

## An evaluation model for air traffic systems

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Received 16.10.2009

### Abstract

Each system is specifically designed to achieve certain goals, and an important component of systems is regular evaluation processes to determine to what extent these goals are achieved. Air traffic systems are not an exception for the application of such evaluation processes. In fact, there is a great demand in this field for effective and efficient processes of evaluation. This study presents an evaluation method developed by considering the needs or demands of the international civil aviation sector and air traffic systems. This development process includes the initial determination of the areas for evaluation and the designing of various figures of merit for both fields accordingly. This model was applied to the air traffic systems of 16 EUROCONTROL member countries and important results were obtained.

**Key Words:** Air traffic system, system evaluation, figures of merit, air traffic service providers, air traffic service users

### Introduction

Air traffic systems provide services by achieving certain outcomes by processing certain inputs according to certain principles.

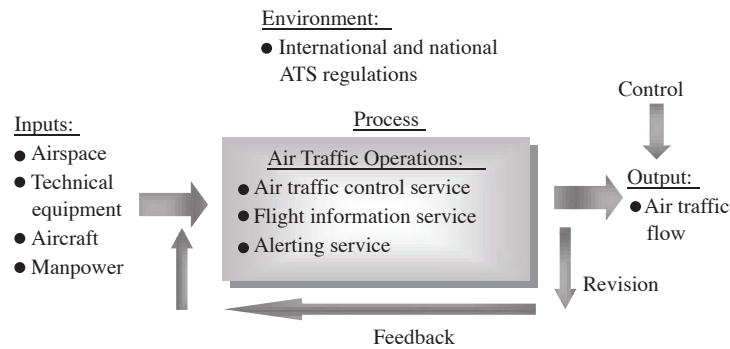
The main function of such systems is to provide air traffic services so as to regulate air traffic flow. For an effective provision of such services, they bring certain components together, such as air space, air navigation technical equipment, aircraft, and human labor (Cavcar, 1998).

The Figure displays the operation of an air traffic system in terms of input-process-output flow.

As the Figure clearly shows, the main inputs of air traffic systems include air space, technical equipment, aircraft, and human labor. Air traffic operations are mainly carried out by bringing this input together within a process that results in regular air traffic flow. In other words, the main output of an air traffic system is air traffic flow.

The main framework of air traffic systems consists of regulations regarding international and national air traffic services, feedback on the service provided and the system capacity (the possible service that can be provided during certain time intervals), and air traffic clearance issues.

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**Figure.** Operation of air traffic system.

It is clear that certain evaluations are necessary to make sound regulatory decisions in air traffic systems. Such evaluations enable air traffic authorities to determine the procedures within the system effectively.

Similarly, evaluation processes are also useful in identifying and eliminating possible problems. In other words, the success level of the system should be known first, and the most effective method to determine this level is to evaluate the system thoroughly. As a result, the problematic areas in the system and the ways to improve it by solving those problems can be the main focus for the authorities.

The main component of evaluation in air traffic systems should be the efficiency of the feedback mechanism, which implies to what extent the attempts to improve the system are successful. At the same time, the factors preventing such attempts from being effective can be determined, and necessary precautions can be taken on time.

Finally, the evaluation process can also lead to higher motivation for employees, especially for managers and air traffic controllers. The main factor affecting this motivational increase is the involvement of all employees in system improvement through evaluation processes (Akal, 1992).

## Background

### Conceptual background

A detailed literature review on evaluation of air traffic systems shows that there is not a clear-cut consensus on the concepts related to the field. The terms that are most frequently used in the related literature are “performance,” “productivity,” “efficiency,” and “effectiveness.” However, these concepts are generally defined in different ways, which leads to serious confusion in the literature.

Therefore, “evaluation,” rather than the terms mentioned above, is used in this study to avoid such confusion.

### Institutional background

Nowadays there is a considerable increase in the number of studies dealing with the evaluation of air traffic systems.

The institutions conducting research on this topic can be classified into 2 main categories:

1. Air traffic service providers and
2. Air traffic service users (recipients).

Since each study is conducted by only one of the parties mentioned above (air traffic service providers or air traffic users), there is a bias regarding figures of merit, evaluation methods, and the related analyses and

comments in such studies. This situation makes it difficult to have objective and accurate evaluations of such systems.

Furthermore, some of these studies are also conducted by some institutions that are not actually air traffic service providers or users, but have close relationships with air traffic service providers or users due to their business activities and institutional goals and missions (Uslu, 2005).

Therefore, in this study, objective and accurate figures of merit and evaluation methods were designed by taking both viewpoints available in the literature into consideration.

Among the major air traffic service providers and other institutions carrying out such studies are the following:

1. ICAO (International Civil Aviation Organization),
2. FAA (Federal Aviation Administration),
3. EUROCONTROL (European Organization for the Safety of Air Navigation), and
4. CANSO (Civil Air Navigation Services Organization).

ICAO is an international institution that is not actually an air traffic service provider or user, but has close relationships with air traffic service providers or users due to its business activities and institutional goals and missions. It has an important function in the evaluation of air traffic systems by establishing some rules and conducting necessary planning.

Although ICAO has not conducted research specifically on air traffic system evaluation, it has invaluable and rich databases, which include statistical data about various issues in international air carriage, such as passengers, cargo and other aircraft services, aircraft accidents, costs, income, expenses, and staff. These data can be used in comparisons and in all kinds of evaluation processes effectively.

The FAA is an institution that is not only a rule setter and planner, but also an air traffic service provider. The FAA generally conducts its studies through the Center for Advanced Aviation Systems Development (CAASD), which is a subsidiary of MITRE Corporation in the USA (Sinnott and MacReynolds, 1998).

EUROCONTROL established the Performance Review Commission (PRC) and founded the Performance Review Unit (PRU) to measure the performances of European air traffic systems in 1998.

The PRC publishes annual reports titled “Performance Review Report” (PRR), which include statistical information about air traffic service providers operating in EUROCONTROL member countries and the definitions and remarks related to the fields for which air traffic service providers are evaluated (EUROCONTROL-PRC/PRR-7, 2004).

CANSO carries out performance evaluations for its members, which are air traffic service providers (CANSO, 2005).

Institutions using air traffic services can be examined in 2 groups:

1. Aircraft operators and
2. Aircraft manufacturers.

As an example of the first group, the International Air Transportation Association (IATA), an organization established by airlines, carries out studies on the evaluation of air traffic systems.

The second group of users of air traffic services is aircraft manufacturers. They are indirect users of air traffic services since they manufacture aircrafts demanded by the aircraft operators. The most outstanding aircraft manufacturing company that conducts studies on air traffic is the Boeing Company. Boeing founded a department called “Air Traffic Management” in November 2000 (Boeing, 2005a). The major aim of the unit is

to contribute to the development of air traffic systems worldwide. Therefore, it carries out various studies on the evaluation of air traffic systems (Boeing, 2005b).

### **Areas of Evaluation of Air Traffic Systems**

The following are the areas of evaluation for which certain figures of merit were developed within the scope of this study:

1. Safety,
2. Delay,
3. Cost,
4. Human resources,
5. Airspace, and
6. Traffic.

### **Figures of Merit Related to the Areas of Evaluation of Air Traffic Systems**

This section will deal with “figures of merit” based on the “areas of evaluation” determined above for air traffic systems.

#### **Figures of merit for safety**

Safety must be a main concern in air traffic systems and be always available, at least, at a reasonable level. For this reason, air traffic systems should be evaluated regularly in terms of safety.

Three factors have been highlighted for the determination of evaluation criteria, namely the total number of flights, density in airspace, and frequency of accidents.

There is a direct proportion between the number of flights and airspace density. In other words, as the number of flights increases, airspace density also increases, and as the number of flights decreases, airspace density also decreases. Similarly, airspace density is in direct proportion with the number of accidents and accident risks. In other words, as airspace density increases, the number of accidents and the risk increases; as airspace density decreases, these numbers and risks decrease, as well.

Here “accident” and “incident” have the following meanings (ICAO-Annex 13, 2001).

An “accident” is an occurrence associated with the operation of an aircraft that takes place between the time any person boards the aircraft with the intention of flight until such time as all such persons have disembarked, in which:

a) a person is fatally or seriously injured as a result of:

— being in the aircraft, or

— direct contact with any part of the aircraft, including parts which have become detached from the aircraft,

or

— direct exposure to jet blast,

except when the injuries are from natural causes, self-inflicted, or inflicted by other persons, or when the injuries are to stowaways hiding outside the areas normally available to the passengers and crew; or

b) the aircraft sustains damage or structural failure which:

— adversely affects the structural strength, performance, or flight characteristics of the aircraft, and

— would normally require major repair or replacement of the affected component,

except for engine failure or damage when the damage is limited to the engine, its cowlings, or accessories; or for damage limited to propellers, wing tips, antennas, tires, brakes, fairings, small dents, or puncture holes in the aircraft skin; or

c) the aircraft is missing or is completely inaccessible.

An “incident” is an occurrence, other than an accident, associated with the operation of an aircraft which affects or could affect the safety of operation.

Due to the linear relationships among these factors, they were considered in the development of a figure of merit for safety. The density of airspace  $\rho$  is the ratio of the total number of flights on a yearly basis  $F$  and the size of the airspace  $A$  in  $\text{km}^2$ .

$$\rho = \frac{F}{A} \quad (1)$$

The number of accidents/incidents is calculated by dividing the number of accidents/incidents by the number of years examined. In Eq. (2),  $ai$  and  $Y$  denote the accident/incident parameter and the number of years examined, respectively.

$$ai = \frac{AI}{Y} \quad (2)$$

According to these 2 parameters, the figure of merit related to safety,  $FM_s$ , can be found by the ratio of the number of accidents/incidents to the density of airspace, as given in Eq. (3).

$$FM_s = \frac{ai}{\rho} \quad (3)$$

The figure of merit given by Eq. (1) measures the density of air traffic in the airspace. As the airspace density  $\rho$  increases, the risk of accident/incident increases and safety decreases. Therefore, the calculations in this equation should be preferably quite small. In other words, the number  $\rho$  is preferred to be as small as possible.

The figure of merit given by Eq. (2) is the calculation of the number of accidents/incidents per year. When the calculations are closer to 0, the success level increases, which is the ideal situation. For this reason, the numerator (the total number of accidents/incidents) should be 0 to obtain this ideal situation.

The figure of merit (3),  $FM_s$ , which is obtained by using figures of merit (1) and (2), should also be ideally small, because the figures of merit (1) and (2) that form the numerator and denominator of the figure of merit given by Eq. (3) are preferred to be as small as possible. Thus, the fact that the numerator and the denominator should be ideally small in the figure of merit given by Eq. (3) leads to the result that  $FM_s$  will be small, as well. The lower the results are, the higher the success level is regarding the safety of the system.

### Figures of merit for delay

Delays can occur in different phases of flight, namely during takeoff, landing, and flight (EUROCONTROL-PRU, 1999). However, almost all of the analyses, statistics, and databases are related to delays during takeoffs. Therefore, the figures of merit developed in this study deal with delays during takeoffs.

Takeoff delay is the difference between the scheduled takeoff and real takeoff time. Scheduled takeoff time refers to the time specified in the flight plan.

Two factors are important in determining the figure of merit for delay:

1. Duration of delay and

2. Number of delayed flights.

There is a direct proportion between the duration of delay and the number of delayed flights. In other words, as the duration of delay increases, the number of delayed flights increases, since each delayed flight causes other delays consequently.

Similarly, an increase in the duration of delays leads to a decrease in the success level of an air traffic service provider and its service quality.

This study uses 2 figures of merit developed by using “duration of delay” and “number of delayed flights.” The first figure of merit is shown in Eq. (4) as  $FM_{D_1}$ . Here  $\Delta T$  and  $F_d$  denote the total duration of delays in minutes and the number of delayed flights, respectively.

$$FM_{D_1} = \frac{\Delta T}{F_d} \quad (4)$$

The second figure of merit for delay, which is shown as  $FM_{D_2}$  in Eq. (5), is the ratio of the number of delayed flights  $F_d$  to the total number of flights.

$$FM_{D_2} = \frac{F_d}{F} \quad (5)$$

The figures of merit given by Eqs. (4) and (5) are related to “duration” and “number,” respectively. Therefore, both dimensions of delay are calculated.

The duration of delay per delayed flight can be calculated by using the figure of merit given by Eq. (4). If the result obtained by this figure of merit is closer to 0, it means an increase in success level.

The figure of merit given by Eq. (5) is used to determine the ratio of delayed flights to the total number of flights. If the result obtained by this figure of merit is closer to 0, it means an increase in the success level of the air traffic system.

**Figures of merit for human resources**

This study assumes an increase in the workload of air traffic controllers, which highly depends on the number of aircrafts in air traffic and the size of airspace, and this situation causes a decrease in service quality.

In this study, 4 figures of merit were used regarding human resources. The first,  $FM_{H_1}$ , is the ratio of the total number of air traffic controllers  $N_C$  to the total number of staff  $N_T$ .

$$FM_{H_1} = \frac{N_C}{N_T} \quad (6)$$

The second figure of merit used for this issue is given in Eq. (7), which is the ratio of the total number of flights to the total number of air traffic controllers.

$$FM_{H_2} = \frac{F}{N_C} \quad (7)$$

The third figure of merit shows the airspace size per air traffic controller and is given in Eq. (8).

$$FM_{H_3} = \frac{A}{N_C} \quad (8)$$

Finally, the fourth figure of merit displays the distance flown  $L$  per air traffic controller and is given in Eq. (9).

$$FM_{H_4} = \frac{L}{N_C} \quad (9)$$

Except for the figure of merit given in Eq. (6), the results obtained by using the remaining 3 figures of merit imply positive results, provided that they have lower values. In other words, if the value is low, the levels of safety and service quality are considered high. As for the results obtained from the figure of merit given in Eq. (6), they are regarded as valuable if they have a high value, that is, if they converge to 1. The reason for this situation is that air traffic controllers, as the human resources available for air traffic services, have the primary responsibility in an air traffic system.

### Figures of merit for cost

Air traffic services are one of the considerable costs for users. Therefore, air traffic service providers feel it necessary to provide optimum safety at a minimum cost, especially in the long run. While developing figures of merit for cost, service providers should keep in mind that safety standards and regulations should not be ignored or violated (EUROCONTROL-PRU, 1999).

Among some possible costs emerging during provision or use of air traffic services are the following:

1. Staff cost and
2. En route charges.

Developing figures of merit for such costs enables those concerned to carry out detailed calculations regarding the cost analysis of an air traffic system.

Staff costs are an important component of any air traffic system, and wages constitute a considerable percentage of this type of cost.

The figure of merit used for staff costs herein is given in Eq. (10).

$$FM_{PC} = \frac{C_C}{C_T} \quad (10)$$

Here,  $C_C$  denotes air traffic controller cost and  $C_T$  total cost. The expected result in this equation is not a low air traffic controller cost. On the contrary, service providers prefer this cost to constitute an important proportion of the total cost. As mentioned earlier, the most significant staff members in air traffic systems are air traffic controllers, because they have the primary responsibility in the provision of air traffic services. A high percentage of air traffic controller cost in the total cost is an indicator of the presence of high quality service and a considerable level of success. This approach matches the one used earlier while developing figures of merit for human resources. In short, it can be concluded that quality and success are quite high when the result obtained is closer to 1.

En route charges are those paid by airspace users when they use particular airspace, radio navigation aids, and air traffic services. Also called user charges or navigation charges, these charges change according to aircraft weight, distance flown within the particular country, and the unit charge applicable in the country (Doganis, 1998).

While en route charges are a source of income for air traffic service providers, they are a considerable cost item for users. Especially for big airlines, en route charges constitute 4% of operating costs. When we consider that fuel costs, one of the main cost items of airlines, constitute almost 10% of total cost, we can get an idea

about the importance of en route charges for those companies. Thus, there is a great demand by users of air traffic service providers to lower charges (Fron, 1998).

En route charges are an important income for service providers. Otherwise stated, an en route charge is the unit sale price for air traffic service. Hence, costs are taken into consideration to a great extent while adjusting the charge. In short, it can be said that a high unit rate means a high cost for the service provider, and a low unit rate implies a low cost.

Users may assume that a low unit rate is likely to lead to an increase in the success level of the air traffic system as well as service quality. However, a high unit rate results in fewer customers, and, therefore, less income in the long run, although it might seem to bring more income in the beginning. This situation is highly likely to affect the success level negatively in the long run.

Based on the ideas presented above, the figure of merit used regarding en route charges herein is “unit rate predetermined for each system, *EC*.”

$$FM_{EC} = EC \tag{11}$$

**Figures of merit for airspace**

The following components are essential in the subject of air space evaluation:

1. Adequacy of technical equipment,
2. Military (special use) airspace, and
3. Ideal flight route.

*Adequacy of technical equipment* Technical equipment refers to machinery-based components of an air traffic system, which are a combination of human and machinery systems.

Radio navigation equipment is used in airspace both to determine the routes and to provide service to users.

VHF omnidirectional ranges (VOR), distance measuring equipment (DME), nondirectional beacons (NDB), and instrument landing systems (ILS) are the most commonly used navigation aids in the field of civil aviation.

If technical equipment is inadequate in an air traffic system, flight delays, route changes, and even flight cancellations increase. Furthermore, collision risk or air proximity increases. In a sense, the safety level of the system decreases.

In this study, the figure of merit for the adequacy of technical equipment is determined by calculating the ratio of the number of technical equipment to the size of the airspace.

$$FM_{TE_1} = \frac{n(TE)}{A} \tag{12}$$

By applying this figure of merit to various types of technical equipment one by one, several figures of merit can be obtained, such as (12a), (12b), (12c), and (12d).

$$FM_{TE_{1a}} = \frac{n(VOR)}{A} \tag{12a}$$

$$FM_{TE_{1b}} = \frac{n(DME)}{A} \tag{12b}$$

$$FM_{TE_{1c}} = \frac{n(NDB)}{A} \tag{12c}$$



$$FM_{TE_{1d}} = \frac{n(ILS)}{A} \quad (12d)$$

In airspace, the length of flown routes shows the level of airspace use. The increase in this level implies the success of the relevant air traffic system. On that point, another figure of merit can be used.

$$FM_{TE_2} = \frac{L}{A} \quad (13)$$

If the values to be obtained from the calculations made by using these figures of merit are high, it shows high quality and a considerable success level for this particular air traffic system.

*Military (special use) airspace* A great percentage of available airspace is used by both military and civil airplanes, which might impose some restrictions on civil flights. The reason for these restrictions is that military aircraft use airspace, routes, and flight levels used by civil airplanes. Also, due to national security issues, civil flights are restricted. In that matter, the level of success and the quality of the air traffic system decrease.

The figure of merit developed based on this approach is as follows.

$$FM_M = \frac{A_M}{A} \quad (14)$$

In Eq. (14),  $A_M$  denotes the total size of military air space.

The closer the value obtained from this equation is to 0, the more successful the system is.

*Ideal flight route* Aircraft follow the airways already published in aviation publications (Fron, 1998). The structure of airways in airspace may change according to each air traffic system. In other words, they are longer in some systems while shorter in others.

What is meant by the phrase “ideal flight route” in this paper is the “great circle distance” between 2 destinations.

“Great circle” refers to a circle dividing the earth into 2 equal parts, connecting any 2 points in the world. The center of this circle is the same as that of the earth. The shortest distance between 2 points is the curve of the great circle intersecting these points. “Great circle distance” is the distance measured on the great circle.

Any deviation from the great circle during the flights made between any 2 destinations implies a deviation from the ideal flight route. Due to predetermined routes, many deviations from ideal routes are observed during regular flights. These deviations result in flying longer distances and therefore lead to more time wasted and higher costs (Bradford et al., 2000). The ultimate consequence of these negative situations is lower service quality and more cases of failure.

Fron, in his study, claims that direct flights to any destination save 450 million euros and lead to 5% less air pollution on a yearly basis (Fron, 1998).

According to Castelli et al., the deviations from ideal flight routes result in approximately 9% extra fuel consumption (Castelli et al., 2003).

The figure of merit developed for the purposes of this study called “ideal flight route” is given below.

$$FM_R = L_T - L_I \quad (15)$$

In Eq. (15),  $L_T$  denotes true route length and  $L_I$  ideal route length.

The results to be obtained from Eq. (15) are more positive if these values are lower, since the differences show the deviations from the ideal flight route. The higher the deviation from the ideal flight route, the lower the success and quality are.

In this study, the length of the ideal and the true route between 2 airports in any country in the sampling was measured. The airports mentioned here have been determined by choosing the farthest ones from each other in that specific air traffic system.

**Figure of merit for traffic**

The figure of merit for traffic was based on statistical data. The figure of merit used in this study is given below.

$$FM_T = \frac{(F_i - F_{i-1})}{F_{i-1}} * 100 \tag{16}$$

In this equation,  $FM_T$  denotes the figure of merit for traffic,  $i$  the  $i$ th year, and  $F_{i-1}$  the total number of flights carried out in the previous year.

The results obtained from this figure of merit show the possible increase or decrease in the amount of traffic in percentages within a 1-year period. Here, a high percentage implies growth and improvement in the system. Otherwise stated, a high percentage is considered positive, while a low percentage is negative. For this evaluation, the evaluator has the initiative to change the time interval (such as 1 year or 5 years) and make the calculations accordingly.

**Applications of Figures of Merit**

**The Aim of the Application**

The application basically aims at evaluating the air traffic systems of 16 countries, members of EUROCONTROL, according to the figures of merit summarized in Table 1.

**Table 1.** Areas of evaluation and figures of merit for air traffic systems.

Areas of Evaluation	Figures of Merit
Safety	$\rho = \frac{F}{A}$ $ai = \frac{AI}{Y}$ $FM_s = \frac{ai}{\rho}$
Delay	$FM_{D1} = \frac{\Delta T}{F_d}$ $FM_{D2} = \frac{F_d}{F}$
Human Resources	$FM_{H1} = \frac{N_C}{N_T}$ $FM_{H2} = \frac{F}{N_C}$ $FM_{H3} = \frac{A}{N_C}$ $FM_{H4} = \frac{L}{N_C}$
Cost	$FM_{PC} = \frac{C_C}{C_T}$ $FM_{EC} = EC$
Airspace	Adequacy of technical equipment: $FM_{TE1} = \frac{n(TE)}{A}$ $FM_{TE2} = \frac{L}{A}$ Military (special use) airspace: $FM_M = \frac{A_M}{A}$ Ideal flight route: $FM_R = L_T - L_I$
Traffic	$FM_T = \frac{(F_i - F_{i-1})}{F_{i-1}} \times 100$

**Application model**

The evaluation model used in this paper was based on the comparison of the air traffic systems of 16 EUROCONTROL member countries, ranking them according to the success levels calculated. The adequacy and

success of air traffic systems evaluated here were determined through comparisons among themselves rather than through individual evaluations.

The evaluation points for each country within the framework of the study were calculated through the comparisons of the results obtained.

The evaluation points reveal the ranking of the success level of each country's air traffic system.

The highest possible number of evaluation points (good) was the number of countries included in the sample, 16. Later, the points were sorted, starting from the highest downwards.

Points for each air traffic system were calculated for each area of evaluation. In addition to points and success rankings for each area of evaluation, means for total points obtained were also calculated, and similar points and success rankings were assigned accordingly.

### **Sampling**

Since the most accurate and more detailed data regarding the figures of merit in the evaluation model are available for the year 2004, calculations were based on that year's data.

The selection of the air traffic systems in the sampling were based on the data displaying the "total number of flights on a yearly basis" in 2004 for each of the 34 countries that are members of EUROCONTROL. The air traffic systems of 16 countries whose number of total flights were over 500,000 per year were included in the study.

### **Result of the Application Model**

Since the calculation tables prepared using the data regarding the air traffic systems of the countries in the sampling and the calculations made were quite great in number, they are not displayed here one by one. Only the highest and lowest values are shown in the tables.

#### **Application of figures of merit for safety**

As can be seen in Table 3, the highest evaluation points, 16, belonged to Belgium-Luxemburg, the result being 0.02. According to this result, it can be concluded that Belgo Control was the safest air traffic system in the sampling. The calculations made also showed that UK NATS was found to be the most risky air traffic system, since it had the lowest evaluation points at 1, the result being 7.07.

#### **The application of figures of merit for delays**

According to figure of merit (4), the highest evaluation points were calculated for Austro Control, NAVIAIR, and DHMÍ, the results being 0. The lowest evaluation points, on the other hand, belonged to HCAA, with an average delay of 37 min per delayed flight.

According to figure of merit (5), the highest evaluation points were calculated for Austro Control, NAVIAIR, and DHMÍ, the results being 0. The lowest evaluation points belonged to Skyguide, which received only 3 points, the result being 0.240.

**Table 2.** Countries in the sampling and air traffic systems (EUROCONTROL-PRC/PRR-5, 2002).

Countries	Short Name	Full Name	Owner and Operator	ACC <sup>a</sup> Num. Num.	APP <sup>b</sup> Num.	TWR <sup>c</sup> Num.
Germany	DFS	Deutsche Flugsicherung GmbH	State	5	5	17
Austria	Austro Control	Austro Control	State	1	6	6
Belgium	Belgo Control	Belgo Control	State	1	3	5
Czech Republic	ANS CR	Air Navigation Services of the Czech Republic	State	1	4	5
Denmark	NAVIAIR	Air Navigation Services	State	1	4	8
France	DNA	Directorate of Air Navigation	State	5	11	66
Netherlands	LNVL	Luchtverkeersleiding Nederland	State	1	4	4
United Kingdom	UK NATS	National Air Traffic Services Ltd.	State-Private	3	11	14
Ireland	IAA	Irish Aviation Authority	State	2	3	3
Spain	AENA	Aeropuertos Espanoles y Navegacion Aerea	State	4	9	34
Sweden	LFV	Swedish Civil Aviation Administration Luftfartsverket	State	3	10	36
Switzerland	Skyguide	Skyguide	State-Private	2	2	4
Italy	ENAV	Company for Air Navigation Services	State	4	19	25
Hungary	Hungaro Control	Hungaro Control	State	1	1	1
Turkey	DHMI	General Directorate of State Airports Authority	State	2	17	34
Greece	HCAA	Hellenic Civil Aviation Authority	State	2	13	25

<sup>a</sup>Area Control Center<sup>b</sup>Approach Control Office<sup>c</sup>Aerodrome Control Tower

### The application of figures of merit for human resources

The calculation made by using figure of merit (6) revealed the highest evaluation points for ENAV, the result being 0.491. Hungaro Control had the lowest evaluation points at 0.067.

As Table 3 presents, the highest evaluation points according to figure of merit (7) were calculated for DNA, the result being 803.571. LNVL had the lowest evaluation points at 4554.370.

According to figure of merit (8), the highest evaluation points in the sampling were for Belgo Control, at 107.463. On the other hand, the lowest points were calculated for DHMI, the result being 2650.549.

Finally, the calculation made by using figure of merit (9) showed that LFV had the highest points at 321,381.381. On the other hand, the lowest points were calculated for LNVL, at 740,013.889.

### Application of figures of merit for cost

According to the figure of merit given in Eq. (1), the highest evaluation points belonged to AENA, at 0.693, while the lowest points were calculated for DHMI, at 0.148. The data for HCAA were not available for this application.

The second figure of merit regarding the evaluation area of cost (Eq. 11) revealed that ANS CR had the highest evaluation points (30.4) in the sampling. The lowest evaluation was for Skyguide, at 92.4.

### **Application of figures of merit for airspace**

According to figure of merit (12), Belgo Control received the highest points (0.00169) and IAA the lowest (0.00010).

According to the figure of merit given in Eq. (13), the highest points were for Belgo Control, with a score of 4168.111. The lowest points were calculated for DHMI, at 211.527.

The figure of merit given in Eq. (14) was developed as another important issue regarding airspace, under the title of “military (special use) airspace.” However, no calculations were made regarding this application due to a lack of data.

The application of figure of merit given in Eq. (15) shows the highest points (6.80) for NAVIAIR and the lowest (216.10) for IAA (see Table 3).

### **Application of figure of merit for traffic**

As Table 3 presents, ANS CR had the highest evaluation points, with an increase of 17.877% in traffic. The lowest points belonged to Belgo Control, with a 1.492% traffic increase.

### **Analysis and Final Remarks**

Table 3 summarizes 6 evaluation areas and 16 figures of merit regarding these areas, as well as overall results obtained in this study conducted on the air traffic systems of the 16 countries in the sampling.

As Table 3 presents, Belgo Control, the air traffic system of Belgium and Luxemburg, was found to be the most successful system, with a total of 140 points in the evaluation areas. The mean for this overall score of 140 in 13 evaluation areas was 10.77.

According to the results obtained in the evaluation, the lowest points calculated were for UK NATS, the British air traffic system, with 86 points and a mean of 6.62.

The difference between the highest and lowest number of points was 54, and the difference between the highest and lowest means was 4.15. As for Belgo Control, the most successful air traffic system, the standard deviation for the highest points, 16, was 5.23. The same standard deviation was calculated as 9.38 for UK NATS, the least successful air traffic system.

A detailed analysis shows that Belgo Control received the highest points, 16, from 4 figures of merit out of 13, and the lowest points, 1, from only 1 figure of merit. To be specific, Belgo Control was found to be the most successful in the following areas: “safety,” “human resources,” and “airspace.” Traffic was the area in which Belgo Control had the lowest points mentioned above.

UK NATS received its highest score in “human resources,” at 14, and the lowest scores in “safety” and “airspace.”

Table 3. Evaluation points for countries and evaluation areas.

Figures of Merit	$FM_S$ Figure of Merit for Safety	$FM_{D_1}$ Figure of Merit for Delay	$FM_{D_2}$ Figure of Merit for Delay	$FM_{H_1}$ Figure of Merit for Human Resources	$FM_{H_2}$ Figure of Merit for Human Resources	$FM_{H_3}$ Figure of Merit for Human Resources	$FM_{H_4}$ Figure of Merit for Human Resources	$FM_{PC}$ Figure of Merit for Cost	$FM_{EC}$ Figure of Merit for Enroute Charge (Airspace)	$FM_{TE_1}$ Figure of Merit for Technical Equipment (Airspace)	$FM_{TE_2}$ Figure of Merit for Technical Equipment (Airspace)	$FM_R$ Figure of Merit for Ideal Flight Route (Airspace)	$FM_T$ Figure of Merit for Traffic	$FM$ Total
Countries														
Belgium-Luxembourg	16	8	14	12	5	16	7	13	3	16	16	13	1	140
Denmark	10	16	16	9	7	7	9	11	8	11	7	16	10	137
Austria	15	16	16	7	2	12	2	9	6	12	13	11	12	133
Sweden	7	11	15	5	14	5	16	15	9	9	5	9	11	131
Czech Republic	11	12	4	6	3	9	8	9	16	13	9	10	16	126
Switzerland	14	9	3	11	4	15	15	8	2	11	14	15	5	126
Germany	9	13	10	10	9	14	5	5	4	15	15	6	9	124
Hungary	12	7	9	2	6	8	3	10	13	11	11	16	14	122
Italy	5	5	8	16	13	10	10	14	8	8	8	14	2	121
France	4	6	5	14	16	13	13	6	10	10	10	7	3	117
Netherlands	13	14	12	8	1	11	1	4	11	14	12	5	7	113
Ireland	8	15	13	15	8	2	6	12	15	4	4	2	4	108
Turkey	3	16	16	3	10	1	4	3	14	6	1	12	15	104
Greece	6	3	11	4	15	6	12	-	12	7	6	8	13	103
Spain	2	4	7	5	12	4	11	16	7	5	3	4	8	88
United Kingdom	1	10	6	13	11	3	14	7	5	5	2	3	6	86

## Conclusions

By using this evaluation model, each country can find an opportunity to compare its own air traffic system with those of other countries and determine certain weak and strong points they have, especially the weaknesses. This awareness may help them to initiate attempts to compensate for such weakness so that success levels may increase.

In addition, this evaluation model is useful in making sound and effective decisions, especially regarding a company's investment policy. Today, a considerable amount of investments are made in air traffic systems. Therefore, it is crucial to use available resources very carefully in order to obtain optimum productivity and efficiency. Thanks to the model presented in this study, weak points can be determined very easily and investments can be managed more efficiently.

In addition to the fact that the model developed here is an excellent self-evaluation opportunity for air traffic systems, it is also possible that businesses other than air traffic systems can apply this model for their own benefits and needs.

Finally, this evaluation model might also play a significant role during the decision making process of possible purchasers of air traffic systems, due to recent developments regarding the increasing attempts at privatization of such systems. In other words, the evaluation of an air traffic system that is subject to privatization is highly likely to be useful in giving some ideas to the possible purchasers or stockholders in deciding whether to invest in that particular system or not, since they mostly need tangible information for an accurate decision. It is true that obtaining such tangible information is more difficult for service providers such as air traffic systems than for manufacturing businesses. Therefore, it is essential to develop an evaluation model and figures of merit for service providers, and the results obtained should be usable in decision making processes. Information to be obtained by using the evaluation model developed in this study will surely fulfill the above mentioned goals.

## Nomenclature

$A$	size of airspace, km <sup>2</sup>	$FM_R$	figure of merit for ideal flight route
$AI$	number of accidents/incidents	$FM_S$	figure of merit for safety
$ai$	parameter of accidents/incidents	$FM_T$	figure of merit for traffic
$A_M$	size of military (special use) airspace, km <sup>2</sup>	$FM_{TE}$	figure of merit for adequacy of technical equipment
$C_C$	cost of air traffic controllers,	$L$	total distance flown per year, km
$C_T$	total personnel cost,	$L_I$	length of ideal flight route, km
$EC$	unit en route rate,	$L_T$	length of true flight route, km
$F$	number of total flights per year	$N_C$	number of air traffic controllers
$F_d$	number of delayed flights	$N_T$	number of total personnel
$FM$	figure of merit	$TE$	number of technical equipment
$FM_D$	figure of merit for delay	$Y$	examined number of years
$FM_{EC}$	figure of merit for en route charge	$y$	examined year
$FM_H$	figure of merit for human resources	$\Delta T$	total delay time, min
$FM_M$	figure of merit for military (special use) airspace	$\rho$	density of airspace, flights/km <sup>2</sup>
$FM_{PC}$	figure of merit for personnel cost		

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