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

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KEYWORDS

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).

The state of art overview highlights different research works in modeling airport terminal operations. Brunetta and Romanin–Jacur (1999) implement a simulation model to analyze passenger and baggage flow in an airport terminal, Gatersleben and Van Der Wej (1999) analyze the bottlenecks in the passengers flow and provide integral solutions for supporting future airport developments. Modeling & Simulation in airport terminals is widely used for:

- runway capacity;
- parking area capacity and location;
- ramps management;
- baggage handling;
- passengers flows;
- cargo hub management.

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

Proceedings 21st European Conference on Modelling and Simulation
Ivan Zelinka, Zuzana Oplatková, Alessandra Orsoni ©ECMS 2007
ISBN 978-0-9553018-2-7 / ISBN 978-0-9553018-3-4 (CD)

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).

Figure 2: Location of the Airport Terminal

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.

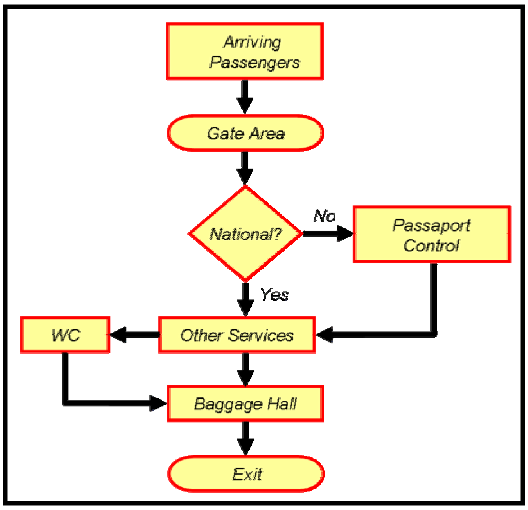

Figure 3: Arrival process

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.

AirLine	DepartureCity	ArrivalCity	Dep.Time	Arr.Time	FlightNumber	Frequ.1	Period
VOLAREWEB	Milano-Linate	L.Terme	6.45	8.20	VA 8268	12345..	GIU1-LUG28
VOLAREWEB	Milano-Linate	L.Terme	6.45	8.20	VA 8268	12345..	SET4-OTT27
HELVETIC.COM	Zurigo	L.Terme	6.45	8.45	2L342	…4…	MAG18-OTT19
HELVETIC.COM	Zurigo	L.Terme	7.20	9.20	2L344	……7	MAR26-OTT22
RYANAIR	London Stansted	L.Terme	6.10	10.05	FR9453	1.3…7	
ALITALIA	Roma-Fiumicino	L.Terme	9.30	10.40	AZ1163	123456.	
ALITALIA	Milano-Malpensa	L.Terme	9.40	11.25	AZ1177	1234567	
AIRONE	Torino	L.Terme	9.55	11.35	LH2830	……7	
ALITALIA	Roma-Fiumicino	L.Terme	10.30	11.40	AZ1169	1234567	LUG5-DIC31
ALPIEAGLES	Venezia	L.Terme	10.45	12.15	E8 1192	12345..	GIU3-SET17
ALPIEAGLES	Venezia	L.Terme	10.45	12.15	E8 1192	1234567	SET18-OTT28
AIRONE	Torino	L.Terme	10.40	12.20	LH2830	…..6.	
MYAIR	Bologna	L.Terme	10.55	12.25	8I 4019	.2.4…6	GIU1-SET17
AIRONE	Torino	L.Terme	11.20	13.00	AP6820	12345..	
ALITALIA	Milano-Linate	L.Terme	11.45	13.15	AZ1175	123456.	LUG1-LUG31
ALPIEAGLES	Venezia	L.Terme	11.50	13.20	E8 1192	123456.	OTT29-DIC31
ALPIEAGLES	Venezia	L.Terme	11.50	13.20	E8 1192	123456.	GEN1-MAR24
MERIDIANA	Verona	L.Terme	11.55	13.30	IG 559	1.3. 5 6.	
AIRONE	Milano-Linate	L.Terme	12.10	13.45	LH2840	1234567	
ALITALIA	Roma-Fiumicino	L.Terme	13.00	14.10	AZ1165	1234567	
ALITALIA	Milano-Linate	L.Terme	13.55	15.35	AZ7923	12345..	LUG3-DIC31
VOLAREWEB	Milano-Linate	L.Terme	14.50	16.25	VA 8268	……7	GIU4-OTT27
AIRONE	Bologna	L.Terme	16.40	18.05	LH2820	1234567	
ALITALIA	Roma-Fiumicino	L.Terme	17.10	18.20	AZ1167	1234567	
VOLAREWEB	Milano-Linate	L.Terme	16.55	18.30	VA 8268	……7	SET17-OTT22
HELVETIC.COM	Zurigo	L.Terme	17.55	19.50	2L346	1……	LUG10-LUG31
HELVETIC.COM	Zurigo	L.Terme	17.55	19.50	2L346	12…..	AGO8-AGO14
VOLAREWEB	Milano-Linate	L.Terme	18.55	20.30	VA 8268	…..6.	GIU3-OTT28
ALPIEAGLES	Venezia	L.Terme	20.00	21.30	E8 1198	…..67	GIU12-OTT28
VOLAREWEB	Milano-Linate	L.Terme	20.00	21.35	VA 8268	12345..	LUG31-SETT1
AIRONE	Venezia	L.Terme	19.05	22.05	LH2882	1234567	
AIRONE	Roma-Fiumicino	L.Terme	21.00	22.10	LH2882	1234567	
ALITALIA	Roma-Fiumicino	L.Terme	21.20	22.30	AZ1173	1234567	
ALITALIA	Milano-Malpensa	L.Terme	21.20	23.05	AZ1181	1234567	

Figure 5: Arriving flight timetable

For example, arriving/departing time of each flight has been converted using the model time unit (second); information about flight frequency are represented using the following format: the value "1" indicates the presence of the flight in that day, the value "0" indicates the absence. In Figure 6 the modified arriving flight timetable is reported.

AirLine	DepartureCity	ArrivalCity	FlightNumber	ArrivalTimeSec	StartP	EndP	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
VOLAREWEB	Milano-Linate	L.Terme	VA 8268	30000	13046400	17971200	1	1	1	1	1	0	0
VOLAREWEB	Milano-Linate	L.Terme	VA 8268	30300	18576000	25833600	1	1	1	1	1	0	0
HELVETIC.COM	Zurigo	L.Terme	2L342	31500	11836800	25142400	0	0	0	1	0	0	0
HELVETIC.COM	Zurigo	L.Terme	2L344	33600	7257600	25401600	0	0	0	0	0	0	1
RYANAIR	London Stansted	L.Terme	FR9453	36300	0	0	1	0	1	0	0	0	1
ALITALIA	Roma-Fiumicino	L.Terme	AZ1163	38400	0	0	1	1	1	1	1	1	0
ALITALIA	Milano-Malpensa	L.Terme	AZ1177	41100	0	0	1	1	1	1	1	1	1
AIRONE	Torino	L.Terme	LH2830	41700	0	0	0	0	0	0	0	0	1
ALITALIA	Roma-Fiumicino	L.Terme	AZ1169	42000	15984000	31449600	1	1	1	1	1	1	1
ALPIEAGLES	Venezia	L.Terme	E8 1192	44100	13219200	22377600	1	1	1	1	1	0	0
ALPIEAGLES	Venezia	L.Terme	E8 1192	44300	22464000	25920000	1	1	1	1	1	1	1
AIRONE	Torino	L.Terme	LH2830	44400	0	0	0	0	0	0	0	1	0
MYAIR	Bologna	L.Terme	8I 4019	44700	13046400	22377600	0	1	0	1	0	1	0
AIRONE	Torino	L.Terme	AP6820	46800	0	0	1	1	1	1	1	0	0
ALITALIA	Milano-Linate	L.Terme	AZ1175	47700	15638400	18230400	1	1	1	1	1	1	0
ALPIEAGLES	Venezia	L.Terme	E8 1192	48000	25920000	31449600	1	1	1	1	1	1	0
ALPIEAGLES	Venezia	L.Terme	E8 1192	48300	1	7171200	1	1	1	1	1	1	0
MERIDIANA	Verona	L.Terme	IG 559	48600	0	0	1	0	1	0	1	1	0
AIRONE	Milano-Linate	L.Terme	LH2840	49500	0	0	1	1	1	1	1	1	1
ALITALIA	Roma-Fiumicino	L.Terme	AZ1165	51000	0	0	1	1	1	1	1	1	1
ALITALIA	Milano-Linate	L.Terme	AZ7923	56100	15811200	31449600	1	1	1	1	1	0	0
VOLAREWEB	Milano-Linate	L.Terme	VA 8268	59100	13305600	25833600	0	0	0	0	0	0	1
AIRONE	Bologna	L.Terme	LH2820	65100	0	0	1	1	1	1	1	1	1
ALITALIA	Roma-Fiumicino	L.Terme	AZ1167	66000	0	0	1	1	1	1	1	1	1
VOLAREWEB	Milano-Linate	L.Terme	VA 8268	66600	22291200	25401600	0	0	0	0	0	0	1
HELVETIC.COM	Zurigo	L.Terme	2L346	71400	16416000	18230400	1	0	0	0	0	0	0
HELVETIC.COM	Zurigo	L.Terme	2L346	71700	18835200	19440000	1	1	0	0	0	0	0
VOLAREWEB	Milano-Linate	L.Terme	VA 8268	73800	13219200	25920000	0	0	0	0	0	1	0
ALPIEAGLES	Venezia	L.Terme	E8 1198	77400	13996800	25920000	0	0	0	0	0	1	1
VOLAREWEB	Milano-Linate	L.Terme	VA 8268	77700	18230400	20995200	1	1	1	1	1	0	0
AIRONE	Venezia	L.Terme	LH2882	79500	0	0	1	1	1	1	1	1	1
AIRONE	Roma-Fiumicino	L.Terme	LH2882	79800	0	0	1	1	1	1	1	1	1
ALITALIA	Roma-Fiumicino	L.Terme	AZ1173	81000	0	0	1	1	1	1	1	1	1
ALITALIA	Milano-Malpensa	L.Terme	AZ1181	83100	0	0	1	1	1	1	1	1	1

Figure 6: Modified arriving flight timetable

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

PERIOD	NATIONAL	INTERNATIONAL
01/01/2005 31/12/2005	925952	229342
01/01/2006 31/05/2006	439961	146262
TOTAL pax	**1741517**	

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 (MS_{PE}) 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 MS_{PE} is small enough for assuring the goodness of the simulation model statistic results.

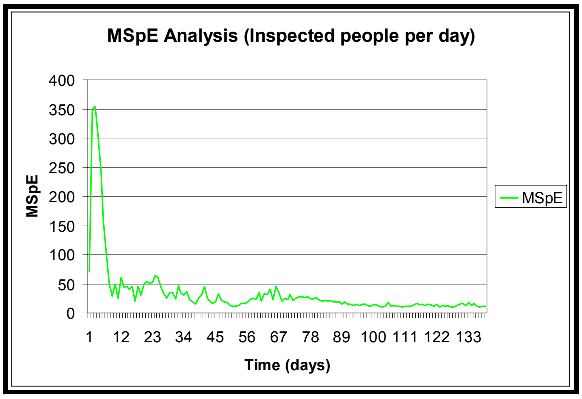

Figure 7: MSpE Analysis

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 3: Results of the Global Validation

	01/01/05 31/12/05	01/01/06 31/05/06	Total
	National	*National*	
Real	925952	439961	1365913
Model	988824	454672	1443496
Difference	6.36%	3.24%	5.37%
	Internat.	*Internat.*	
Real	229342	146262	375604
Model	235349	148542	383891
Difference	2.55%	1.53%	2.22%

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 4: Results of the Specific Validation

Origin Destination	Real	Model	Difference
L.Terme Roma F.co	215239	203908	5.26 %
L.Terme Milano Lin.	105320	99862	5.18 %
L.Terme Milano Mal	104155	98101	5.81 %
L.Terme Torino	38926	36966	5.04 %
L.Terme Bologna	32322	34004	4.95 %
L.Terme Venezia	22705	21301	6.18 %
Roma F.Co L. Terme	215520	204567	5.08 %
Milano Mal L. Terme	110617	104900	5.17 %
Milano Lin. L. Terme	97738	92701	5.15 %
Torino L. Terme	38969	39870	2.26 %
Bologna L. Terme	32925	31234	5.14 %
Venezia L.Terme	22491	21410	4.81 %
	1036927	**988824**	**4.64 %**

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

Factor	ID	Level 1	Level 2
Time before flight (min.)	X1	-180 (-1)	-60 (+1)
Check-in points	X2	10 (-1)	15 (+1)
Security control lines	X3	2 (-1)	4 (+1)

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 2^3. 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:

$$Y = \sum_{j=1}^{j=k} \beta_j x_j + \sum_{i<j}\sum \beta_{ij} x_i x_j + \varepsilon \qquad k=3 \qquad (1)$$

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

Table 6: ANOVA results

Source	DF	Adj MS	F	P
X1	1	4764013	173,95	0
X2	1	6073484	221,76	0
X3	1	5929707	216,51	0
X1* X2	1	4022157	146,86	0
X1* X3	1	3733961	136,34	0
X2* X3	1	5910782	215,82	0
X1* X2* X3	1	3727133	136,09	0
Error	24	634614		
Total	31			

From the ANOVA theory, factors that have a significant impact on the passengers average wait time have a value of $p \le \alpha$, where α 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.

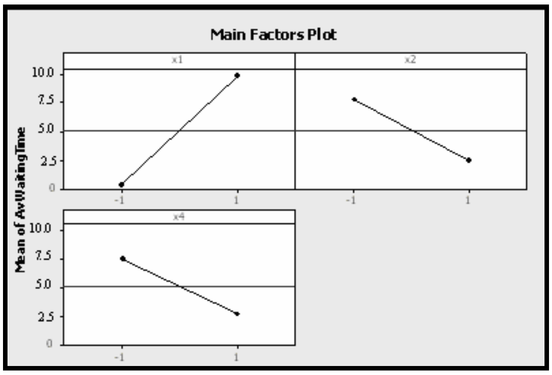

Figure 8: First order effects

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

$$Y = 14.72 + 7.20 * x_1 + 2.76 * x_2 + 2.72 * x_3 - 2.87 * x_1 x_2 + \\ - 2.67 * x_1 x_3 - 0.90 * x_2 x_3 \qquad (2)$$

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*.

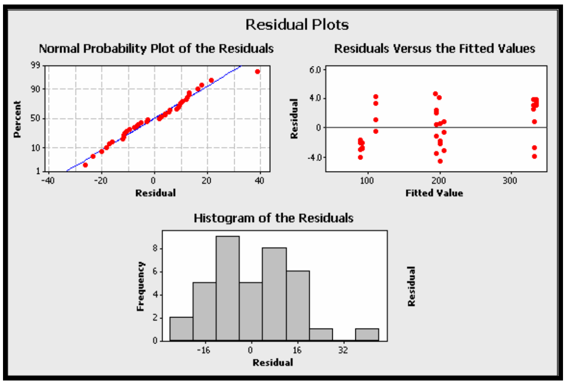

Figure 9: Residuals analysis

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 model to recreate with satisfactory accuracy the real 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.

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