AN APPLICATION OF DEA ANALISYS TO EVALUTATE THE EFFICIENCY OF THE LAMEZIA AIRPORT PASSENGER TERMINAL

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ABSTRACT

This study analyzes the airport passenger terminal structure, and the indicators to verify its efficiency (in terms of spaces and offered facilities), according to the actual and the potential demand.

The passenger terminal is physically formed by two connected sectors for arriving and departing passengers. Incoming passengers, normally, follow a linear way (disembark - transfer - luggage reclaim - exit) and they perceive only some airport facilities. Departing passengers, for all boarding operations, have to explain a forced series of actions, which require suitable spaces and efficient facilities, and determine the terminal level of service.

The study, conforming to the Normative of the Italian National Authority of the Civil Aviation (ENAC), preliminarly references to the structure of the services Charter; successively it has used in joined way two methodologies, the first one to estimate the passengers traffic in the peak hour, by the TPHP method, and the second one to evaluate the quality of facilities, by the application of the Data Envelopment Analysis.

The Data Envelopment Analysis (DEA) has been joined to the TPHP method to identify the essential actions to maintain the terminal facilities at an suitable quality level, in relation to the demand level. The method evaluates the relative efficiency of a terminal, or compares the efficiency of different terminal, and gives a relative measure of efficiency, without the need to expressly determine the production functions for single components of the airport system (check in, baggages handling, safety controls, etc.).

The methodology has been applied to the airport of Lamezia Terme, with the collaboration of SACAL society, corporate body manager of the airport, which has provided the data of traffic and the actual technical characteristics.

Keywords: Airport passengers terminal, Typical Peak Hour Passenger, Data Envelopment Analysis

1. THE SERVICE CHARTER

In June 1999 the National Civil Aviation Authority (ENAC) has founded the Committee for the standard Services Charter of the airport Managers.

The airport Managers are obliged to compile the S.C., and to divulge it through the informative systems (papery and telematic), to make transparent to customers the features of the offered airport services, in the reference year, and to explicit the promise to improve them during the years to come.

The S.C. is a document constituted to improve the quality of the services offered in the Italian airports and the target is to verify the level of customer satisfaction for every terminal service; in the S.C. the results of the sample inquire, annually developed by the Corporate body manager of the airport, the useful information to the customers and the card for possible reports, suggestions and claims, are reported.

The S.C. includes a whole precise appointments by airport manager in theme of trip safety, personal and property safety, service reliability (and means of transport timekeeping), airport cleanliness, airport comfort, other services, information service, staff attitude, counter and control service, modal integration, attention to the pollution.

The quality indicators have to be "measured" through exam of registers related to terminal operations, analysis of functional spaces, direct survey of waiting times and queuing times, customers sample survey.

On the base of the indications of the Committee for the Service Charter, ENAC furnishes airports managers the work methodology, to which they have to follow as it regards the procedures, the investigations and inherent statistic elaborations, and the determination of the quality indicators values. The obligation to verify the achieved results, in relationship to the established standards, derives from Ministerial Order. 27.1.1994 "Principles on the supply of the public services".

The individuated indicators to verify the terminal quality services need different methods of calculation, for objective conditions of survey and elaboration of the data; ENAC foresee four typologies of survey, including:

- verification of the presence of particular airport equipment;
- consumers surveys;
- monitoring of quantitative data;
- exhaustive calculation of particular equipment.

The sample survey is effected on a casual sample of customers; ENAC defines the sample size in function of the airport annual passengers traffic (tab. 1)

Table 1. Sample size referred to total annual passengers

Total annual passengers	Sample size
Until 600.000	400
From 600.000 to 2.000.000	600
Over 2.000.000	1100

The surveys must be performed in two different periods of the year (high and low season); the results, in the S.C., have to reference to the total annual sample submitted to survey. In particular, the measurement of queue times for various operations (check-in, baggage claim) is demanded; customers times of queue are sampled, and average waiting time and distribution of the waiting times are calculated.

ENAC, through the control of the procedures and the measure of quality levels of services offered by the Managers and Vectors (including the Handlers), using the judgments of the Committees of the consumers and of principal terminal operators, identifies the subjects that performed their qualitative standards, and gives suitable publicity.

2. AIRPORT TERMINALS AND FUNCTIONAL SPACES

2.1 The passenger terminal

The primary function of the terminal is that to allow, suitable and with a least number of conflicts, the move and the clearing of the customers and the commodities in the different sectors of the airport and in the connection spaces between inside and outside of the terminal.

The passenger terminal (holding), in particular, is a neuralgic point for the passenger transfer, from the landside to the airside; the terminal services have the double purpose to satisfy the customers demand and to produce profits for the airport Manager.

Before to plan "ex novo" (or to extend) the terminal, it is required to study the potential air traffic and to the analyze the offer of the services (or the inventory of the existing exercises), with the purpose to individuate the functional spaces and their size, that have to be commensurate to suitable qualitative standards, as well as to the respect of the economical and financial budgets.

Usually, the main services of a terminal can be distinguished in two sectors, one related to incoming passengers, the other one to departing passengers, and further classified according to the services and the structures (tab. 2).

The passengers that use terminal can be classified in three principal categories: customers travelling for business, customers travelling for holiday and/or tourism, customers travelling for personal reasons; these three categories present different behaviours. Dealing with departures, for the customers that travel for business, paths and waiting times in the terminal are least, in virtue of the knowledge of boarding procedures and actions. Vice versa, customers that travel for vacation, tourism or for personal reasons, reach the terminal a lot time before their flight, often going along with relatives or friends, and they stop in the area of the terminal for longer times. Then occasional customers, represent therefore the most greater users of the terminal services and they represent an important source of profits for the airport manager. For that reason, the customers characteristics affect substantially the waiting times and therefore the requisite of the functional spaces.

2.2 Capacity and standard levels of service

Functional spaces of the passenger terminal (tab.2) must be sized to the passenger traffic flow, in relation to the queue times of every offered service, but also to the airplanes movements, to customer type and to customer demand. These factors mostly influence the capacity of the passenger terminal and the relative level of service (LOS), that represents the indicator that verifies the quality and the global terminal efficiency.

International Air Transport Association (IATA) defines seven levels of service:

- Level A: excellent service, free flow, direct routes, no delay, excellent level of comfort.
- Level B: high level service, condition of stable flow, high level of comfort.

- Level C: good level of service, conditions of stable flow, acceptable throughput, related sub-systems in balance.
- Level D: adequate level of service, condition of unstable flow, delay for passengers, conditions acceptable for short periods of time.
- Level E: unacceptable levels of service, conditions of unstable flow, subsystems not in balance, ultimate capacity of the system.
- Level F: system breakdown, unacceptable congestion and delays.

Table 2. Terminal services and required spaces

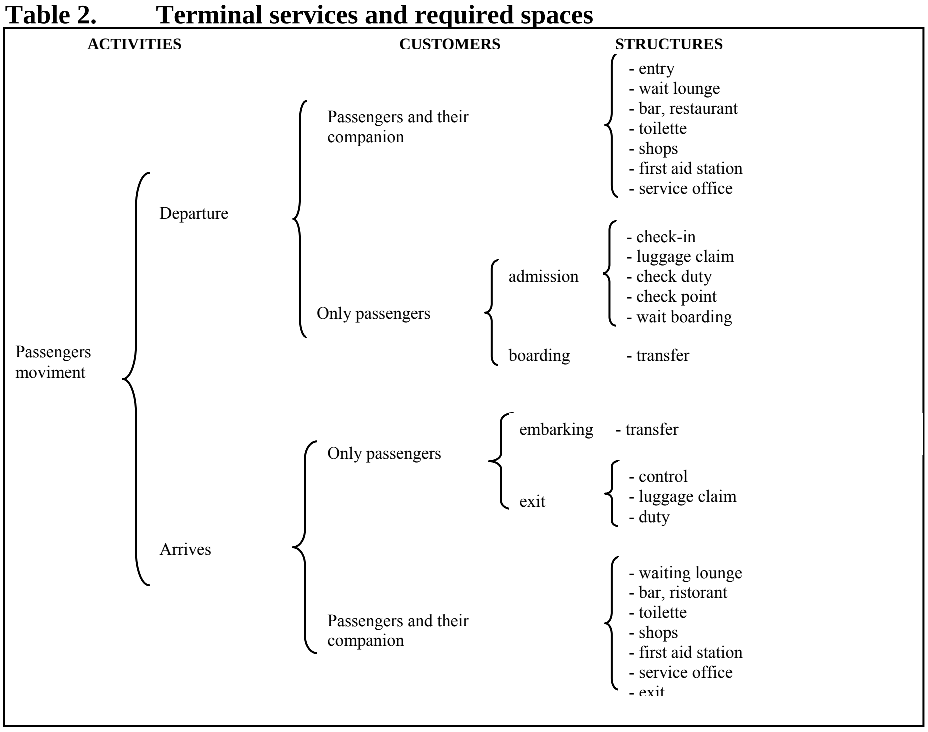

Table 3. IATA Level of Service Space Standards based on Tphp (m^2/passenger)

Level of service (sqm)	A	B	C	D	E
Check-in, queue area	1.8	1.6	1.4	1.2	1.0
Wait / circulate area	2.7	2.3	1.9	1.5	1.0
Hold Room	1.4	1.2	1.0	0.8	0.6
Bag claim area	2.0	1.8	1.6	1.4	1.2
Government inspection	1.4	1.2	1.0	0.8	0.6

LOS is connected both to the typology of the offered services, and to the average available space for every single passenger in the clearing area, in the holding area, and in the circulation area, in a definite period. Therefore, LOS is a measure of the functional qualities of the terminal in the period (and in the hours) of maximum use; LOS can be used to size the terminal spaces, in phase of airport extension or planning (on the base of the potential demand). The elements to determinate the level of service can be acquired through the airport Master Plan, for the terminal areas, and through sample surveys in the terminal. For every LOS, IATA defines standard spaces of different areas (tab. 3)¸ whose values are applicable to plan or to extend the terminal.

2.3 Identification of functional spaces

Dimensions of the required spaces for every single service are function of four fundamental parameters:

- demand in the peak hour;
- typology of passenger traffic;
- analysis of the flows and the identification of individual services volume;
- calculation of the required spaces services.

The knowledge of annual movements of the passengers is fundamental to forecast the potential incomes of airport manager. To size the terminal functional areas, the demand of “thirtieth peak hour” is applied, which is derived from the annual traffic, through appropriate factors of conversion.

In the air transport the definition of the “thirtieth peak hour” it is not univocal, because of the different airport typology, different sequence and typology of passengers flows, different passengers waiting time for every service, different typology of the flight, etc. Between different methods to calculate passenger traffic in the "thirtieth peak hour" the most direct consists in ordering in decreasing way passenger number in every hour of the year and then to choose the thirtieth hour; however, this method could be long and onerous and sometime not applicable. The difficulty to define a clear and single peak hour has induced various airport corporate body, on the base of their own experiences and performed studies, to define specific methods of calculation to forecast it; for example BAA uses Standard Busy Ratio (SBR); Transport Canada uses Planning Peak Hour Passenger (PPHP) and FAA uses Typical Peak Hour Passenger (TPHP). The last method is actually required by ENAC.

The study of the movement of the various categories of passengers through the terminal allows to individuate the busy spaces in the various services, with particular reference to the peak hours. The required space of single terminal services can be calculated in different ways:

- queue theory;
- graphic analysis, with the use of cumulative diagrams;
- simulation models;
- parametric equations;
- DEA method.

3. THE 30TH PEAK HOUR DEMAND (TPHP)

The terminal capacity can be defined as the ability of airport system to provide customer needs in terms of satisfaction and functional spaces.

Capacity definition introduces some objective difficulties for the high number of correlate variable, that condition the terminal operability and the quality services, and for the complexity of the system, that is sensitive to the demand (customers) and to the offer (services) characteristics, and to the flight traffic typology. Besides, the typology of the aerial traffic and the terminal services are not the same for all airports, because every airport is a distinct reality, located in different social, economical and territorial contexts.

The studies to determine the terminal level of service have produced various methodologies of calculus, that have as reference “the average space occupied by a passenger in the terminal, in a definite period of the year and for a definite time” and “the number of passengers present in the terminal, in the period of maximum overcrowding (peak hour)”. To determine traffic in peak hour, Federal Aviation Administration (FAA) has elaborated (and recommends) the use of the Typical Peak Hour Passengers for sizing airport spaces. The TPHP is conceptually similar to the thirtieth peak hour used in road planning. The TPHP is obtained from the product between annual passengers, peak hour factor and directional adjustment factor:

$$TPHP = Mpa * Phf * f_d \qquad \text{(Eq.1)}$$

The following correction factors are recommend from FAA, in relation of the number of annual passengers:

Table 4. FAA recommended correction factors for Tphp

Annual passengers	TPHP (annual flows %)
≥ 30 millions	0.035
20-30 millions	0.040
10-20 millions	0.045
1-10 millions	0.050
500,000 -1 millions	0.080
100,000 -500,000	0.130
≤ 100,000	0.200

In reality, inside the terminal, the system is dynamic, with a non negligible factor represented by the “time of break” of the customers in determinate functional areas and from the times of the casual customers moves across the various devoted areas. Also, in function of embark procedures, there are time intervals in which “customers’ fleets”, coming from the different sectors of the terminal mass themselves near departure gates, safety controls, check-ins, information systems, baggage claim, etc. It derives that a terminal, despite it offers ample spaces, can have in practice a number of problematical areas that make terminal inadequate.

Currently, the studies and the researches devote a greater attention to the dynamics of the movement inside the terminal, both for a real and profitable spaces and services offer, with an appropriate level of service, and for all the customers safety and safeguard conditions within the airport, in general, and inside the terminal particularly.

4. THE DEA METHOD

DEA allows measuring the performances of production units (DMU), as schools, hospitals, public departments, university, bank branches, hypermarkets…, which means organizations that usually pursue multiple targets; the presence of a multiple inputs and outputs makes difficult the comparison between units using traditional methods of efficiency measurement. The technique DEA, developed by A. Charnes, W. Cooper and

E. Rhodes (1978), is born from the need to resolve a not linear multiple object problem, in which we want to maximize output, minimizing required resources (input).

Every DMU uses m different input to produce s different output. In practice the DMU j-th uses a x_{ij} amount of the input i-th in order to produce an y_{rj} amount of the output r-th. Necessary condition is that the inputs and the outputs assume positive values; the efficiency can be generally expressed as the rate of weighted sum of outputs and weighted sum of inputs. So, under hypothesis of n DMU, each one characterized of m input and s output, the relative efficiency of DMU p-th results solving Charnes, Cooper and Rhodes model (CCR model) (1978):

$$\max \quad \frac{\sum_{k=1}^{s} v_k y_{kp}}{\sum_{j=1}^{m} u_j x_{jp}} \qquad s.t. \quad \frac{\sum_{k=1}^{s} v_k y_{ki}}{\sum_{j=1}^{m} u_j x_{ji}} \le 1 \quad v_k, u_j \ge 0 \qquad \forall i, k, j \qquad \text{(Eq. 2)}$$

where $k = 1...s$; $j = 1....m$; $i = 1....n$; y_{ki} is sum of k-th output of unit DMUj; x_{ji} is sum of j-th output of unit DMUi; v_k are weights assigned to k-th output; u_j are weights assigned to j-th input. The problem (1) is very hard to solve; therefore the model has been reformulated in terms of linea programming, thus obtainig two types of linear programming problems used in DEA:

- Output-Oriented;
- Input-Oriented.

The problem maximizes (minimizes) decisional unit efficiency relatively to other decisional units. If the solution value is equal to 1 the DMU is efficient, if solution value is inferior (superior) to 1 the DMU is inefficient. For every inefficient DMU, DEA identifies efficient units that can be used as parameters of improvement in the CCR model.

Table 5. CCR model

Output-Oriented		Input-Oriented	
$\max\limits_{\phi,\lambda,s^+,s^-}$	$g = \phi + \varepsilon(s^+ + s^-)$	$\min\limits_{\phi,\lambda,s^+,s^-}$	$g = \phi - \varepsilon(s^+ + s^-)$
$s.t.$	$\phi Y_q - Y\lambda + s^+ = 0$	$s.t.$	$Y_q - Y\lambda + s^+ = 0$
	$X\lambda + s^- = X_q$		$X\lambda + s^- = \phi X_q$
	$\lambda, s^+, s^- \ge 0$		$\lambda, s^+, s^- \ge 0$

DEA method was subsequently modified by Banker, Charnes and Cooper in 1984, introducing convexity condition; this model, known as BCC model (tab. 6), assumes the following formulation, where X is the vector of inputs used by the DMUs; Y the vector of quantities produced by the DMUs; ε the infinitesimal non-Archimedean constant which assures that no input or output is assigned zero weight, generally indicated as 10^{-6} or 10^{-8}; $e^T = (1,1,.....,1)$; s^+, s^- the slack vector, respectively, of the outputs and inputs; ϕ a scalar variable that represents the possible radial increase to be applied to all outputs;

$\lambda = (\lambda_1, \lambda_2, ..., \lambda_n), \lambda \geq 0$ is the vector whose optimal values form a combination of units which make up the performance of the DMU under study.

Table 6. BCC model

Output-Oriented		Input-Oriented	
$\max\limits_{\phi,\lambda,s^+,s^-}$	$g = \phi + \varepsilon(e^T s^+ + e^T s^-)$	$\min\limits_{\phi,\lambda,s^+,s^-}$	$g = \phi - \varepsilon(e^T s^+ + e^T s^-)$
$s.t.$	$\phi Y_q - Y\lambda + s^+ = 0$	$s.t.$	$Y_q - Y\lambda + s^+ = 0$
	$X\lambda + s^- = X_q$		$X\lambda + s^- = \phi X_q$
	$e^T \lambda = 1$		$e^T \lambda = 1$
	$\lambda, s^+, s^- \geq 0$		$\lambda, s^+, s^- \geq 0$

5. AN APPLICATION TO THE LAMEZIA TERMINAL

Analysis deals with the monitoring and the upgrading of the functional spaces of the terminal. Used procedure is made by the following steps:

- calculation of TPHP for historical traffic data and for traffic forecasts in 2009 and 2015;
- analysis of the dimensions of the functional spaces and of the number of the services, for the years under examination, on the basis of the Master Plan;
- analysis of the queue times, at the ticket-office, at the check-in and at the safety control, resulting from the sample surveys;
- calculation of the level of service (LOS);
- application of DEA method.

5.1 Customers in the 30th peak hour

TPHP values, with regard to departure passengers, (tab. 7) have been calculated for years 1999-2005 on the basis of historical series of annual traffic and for year 2009 and 2015 on the basis of traffic forecasts in the Master Plan.

Table 7. Value of the TPHP for the reference years

Years	Annual passengers	Annual departure passengers	TPHP
1999	719.764	358.783	242
2000	778.445	387.828	247
2001	767.857	383.167	246
2002	895.187	446.590	253
2003	940.562	473.248	251
2004	1.192.496	601.929	295
2005	1.155.294	580.002	288
2009	1.311.000	-	327
2015	1.787.000	-	443

The airport Master Plan indicates the size of the functional spaces in sqm, for sidewalk of approach, boarding lounge, gates lounge, shopping area, vip lounge, refreshments, circulation and check-in area; this includes both the check-in (80%) and the ticket counters area (20%). Data are relative to years 1999 e 2004; from 1999 to 2003 they don't have significant modifications (table 8).

Table 8. Functional areas dimensions

	Functional services	1999	2004	Forecast Master Plan 2009	DEA 2009	DEA 2015
MA	Sidewalk (sqm)	850	850	850	850	850
AP	Waiting area (sqm)	825	784	2552	784	1350
SI	Boarding lounge (sqm)	560	690	1492	690	1020
ACC	Shopping area (sqm)	510	510	510	510	783
SV	Vip lounge (sqm)	84	84	84	84	123
MN	refreshments (sqm)	380	380	380	380	582
CNN	Connective (sqm)	730	730	730	730	1114
AC	Check-in waiting area (sqm)	120	120	166	120	198
ACS	Security control area (sqm)	10	10	10	10	14
AB	Ticket counters (sqm)	31	31	42	31	50
BA	Check-in (n.)	10	10	28	14	19
CP	Passport controls (n.)	1	3	6	3	3
CS	Security control (n.)	2	3	4	3	3
GT	Gates (n.)	4	4	5	4	6
BI	Ticket counters (n.)	4	4	4	8	10

The Master Plan offers an exhaustive prospectus of the structural reality of the airport terminal, such knowledge allows to elaborate possible improvements in the middle and long period.

5.2 Effects of the traffic peaks on levels of service

Terminal passengers problems are related to the queues which occur in proximity of some services, as the ticket-office, the check-in and the safety controls. Queues can be represented through an aleatory process, with Poisson arrivals and service time represented by an exponential variable. The stochastic process primarily depends on the time of service for every passenger and on the rate of passenger flow; the passenger traffic volume in the 30° peak hour (TPHP) is usually adopted to proportion the terminal functional areas.

Departure customers move inside the terminal in casual way on the basis of their habit and his needs; generally the standard path is a chain, that origins from the ticket-office, passes to the check-in, and has final destination at the safety controls.

Nevertheless, sample survey, done in Lamezia Terme airport about departure passengers, points out that while all passengers (100%) have to pass check-in and safety controls, only a part of them use ticket-office (39%), 29% of customers use commercial services, 67% of customers use means services (tab.9).

Average queue times at the ticket-office, check-in and safety controls have been for each year from 2003 to 2006 have been have computed from the sample surveys (tab. 10); the average queueing times have been utilized for the years 1999-2002, for which relieves were not available.

On the basis of peak traffics calculated before, the minimum number of counters, needed to avoid congestion of waiting customers, was computed (tab. 11).

Table 9. Percentage of travellers using selected services

	BI	ACC	MN
2003	13%	25%	51%
2004	53%	43%	71%
2005	44%	28%	77%
2006	48%	20%	69%
Average	39%	29%	67%

Table 10. Queue times (seconds)

Year	Ticket counters	check-in	Security control
2003	181	58	14
2004	231	65	13
2005	191	72	11
2006	168	67	9
Average	193	66	12

Table 11. Minimum number of counters needed to avoid congestion

		Check-in		Security control		Ticket office	
	TPHP	counters	Waiting pax	counters	Waiting pax	counters	Waiting pax
1999	242	5	9	1	5	6	7
2000	247	5	11	1	5	6	7
2001	246	5	11	1	5	6	7
2002	253	5	14	1	6	6	9
2003	251	5	13	1	6	6	8
2004	295	6	11	2	2	7	9
2005	288	6	9	2	2	7	7
2009	327	7	7	2	2	8	7
2015	443	9	11	2	4	10	14

To calculate passenger terminal levels of service the IATA standards were used. The levels of service of the functional areas, calculated on the basis of TPHP and related to the dimensions of the functional spaces in the years since 1999 to 2005, resulted optimal (LOS A). The same functional spaces, referring to the forecasted TPHP, assure a level of service to A in the year 2009, and levels of service A - C in the year 2015, (tab. 12).

Table 12. Level of service of the functional spaces in 2009 and in 2015

	MA	AP	SI	ACC	SV	MN	CNN
Sqm / passenger (2009)	2,60	2,40	2,11	7,80	5,14	8,30	2,23
LOS (2009)	A	A	A	A	A	A	A
Sqm / passenger (2015)	1,92	1,77	1,56	5,76	3,79	6,13	1,65
LOS (2015)	C	C	A	A	A	A	C

5.3 DEA model implementation

DEA has been applied to the airport of Lamezia Terme to appraise the performance of the terminal during the years since 1999 to 2005 (historical data).

The application of the DEA is brought to a linear programming problem with one input and 15 outputs. Target is maximizing output (services) (tab. 13) to satisfy input (passengers, TPHP). Through the software LINGO (a tool to solve linear and not linear programming models and to analyze their solutions) it is possible to calculate the efficiencies of the various DMUs and the possible inefficiency, with the purpose to identify the inadequacies and to upgrade the inefficient DMU to a suitable level.

Table 13. Output

MA	sidewalk (sqm)	CS	security control (n.)
AP	waiting area (sqm)	SI	boarding lounge (sqm)
AB	ticket area(sqm)	GT	gates (n.)
BI	ticket counters (n.)	ACC	shopping area (sqm)
AC	check-in area (sqm)	SV	vip lounge(sqm)
BA	check-in (n.)	MN	refreshment (sqm)
CP	passport control (n.)	CNN	circulate (sqm)
ACS	security control area (sqm)		

DEA calculates the relative efficiencies for every decisional unity (airport status in a specific year) and suggests the actions of improvement. From the computation of the relative efficiency of the decisional unity in the year 1999, it results that the output processes input without congestion, therefore in 1999 the terminal is efficient.

For the following years the relative inefficiency of the DMUs has been calculated according to both departure passengers flow, in the 30th peak hour, and the dimensions of the functional spaces. For every decisional unity, the problem solution points out a potential increase in the outputs (tab. 14), which must be implemented to provide a good LOS. From structural and queue times analysis, it results that terminal problems are tied up to the number of the ticket-office windows.

Table 14. Efficient/Inefficient DMU and relative increase percentage of the outputs

DMU i	Historical series	Input - PAX (TPHP)	Output Increase %
DMU 1	1999	242	0,00%
DMU 2	2000	247	2,06%
DMU 3	2001	246	1,65%
DMU 4	2002	253	1,47%
DMU 5	2003	251	0,67%

In 2015, Master Plan forecasts point out an increase of the passenger flow equal to 36% with reference to year 2004, with the TPHP of 443 customers. The application of the DEA method points out that to assure the efficiency of the terminal in the 2015, services must get a 54% increase altogether (tab. 8).

CONCLUSIONS

DEA allows to identify the necessary actions to improve services, quantifying the increment in flexible way. Results point out as DEA, jointly to the TPHP, supplies an estimatem of terminal functional spaces that assure an adequate operativity of the airport. Functional spaces forecasts for year 2009, reported in the Master Plan, presents a passenger terminal oversized in relation to passenger forecasted flow; in fact, the study pointed out as the Lamezia Terme airport terminal could be efficient also with a minimal retraining of the services (tab. 8). However, the actual strong trend to rise of the air traffic, calls for investments in transport facilities, in order to meet the potential demand.

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