airfield and airspace planning at airport terminals. Making considerations on an airport structure, it is possible to detect three different areas:

- the airspace, the section of the airport used by different aircrafts in flight;
- the airfield, the airport area used for aircrafts ground movements;
- the passengers' terminal, used by passengers, staff and crews.

According to Curcio et al. (2007), an airport simulation model should help users in improving the airport terminal management. In effect Hafizogullari et al. (2002) explain that M&S is the only way to represent large-scale problems like those that characterize airport terminals. In this case, the M&S approach is introduced because of its capability to capture complex relationships, scalability and interdependencies among entities of the system analyzed. In this research work, the authors develop a simulation model for evaluating airport terminal performance. The next section explains the simulation model architecture.

3.1. The model architecture

The simulation model reproduces all the most important processes and operations of the airport terminal, related to:

- passengers;
- baggages;
- aicrafts' flow.

The software tool adopted for the model implementation is the commercial package Anylogic™ by *XJ Technologies*. In particular, for reproducing each process and for increasing model flexibility, different classes have been implemented by using library provided by the software. A deeper description of classes implemented is reported in Curcio et al. (2007). Figure 1 displays the structure diagram of the simulation model.

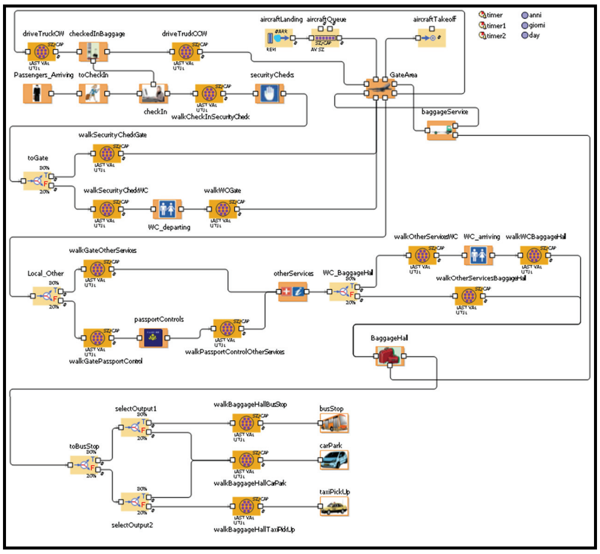

Figure 2: The Structure Diagram of the Model

The structure diagram contains different classes (represented by rectangles) each of them reproducing processes and activities that characterize the real system. More in detail, the approach adopted by authors is the composition approach. As reported in Klein (2000), this approach is based on the segmentation of the system architecture in several functional, geographical components separately implemented. In fact, in this research work the authors implement different functional components, reported as follows.

- *GatesArea*: this is the main class of the simulation model. In this class all the processes and operations related to passengers' departures and arrivals and to aircraft boarding and getting off operations have been implemented.
- *CheckInArea*: this class is implemented in order to reproduce all the operations related to passengers' and baggage check in;

- *SecurityChecksArea*: this class is implemented in order to reproduce all the activities that characterize the security control points;
- *PassportControlsArea*: in this class the operations related to the passport control process are implemented;
- *BaggageArea*, reproduce all the operations related to the baggage hall and the operations related to baggage handling through the terminal;
- *PassengersArrivalArea*: this class reproduces all the operations related to passengers generation ;
- *GeneralServicesArea* which reproduces all the other processes that take place in the terminal;
- *ExitOperationsArea*: this class is introduced for reproducing all the processes related to bus transportation, taxi services and car park.

3.1.1. The SecurityChecks Area

This class reproduces all the operations related to passengers' and baggages' security controls. Figure 3 shows the SecurityChecks Area structure diagram.

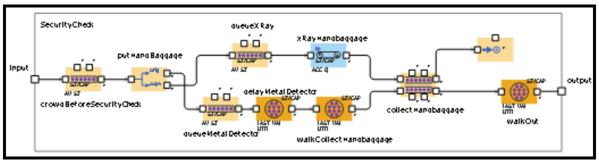

Figure 3: The Security Checks Structure Diagram

The logical sequence of all the activities reproduced in this section by using a block diagram is as follows (see Fig.4).

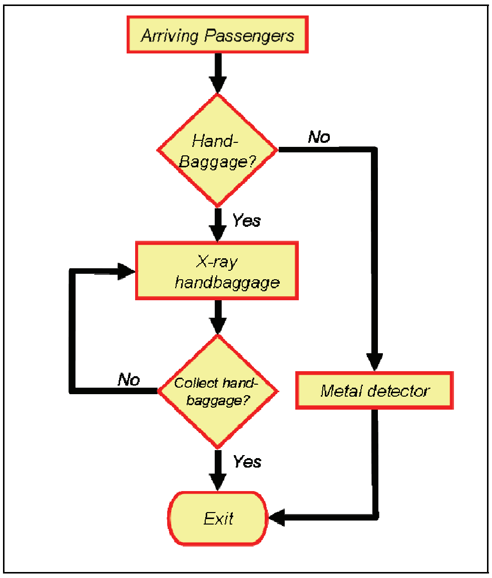

Figure 4: The Security Checks Block Diagram

When passengers enter the Security Check area, they pass through the metal detector while their hand-baggage are checked by X-ray. After taking their hand-baggage, passengers leave the security check area.

3.1.2. The Baggage Area

Figure 5 shows the structure diagram of the Baggage area. This class is implemented in order to reproduce all the operations and activities related to baggage management in the airport terminal (baggage check-in, baggage delivery to/from landing/taking off aircrafts, baggage reclaim, etc.).

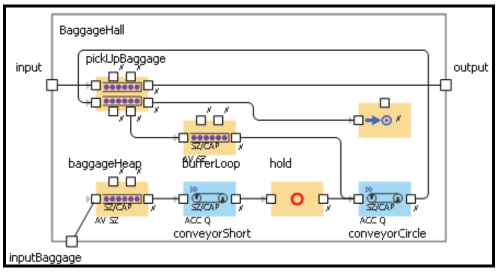

Figure 5: The Baggage Area Structure Diagram

In order to understand more deeply the processes, a block diagram which reproduces in detail the operations related to the baggage hall operations is presented, see Figure 6. Similar approaches have been used for the remaining classes reported in the section 3.1.

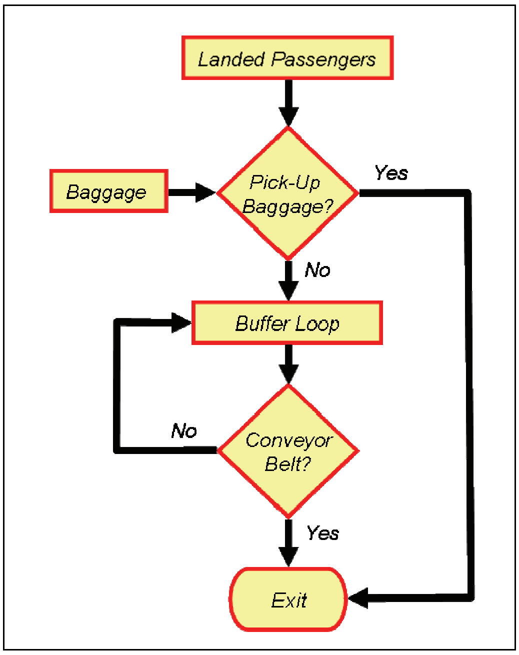

Figure 6: The Baggage Area Block Diagram

3.2. Model verification and validation

The verification of the simulation model implemented is carried out by using an iterative procedure in order to find and eliminate all the possible bugs while the validation is made up by two different steps:

- the first one consists in comparing the historical data about national and international passengers in the period January 2005 – May 2006 and the simulated flow of passengers in the same period;

- the second step compares the real flow of passengers with the flow of passengers obtained by the model for the most important Italian routes.

Figure 7 reports results of the first validation.

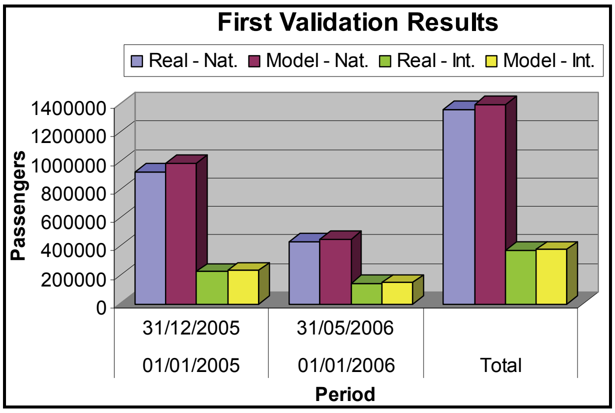

Figure 7: Results of the First Validation

As shown, the difference between real and model results for national passengers is 5.37% while the difference for international passengers is 2.22%: this confirms that the simulation model implemented recreates accurately the real airport terminal.

The simulation run length obtained by using the Mean Sqaure pure Error analysis is 130 days, as reported in Curcio et al. (2007).

4. THE APPLICATION EXAMPLE AND THE DESIGN OF EXPERIMENTS

As before mentioned, the focus of this paper is to implement a model of the Lamezia Terme International airport in order to carry out what-if analysis about its performance under different operative scenarios.

These scenarios are obtained changing system input parameters between specific values. The input parameters (factors) are:

- the number of security control lines (*SCs*) which can assume two different values (2 and 5);
- the number of passport control lines (*PCs*) which can vary from 2 to 5;
- the number of check-in points (*CIs*) which can be changed respectively in 10 and 15.

The combinations of such parameters' values provide different operative scenarios and affect the utilization index (evaluated as the average of the utilization indexes of the of the SCs, PCs and CIs).

For evaluating the effect of each possible parameters combination on the system performance index, the Full Factorial Experimental Design is adopted. Factors and levels adopted for the design of experiments (*DOE*) are reported in Table 1.

Table 1: Factors and Levels of DOE

Factors	***Level 1***	***Level 2***
SC	2 (-1)	5 (+1)
PC	2 (-1)	5 (+1)
CI	10 (-1)	15 (+1)

Each factor has two levels: Level 1 (-1) indicates the lowest value for the factor while Level 2 (+1) represents the greatest value.

In order to test all the possible factors combinations, the total number of the simulation runs is 2^3 (2 levels and 3 factors). Each simulation run has been replicated five times, so the total number of replications is 40 (2^3x5=40).

The output data provided by the simulation model are then studied, according to the various experiments, by means of statistical tools, i.e. the Analysis Of Variance (*ANOVA*), and of several graphical methods.

5. SIMULATION RESULTS ANALYSIS

As before mentioned, the results of the simulation model have been analyzed by means of ANOVA and of several graphical tools.

The ANOVA partitions the total variability of the performance index in different components due to the influence of the factors considered.

According to Montgomery and Runger (2003), the total variability in the data, measured by the total corrected sum of squares SQ_T, can be partitioned into a sum of squares of differences between treatment (factor level) means and the grand mean denoted $SQ_{Treatments}$ and a sum of squares of differences of observations within a treatment from the treatment mean denoted SQ_E, as reported in equation 7.

$$SQ_T = SQ_{Treatments} + SQ_E \qquad (1)$$

More in detail, the difference between observed treatment means and the grand mean defines differences between treatments, while observations' differences within a treatment from the treatment mean can be due only to random errors. As a consequence, examiners can understand how each factor impacts on the performance index introducing an analytical relation (called *meta-model* of the simulation model) between the performance index and factors. In particular, the relation for a three-factor-factorial experiment is:

$$Y = \beta_0 + \sum_{i=1}^{3} \beta_i x_i + \sum_{i=1}^{3} \sum_{j>i}^{3} \beta_{ij} x_i x_j + \sum_{i=1}^{3} \sum_{j>i}^{3} \sum_{k>j}^{3} \beta_{ijk} x_i x_j x_k + \varepsilon_{ijkn} \qquad (2)$$

where:

- Y_{ijkn} is the performance index (utilization index)

- β_0 is a constant parameter common to all treatments;
- $\sum_{i=1}^{3} \beta_i x_i$ are the three main effects of factors;
- $\sum_{i=1}^{3} \sum_{j>i}^{3} \beta_{ij} x_i x_j$ are the three two-factor interactions;
- $\sum_{i=1}^{3} \sum_{j>i}^{3} \sum_{k>j}^{3} \beta_{ijk} x_i x_j x_k$ represents the three-factor interaction;
- ε_{ijkn} is the error term;
- n is the number of total observations.

In this research study, ANOVA is adopted for a twofold reason:

- during the first step, it is used as a screening tool in order to determine which factors are most significant on the performance index (*sensitivity analysis*);
- subsequently, ANOVA allows to make analysis about the most significant factors in order to develop the input-output meta-model and to explain interactions between them.

Table 2 reports the simulation results; the first three columns report the experimental design matrix while the last column contains the simulation results in terms of utilization index (indicated as ATCF, five replications). Table 3 reports the sensitivity analysis results provided by Minitab™: the non-negligible effects are characterized by a *p-value* $\leq\alpha$ where p is the probability to accept the negative hypothesis (the factor has no impact on the performance index) and α=0.05 is the confidence level adopted in the analysis of variance. In this table:

- the first column reports the sources of variations;
- the second column is the degree of freedom (*DOF*);
- the third column is the Sum of Squares;
- the 4th column is the Mean Squares;
- the 5th column is the Fisher statistic;
- the 6th column is the p-value.

In this case the most significant effects are the main effects and the second order effects because their p-value is lower than the confidence level. More in detail, Figure 8 (the Pareto Chart for the Standardized Effects) shows that the most significant effects are:

- SC;
- CI;
- PC*CI.

Table 2: Experimental design matrix and simulation results

Factors			***Utilization Index, ATCF***				
SC	***PC***	***CI***	***Rep1***	***Rep2***	***Rep3***	***Rep4***	***Rep5***
-1	-1	-1	0.835	0.881	0.857	0.873	0.878
1	-1	-1	0.786	0.763	0.791	0.798	0.765
-1	1	-1	0.836	0.823	0.816	0.850	0.828
1	1	-1	0.769	0.758	0.758	0.745	0.756
-1	-1	1	0.801	0.776	0.784	0.803	0.793
1	-1	1	0.728	0.704	0.720	0.733	0.731
-1	1	1	0.790	0.783	0.771	0.773	0.790
1	1	1	0.693	0.806	0.839	0.689	0.716

Table 3: Sensitivity Analysis Results by Minitab™

Source	***DF***	***AdjSS (10^{-3})***	***AdjMS (10^{-3})***	***F***	***P***
Main Effects	4	65,09	21,69	28,91	0
2-Way interactions	1	6,65	2,21	2,95	0,04
3-Way interactions	1	0,38	0,38	0,51	0,48
Residual Error	25	24,01	0,75		
Total	31				

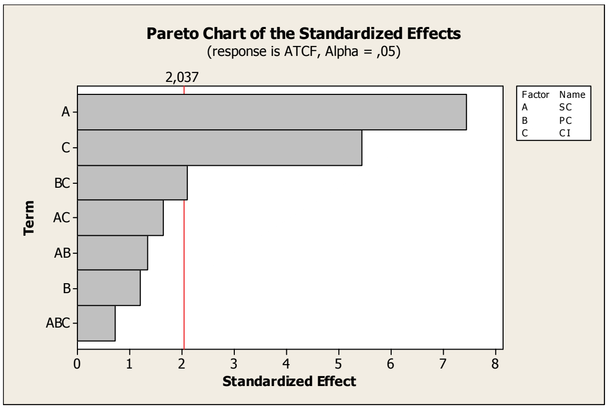

Figure 8: Pareto Chart for the Standardized Effects

This is also confirmed by the Normal Probability Plot of the Standardized Effects reported in Figure 9.

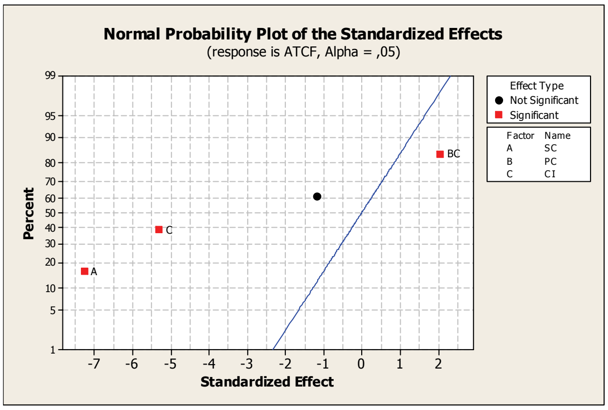

Figure 9: Normal Probability Plot for the Standardized Effect

The input-output meta-model for the airport utilization index is:

$$ATCF = 0.7847 - 0,03228 * SC + \\ - 0,0052 * PC - 0.02358 * CI + \\ 0,00910 * (PC * CI) \quad (3)$$

Figure 10 shows the utilization index ATCF versus the two main effects: the performance parameter decreases when the number of security check and check-in lines increase because passenger flow is not equally distributed among all the security check and check-in points.

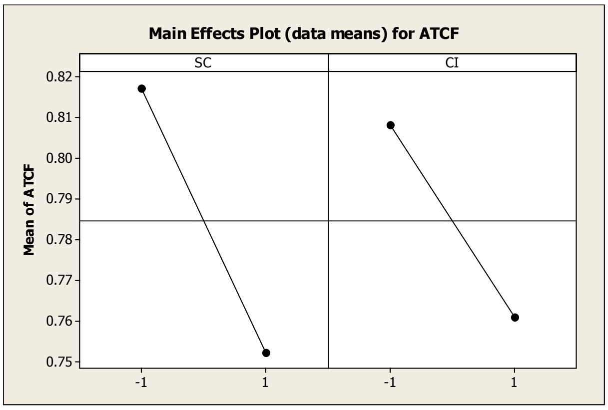

Figure 10: Airport Terminal Capacity Factor versus Main Effects

6. CONCLUSIONS

In this paper a simulation model of a real airport terminal is presented. The software tool adopted for the model implementation is Anylogic™ by *XJ Technologies*. The goal of the research work was the investigation of the system behavior under different operative scenarios. The performance parameter investigated is a mean utilization index including the utilization of check-ins, security control and passports control. The simulation results analyzed by means of ANOVA evidence how input parameters' changes affect the capacity factor of the whole terminal. The final result of the ANOVA is the analytical relation expressing the utilization index as function of the parameters being considered.

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