AN APPLICATION OF THE METHODOLOGY FOR ASSESSMENT OF THE SUSTAINABILITY OF AIR TRANSPORT SYSTEM

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Abstract

An assessment and operationalization of the concept of sustainable air transport system is recognised as an important but complex research, operational and policy task. In the scope of the academic efforts to properly address the problem, this paper aims to assess the sustainability of air transport system. It particular, the paper describes the methodology for assessment of sustainability and its potential application. The methodology consists of the indicator systems, which relate to the air transport system operational, economic, social and environmental dimension of performance. The particular indicator systems are relevant for the particular actors such users (air travellers), air transport operators, aerospace manufacturers, local communities, governmental authorities at different levels (local, national, international), international air transport associations, pressure groups and public. In the scope of application of the methodology, the specific cases are selected to estimate the particular indicators, and thus to assess the system sustainability under given conditions.

Keywords: Air transport system, sustainability, dimensions of performance, indicator systems, assessment

1 INTRODUCTION

What is a sustainable system? According to the numerous definitions, this should be the system whose absolute consumption of the non-renewable energy resources (fossil fuels) and emission of greenhouse gases do not increase over time. According to these criteria, transport system can be considered as an unsustainable system (Daly, 1991; Whitelegg, 1993). However, since transport system also acts as a strong driving force of the economic development and social welfare, the above strict and direct approach to sustainability, particularly for the long-term development, needs to be redefined, at least by taking into account also the system positive effects in addition to the negative impacts. In such a context, sustainability of transport system could be considered as growth of the positive difference between the positive effects and negative impacts. Such development seems to be able to be achieved by establishing a balance (i.e., 'trade-off') between the system effects and impacts. However, the numerous conceptual and practical problems might emerge as barriers. One of the most important conceptual barriers seems to be a rather difficult consistent estimation of the system full effects mainly due to the diversity of approaches and methodologies. The main practical problem seems to lay in difficulty to globalise policies intended to promote the concept of sustainable development primarily due to the heterogeneity of performance of the system components and necessity for permanent compromising the interests of particular actors involved (ATAG, 2000: 2000a; DETR, 2000, 2001; EC, 1997; ECMT, 1998; Hewett and Foley, 2000; Levison et al., 1996 WCED, 1987).

This paper makes an academic effort in applying the methodology to assessment of the sustainability of air transport system (Janic, 2003). This methodology has been based on definition of the indicator systems of sustainability reflected the system operational, economic, social and the environmental dimension of performance[1] (FAA, 1996). The indicator systems for each dimension of performance contained the individual indicators and their measures have been defined with respect to sometimes the very confronted objectives of the various actors involved such as users (air travellers), air transport operators, aerospace manufacturers, local communities, governmental authorities at different levels (local, national, international), international air transport associations, pressure groups and public. By using the relevant inputs based on the structure of the indicator systems and particular measures, an assessment of the current level of sustainability of the air transport system with respect to particular indicators and measures is carried out (EC, 1999).

In addition to this introductory section, this paper consists of four sections. Section 2 describes the concept of sustainable air transport system. Section 3 deals with the sustainability indicators assumed to be relevant for particular actors. Section 4 contains estimation of the particular indicators for different cases thus illustrating an application of the methodology. The last section contains some conclusions.

[1] This is an analogous definition to the definition of sustainable society, which is supposed to possess three essential dimensions of performance: economic, social, and environmental (Agenda 21 of the UNCED (United Nations Conference on Environment and Development) Conference in Rio de Janeiro, Brasil/1992).

2 THE CONCEPT OF SUSTAINABLE AIR TRANSPORT SYSTEM

2.1 Basic principles of sustainability

In the light of the refined definition of sustainability, air transport system is considered to be sustainable if the net benefits of its operations increase with increasing of the system output either in the absolute (total) or relative terms (per unit of output). The net benefits are represented as the sum of differences between the positive effects ("benefits") and the negative impacts ("costs") at different geographical scales such as global (intercontinental), regional (national/continental), and local (community) scale (INFRAS, 2000).

2.1.1 Sustainability at global scale

At global scale, growth of economy and air transport demand have been strongly driven by each other with the evident negative consequences in terms of the absolute increase in energy (fossil fuels) consumption and global emission of greenhouse gases. In such a context, several options (scenarios) is thought to be useful to drive the system towards sustainable development, i.e., to setting up of trade-off between the positive effects and the negative impacts, as follows (Janic, 2003):

- *Constraining the system growth at global scale*, which would include setting up an absolute limit to growth of the air transport demand and consequently to growth of the associated negative impacts;
- *Setting up a cap on the impacts*, which would limit the system energy consumption, associated air pollution, and thus indirectly its growth (Hewett and Foley, 2000);
- *Decoupling growth of the system demand* and *the economic growth*, which would include weakening of the strong links between the air transport demand and GDP (Gross Domestic Product). This has seemed to be able to be carried out by stimulating people to change their habits in the long-term (EC, 1999); and
- *Trading-off between global effects and impacts,* which as a compromise scenario would provide mechanisms for the faster growth of the system long-term global positive effects than the negative impacts.

2.1.2 Sustainability at regional scale

At a regional (national, continental) scale, particularly in the U.S. and Western Europe, the growth of air transport demand been additionally driven by local forces such as liberalisation of air transport market(s), increasing of the system productivity and diminishing of airfares. Such growth has been confronted with the limited capacity of airports and ATM (Air Traffic Management)/ATC (Air Traffic Control), which has increased congestion and ultimately compromised the expected efficiency and effectiveness of service. Under such circumstances, a balance between the system growth and the associated negative impacts seems to be able to be achieved by three scenarios as follows (Janic, 2003):

- *Affecting regional demand-driving forces*, which would, as a controversial scenario, include affecting the factors influencing market liberalisation and competition, productivity, and airfares in a way to discourage further growth of air transport demand (Boeing, 2001).

- *Constraining the infrastructure expansion,* which as "do nothing" scenario in terms of constraining the further expansion of the air transport infrastructure under conditions of growing demand could lead to a widespread and severe deterioration of the efficiency and effectiveness of service. In turn, such development might deter both existing and prospective users (EUROCONTROL, 2001).
- *More efficient utilisation of the available infrastructure*, which could lead to improvements of utilisation of existing airport and ATM/ATC infrastructure by using innovative technologies and operational procedures, modification(s) of the airline operational practice, and co-operation with other transport modes (particularly railways) (Arthur, 2000).

2.1.3 Sustainability at local scale

At local scale, the positive effects and the negative impacts of growth of individual airports need to be balanced according to the following scenarios (Janic, 2003):

- *Constraining the airport growth*, which would include constraining the available land for an airport physical expansion, which in turn would compromise its further growth[2].
- *Management of the airport growth*, which, at an airport, would include provision of the higher rates of increase of the total local benefits than the costs of the associated impacts (BA, 2001).

2.2 Dimensions of the system performance

Definition of the indicator systems of sustainability of the air transport system can be carried out with respect to the operational, economic, social, and environmental dimension of performance[3]. The particular dimensions of performance have been dependent on each other, but the operational dimension has mostly influenced the other three. Figure 1 illustrates a generic scheme of these relationships (Janic, 2003).

The operational dimension is the basic one, which relates to the characteristics of the system demand, capacity, effectiveness, safety and security of service (Janic, 2003).

The economic dimension relates to the system operating revenues, costs and productivity (Hooper and Hensher, 1997).

The social dimension relates to the social effects such as the system direct and indirect contribution to employment and GDP at local and regional scale (Button and Stough, 1998; DETR, 1999; 2000). In addition, contribution to globalisation and internalisation of business and leisure activities (international trade, investments, tourism) could be taken into account.

The environmental dimension relates to the system physical impacts on the people's health and environment in terms of the local (airport) and global (airspace) air pollution, airport noise, aircraft accidents, congestion, generation of waste and land use (Janic, 1999).

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[2] For the first time, at Amsterdam Schiphol airport the government has limited by law the maximum annual number of aircraft movements aiming at controlling the noise. Consequently, in 1998 the maximum number of aircraft movements has been restricted to 380 000 with possible annual increase of 20000 until 2003 (Boeing, 2001; Offerman and Bakker, 1998).

[3] Some studies consider only three dimensions of air transport system performance: economic social and environmental (INFRAS, 2000).

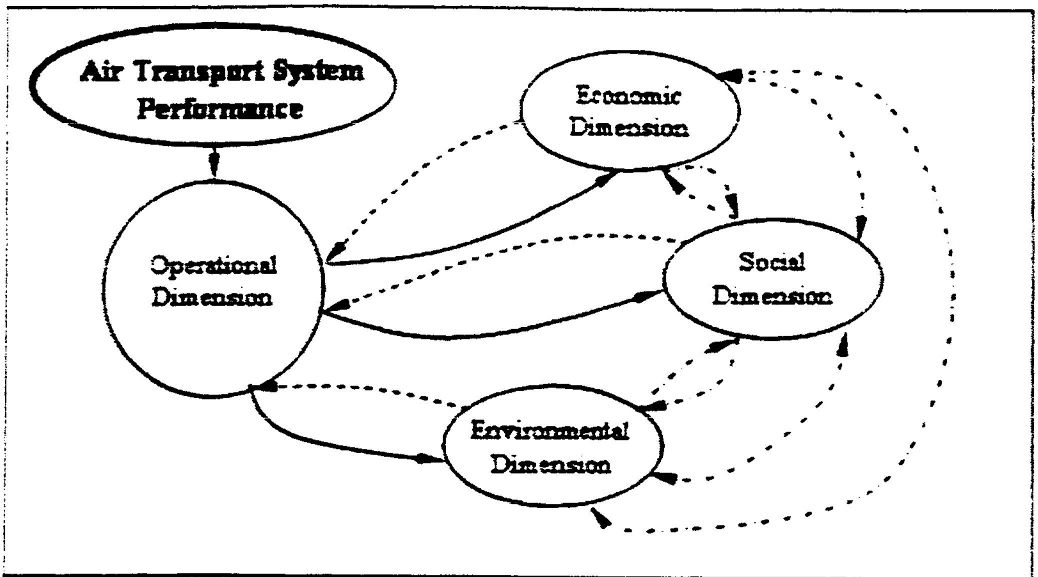

Figure 1 Dimensions of performance of air transport system and their linkage

2.3 The actors, their objectives and preferences

According to the structure of air transport system, the following main actors may be involved in dealing with the sustainability as follows (ATAG, 2000; INFRAS, 2000):

- *Users of services* such as air travellers and shippers of freight and mail constituting the air transport demand;
- *Air transport operators* providing the system services by using the related infrastructure, facilities and equipment such as airports, Air Traffic Management (ATM)/ Air Traffic Control (ATC), and airlines;
- *Aerospace manufacturers* producing the aircraft, ATM/ATC, and airport facilities and equipment;
- *Local community members* (population) living in the vicinity of airports;
- *The governmental bodies* playing the role in the institutional regulation of the system operations at local (community) and central (national) level;
- *Aviation organisations* co-ordinating the system development at global (international) scale;
- *Lobbies and pressure groups* articulating the interests of people who may be for or against an expansion of the system infrastructure; and
- *Public* temporarily interesting in the specific aspects of the system operations.

Figure 2 shows a simplified structure of the air transport system used for development of the indicator systems as the methodology for assessment of its sustainability. Sustainability of the air transport system may have different meaning and contents for the particular actors, which are summarised as follows:

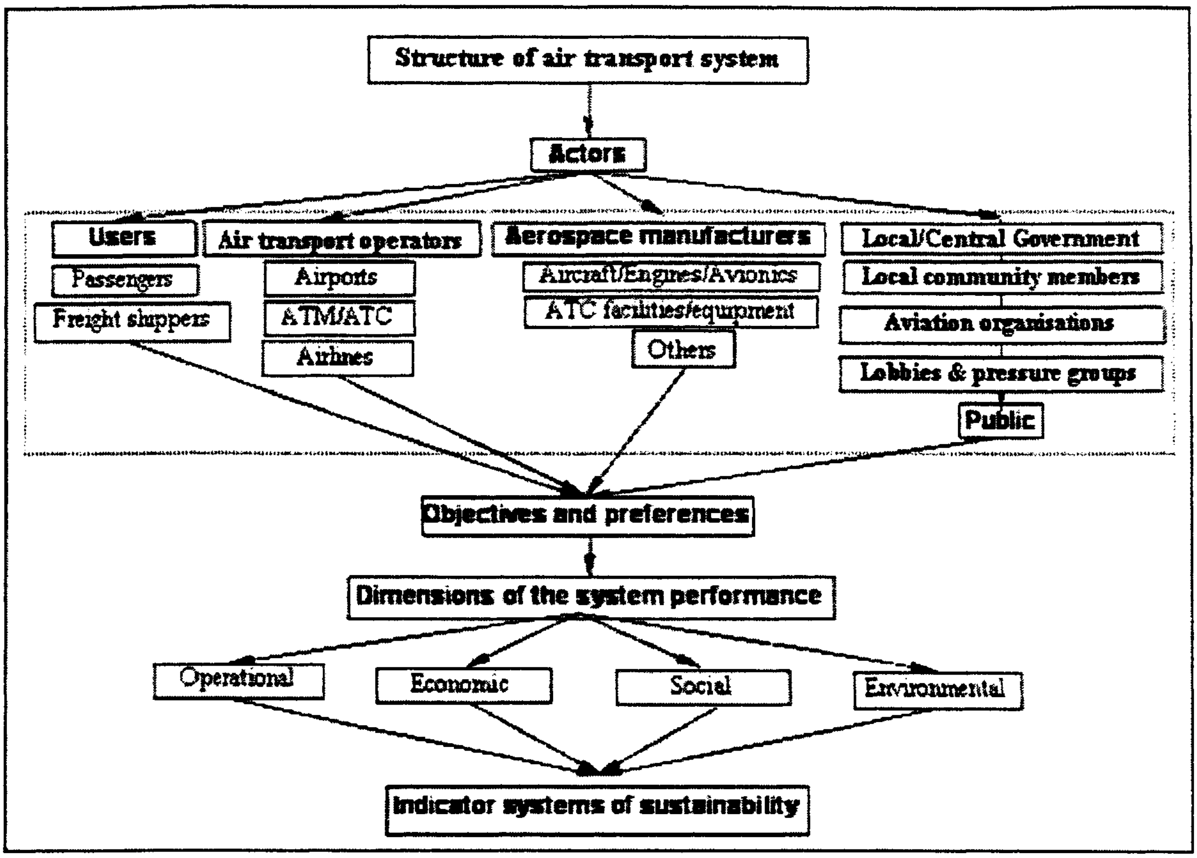

Figure 2 Simplified structure of air transport system used for assessment of sustainability

The *users – air travellers* and *shippers of freight* and *mail* usually prefer frequent, easily accessible, low cost, punctual, reliable, safe and secure services.

The *air transport operators* prefer services according to their business objectives in terms of the profitability, safety and security on the one hand, and the users' preferences on the other.

The *aerospace manufacturers* prefer smooth selling of their reliable, safe, and profitable products to the system operators.

Local community members usually tend to maximise the benefits and minimise the costs of air transport system at their local scale. The employment opportunity and use of efficient air connections to other distant communities (regions) can be considered as the obvious benefits. The costs are regarded as exposure to the airport noise, air pollution, and risk of injury, loss of life and damage of property due to the aircraft accidents.

Local and *central government(s)* are mostly interested in the system overall benefits and externalities. Direct benefits may include the system contribution to the local and national employment and GDP. Indirect benefits may embrace contributions to internalisation and globalisation of manufacturing, trade, investments and tourism. Externalities may be of interest while creating local and global policies to protect the people's health and environment.

International aviation organisations such as ICAO, IATA, ECAC, AEA and ACI provide the framework and guidelines for co-ordinated (sustainable?) development of the system at both regional (national) and global (international) scale.
Different lobbies and pressure groups organise campaigns against global harmful effects of the polluting systems on the people health and environment. In such scope, they also intend to prevent further contribution of the air transport to global warming by strong opposition, sometimes together with local community people to the physical expansion of the system infrastructure - airports.
Public uses media such as radio, TV, Internet and newspapers to get information about the system. This interest is strengthening in the cases of launching innovations (aircraft, airports), severe disruptions of services and air accidents, and changes of airfares. In general, the information about the system should be available to public at any time.

3 THE INDICATOR SYSTEMS OF SUSTAINABILITY

3.1 General

The indicator systems of sustainability of air transport system have been defined to measure the effects ("benefits") and impacts ("costs") in either absolute or relative monetary or non-monetary terms, as functions of the relevant system output (Janic, 2003). In such a context, the system has been assumed to be sustainable if the measure of an indicator reflected the relative effects has increased and the other one reflected the relative impacts decreased (or been constant) with increasing of the relevant system output, and vice versa. Figure 3 shows a generic scheme[4].

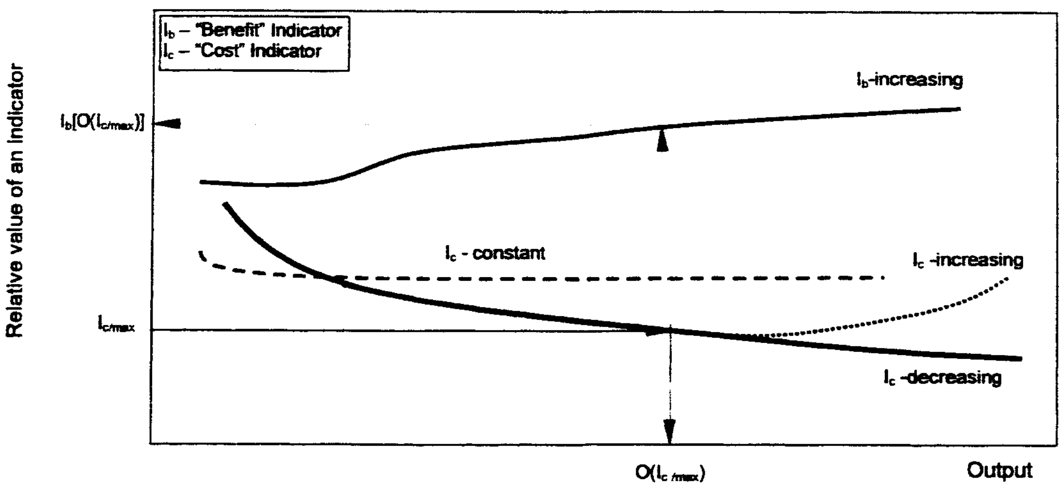

Figure 3 Relationships between the sustainability indicators and the system output

[4] Setting up a limit on the particular indicator may have two-fold effect. For example, if the cost indicator is limited to $I_{c/max}$, the output will be able to rise maximally to $O(I_{c/max})$. Such constrained output will affect a benefit indicator, which will be allowed to rise maximally to $I_b[O(I_{c/max})]$. Consequently, setting up the criteria on indicators should always include balancing (i.e., trading-off) between the effects and impacts.

3.2 Structure of the indicator systems

Different actors might use different indicator systems for assessment of the system sustainability with respect to the particular dimensions of the system performance and their specific preferences. The indicator systems consisted of the individual indicators and their measures have been valid for given period of time (day, month, year) (Janic (2003).

3.2.1 Indicators for users – air travellers

The indicator system for users-air travellers have consisted of eight individual indicators related to the airports and airlines operated at different scales as follows:

i) Operational indicators

The indicators of the operational dimension of performance have been as follows:

- *Punctuality* of service has been measured by the probability that a flight has been on time, and the average delay per flight[5] (Headley and Bowen, 1992; USDT, 2001). Users have usually preferred the former measure to be as high as possible and the latter one as low as possible with increasing of the number of flights.
- *Reliability* of service has been measured as the ratio between the realised and the total number of flights (USDT, 2001). The measure has been preferred to be as high as possible and to increase with increasing of the number of flights.
- *Ratio of lost/damaged baggage* has been expressed as the proportion of the lost (or damaged) baggage compared to the total number of passengers served. This measure has been preferred to be as low as possible and to decrease with increasing of the number of passengers.
- *Safety* has been measured as the ratio of the number of deaths (or injuries) per unit of output - RPK (RPM) (RPK – Revenue Passenger Kilometer; RPM – Revenue Passenger Mile). The users have always preferred this measure to be as low as possible and to decrease with increasing of RPK (RPM).
- *Security* has been measured as the ratio between the number of detected illegal dangerous devices and the total number of passengers screened. It has been preferred to be as low as possible and to decrease with increasing of the number of passengers.

ii) Economic indicators

The indicators of the economic dimension of performance have been as follows:

- *Economic convenience of service* has measured by the average airfare per passenger preferred by users to be as low as possible[6].

iii) Social indicators

The indicators of the social dimension of performance have been as follows:

- *Spatial convenience of service* has been measured by the number and diversity of destinations and flights at an airport with respect to type of destination, connectivity (non-stop, one-stop or multi-stop) and trip purpose (business, leisure). In general, users prefer this measure to be as high as possible.

[5] Usually, delays are categorized as the arrival and departure delays, which may be shorter or longer than 15 minutes (EUROCONTROL, 2001a; USDT, 2001).

[6] Some airfares charged by low-cost air carriers in Europe and the US may represent the exceptions from this general rule.

iv) Environmental indicators

The indicators of the environmental dimension of performance have been as follows:

- *Comfort* and *healthiness* at airports have been measured by the number of passengers per unit of the available space and the average queuing time (Hooper and Hensher, 1997; Janic, 2001). Configuration and size of seats in the economy class[7] and the quantity of fresh air delivered to the passenger cabin per unit of time have been used to measure the passenger comfort while onboard. The airport measures have been preferred to be as low as possible and to decline with increasing of the number of passengers served. The measures of comfort and healthiness while onboard have been preferred to be as high as possible.

3.2.2 The indicator system for airports

The indicator system for airports has consisted of eleven indicators related to an or a set of airports in a given region (Janic, 2003).

i) Operational indicators

The indicators of the operational dimension of performance have been as follows:

- *Demand* has expressed the number of passengers and the number of Air Transport Movements (ATM)[8], which has been preferred to be as great as possible within the available capacity.
- *Capacity* has been measured as the maximum number of passengers and maximum number of ATM. Both measures have been preferred to be as high as possible and to increase in line with growing demand (Janic, 2001).
- *Quality of service* has been measured by the average delay per ATM or per passenger occurred whenever the demand has exceeded the capacity. The measure has been preferred to be as low as possible and to decrease with increasing of demand (Janic, 2001).
- *Flexibility of using the available capacity* has measured by the ratio between the number of substituted flights by other transport modes and the total number of flights[9]. This ratio has been preferred to be as higher as possible and to increase with increasing of the number of flights.

ii) Economic indicators

The indicators of the economic dimension of performance have been as follows:

- *Profitability* has been measured by the operating profits (the difference between operating revenues and operating costs) per unit of the airport output–ATM or passenger[10] (Doganis, 1992). This measure has been preferred to be as high as possible and to increase with increasing of the output.

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[7] Configuration of the economy class seats at long haul flights has recently emerged as a matter of concern due to cases of passenger deaths caused by DVD (Deep in Vein Disease).

[8] An Air Transport Movement (ATM) is either arrival or departure.

[9] For example, three European 'super' hubs, Frankfurt, Paris CDG and Amsterdam Schiphol are connected to High Sped Rail Network. Partial substitution of short-haul flights has already taken place there (EC, 1998; HA, 1999; IFRAS, 2000). If the air-rail substitution were carried out without filling in freed slots by long haul flights, congestion and associated local and global air pollution, and noise would be reduced. Under such circumstances, this indicator could be classified as an environmental indicator.

[10] In many cases, the common unit called 'Workload Unit' or 'WLU' has been used as an equivalent for one passenger or 100 kg of baggage (Doganis, 1992)

- *Labour productivity* has been expressed by the number of ATM, passengers or WLU per employee (Doganis, 1992; Hooper and Hensher, 1997). This measure has been preferred to be as high as possible and to increase with increasing of the number of employees.

iii) Social indicators

The indicators of the social dimension of performance have not been identified.

iv) Environmental indicators

The indicators of the environmental dimension of performance have been as follows:

- *Energy inefficiency* has been measured by the quantity of energy consumed per unit of the airport output – ATM or a passenger. This measure has preferred to be as low as possible and to decrease with increasing of the output.
- *Noise efficiency* has been expressed by the area in square kilometres determined by the equivalent noise level in decibels - dB (A) (DETR, 2000; 2001). This indicator has been preferred to be as small as possible and to diminish with increasing of the number of ATM.
- *Air pollution efficiency* has been measured by the air pollutants per an event - LTO[11] cycle (EPA, 1999; ICAO, 1993a). This measure has been preferred to be as low as possible and to decrease with increasing of the number of LTO cycles.
- *Waste efficiency* has been measured by the quantity of waste per unit of the airport output – ATM or passenger (BA, 2001). The measure has been preferred to be as low as possible and to decrease with increasing of the airport output.
- *Land use efficiency* has been measured in terms of the area of land used for accommodating air transport demand. The measure has been preferred to be as low as possible and to increase with increasing of the volume of demand.

3.2.3 The indicator system for Air Traffic Management (ATM)/Air Traffic Control (ATC)

The indicator system for Air Traffic Management (ATM)/Air Traffic Control (ATC) have consisted of eight indicators, which might be quantified for a part (ATM/ATC sector) or for the whole system (airspace of a country or a wider region – continent) (Janic, 2003).

i) Operational indicators

The indicators of the operational dimension of performance have been as follows:

- *Demand* has been measured as the number of flights demanded to pass through a given ATM/ATC airspace (Janic, 2001). This measure has been preferred to be as great as possible.
- *Capacity* has been measured by the maximum number of flights served in a given airspace per unit of time (Janic, 2001). This indicator has been preferred to be as great as possible and to increase with growing demand.
- *Safety* has been measured by the number of aircraft accidents or the number of Near Midair Collisions (NMAC) per unit of the ATM/ATC output – controlled flight. Both measures have been preferred to be as low as possible and to decrease with increasing of the number of flights.

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[11] ICAO has recommended LTO cycle – Landing/Take-Off cycle as a standardised format for quantifying air pollution at airports (International Civil Aviation Organisation, 1993a)

- *Punctuality of service* has been measured by the proportion of flights being on time and the average delay per delayed flight due to the ATM/ATC restrictions. While former measure has been preferred to be as high as possible and to increase, the latter measure has been preferred to be as lower as possible and to decrease, with increasing of the number of flights.

ii) Economic indicators

The indicators of the economic dimension of performance have been as follows:

- *Cost efficiency*[12] has been measured by the average cost per unit of output – controlled flight. The measure has been preferred to be as low as possible and to decrease with increasing of the number of flights (Janic, 2001).
- *Labour productivity* has been reflected the number of controlled flights per an employee. This measure has been preferred to be as high as possible and to increase with increasing of the number of employees.

iii) Social indicators

The indicators of the social dimension of performance have not been identified.

iv) Environmental indicators

The indicators of the environmental dimension of performance have been as follows:

- *Energy efficiency* has been measured by the extra fuel consumption per flight due to deviations from the prescribed (fuel-optimal) trajectories dictated by the ATM/ATC. It has been preferred to be as low as possible and to decrease with increasing of the number of flights.
- *Air pollution efficiency* has been measured by the average quantity of pollutants per flight caused by the extra fuel consumption. The indicator has been preferred to be as low as possible and to decrease with increasing of the number of flights.

3.2.4 The indicator system for airlines

The indicator system for airlines has embraced eleven indicators, which could be quantified for an individual airline, airline alliance or the whole airline industry of a given region (country or continent) (Janic, 2003).

i) Operational indicators

- *Airline size* has been expressed by the volume of RTK or RTM (RTK (RTM)–Revenue Ton-Kilometre (Mile)), the number of flights, the number of passengers and/or the size of the resources used in terms of the number of aircraft and staff (Janic, 2001). The above measures have been preferred to be as great as possible and to increase over time and under conditions of sufficient demand.
- *Load factor* has been measured as the ratio between the total RTK (RTM) - Revenue Ton-Kilometre (Mile) and ATM (ATK)–Available Ton-Kilometre (Mile). This measure has been preferred to be as great as possible and to increase with increasing of the airline output (Janic, 2001).

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[12] The 'cost' is considered to be more relevant indicator than the 'profitability' because the most ATM/ATC providers charge their services on the cost-recovery principle. For example, EUROCONTROL member States and ATM providers from Canada, Australia, New Zealand, South Africa, etc. fully recover their costs by charges (INFRAS, 2000).

- *Punctuality, reliability* and *safety* of service have been measured and preferred analogously as that of users (Janic, 2001).

ii) Economic indicators

The indicators of the economic dimension of performance have been as follows:

- *Profitability* has been measured by the average profits (difference between the operating revenues and costs) per unit of output – RTK (RTM). This measure has been preferred to be as great as possible and to increase with increasing of the airline output.
- *Labour productivity* has been measured by the average quantity of output - RTK (RTM) - per employee. The preference for this measure has been to be as great as possible and to increase with increasing of the number of employees.

iii) Social indicators

None of these indicators has been identified.

iv) Environmental indicators

The indicators of the environmental dimension of performance have been as follows:

- *Energy* and *air pollution efficiency* have been measured by the average quantity of fuel and associated air pollution, respectively, per unit of output – RTK (RTM), distance flown or the number of flying hour). Both measures have been preferred to be as low as possible and to decrease with increasing of output.
- *Noise efficiency* has been measured by the proportion of the aircraft of Stage 3 and 4 in an airline fleet. This measure has been preferred to be as great as possible and to increase with expansion of the airline fleet[13] (BA, 2001; ICAO, 1993b).
- *Waste efficiency* has been measured by an average quantity of waste per unit of the airline output – RTK (RTM). This measure has preferred to be as low as possible and to diminish with growing of the airline output (BA, 2001).

3.2.5 The indicator system for aerospace manufacturers

The indicator system of the airspace manufacturers has consisted of eight indicators as follows (Janic, 2003).

i) Operational indicators

The indicators of the operational dimension of performance have been as follows:

- *Aircraft innovations* have been measured by technical productivity the cost efficiency (RAS, 2001). The former measure preferred to be as high as possible has been expressed as the product between the aircraft speed and capacity product (ton-kilometres (miles) per hour). The latter preferred to be as low as possible has been expressed by the average operating cost per unit of capacity–ATK (ATM) (ATK–Available Ton Kilometre; ATM-Available Ton Mile) (Arthur, 2000; Janic, 2001).
- *Innovations* of *ATM/ATC* and *airport facilities* have been measured by the cumulative navigational error of an aircraft position, and the capacity of facilities used for processing demand at airports, respectively. The former measure has been preferred to

[13] Once an airline fleet is completely modernized by replacing all aircraft of Stage 2 by the aircraft of noise category 3 and 4, this indicator will become irrelevant.

be as small as possible and the latter one as high as possible (Arthur, 2000; Janic, 2001).

- *Reliability of structures* has been measured by the rate of failures of the particular components per unit of time. Due to the safety and operational reasons, this measure, has been preferred to be as high as possible.

ii) Economic indicators

The indicators of the economic dimension of performance have been as follows:

- *Profitability* has been measured by the average operating profits (the difference between operating revenues and costs) per unit sold. This measure has been preferred to be as great as possible and to increase with increasing of the number of units.
- *Labour productivity* has been measured by the average number of units produced per employee. The measure has been preferred to increase with increasing of the total number of employees.

iii) Social indicators

The indicators of the social dimension of performance have not been identified.

iv) Environmental indicators

The of the environmental dimension of performance have been as follows:

- *Energy, air pollution* and *noise efficiency* have been measured by the absolute or relative decrease in the fuel consumption, air pollution or noise per unit of engine power or the aircraft operating weight. These measures have been are preferred to be as low as possible and to decrease with increasing of the engine power and/or aircraft operating weight.

3.2.6 The indicator system for local community

The indicator system for the local community has consisted of four indicators of sustainability as follows (Janic, 2003):

i) Operational indicators

The indicator system of the operational dimension of performance has not been identified.

ii) Economic indicators

The indicator system of the economic dimension of performance has not been identified.

iii) Social indicators

The indicator system of the social dimension of performance has comprised only one indicator as follows:

- *Social welfare* has been measured by the ratio between the number of people employed by air transport system and the total number of employed people within the local community. This measure has been preferred to be as high as possible and to increase with increasing of employment within the local community (DETR, 1999).

iv) Environmental indicators

The indicator system of the environmental dimension of performance has consisted of three indicators as follows:

- *Noise disturbance* has been measured by the total number of noise events – ATM - during given period of time (day, month, year) and by the \number of complaints per noise event - ATM. Both measures have been preferred to be as low as possible and to decrease with increasing of the number of ATM.
- *Air pollution* has been measured as the ratio between the quantity of air pollutants from air transport system and the total air pollution from all other local sources. This indicator has been preferred to be as low as possible and to decrease with increasing of the total air pollution.
- *Safety* has been measured by the number of aircraft accidents per ATM, which has affected the local community people in terms of damaging their property, injuries or loss of life. This measure has been preferred to be as low as possible and to decrease with increasing of the number of ATM.

3.2.7 The indicator system for (local and central) governments

The indicator system for the local and central government has consisted of seven indicators as follows (Janic, 2003):

i) Operational indicators

The indicators of the operational performance have not been identified.

ii) Economic indicators

The indicators of the economic dimension of performance have been as follows:

- *Economic welfare* has been measured by the proportion of GDP of air transport sector in the total GDP. This measure has been preferred to be as great as possible and to increase with increasing of the total GDP.
- *Internalisation/globalization* has been measured by the proportion of trade in terms of the volume and/or value of export and import by air transport in the total regional (country) trade, and by the ratio between the number of air trips and total number of trips (business/leisure) in a given region (country). These measures have been preferred to be as great as possible and to increase with increasing of the volume (value) of trade and the total number of trips, respectively.
- *Externalities* have been measured by the average expense per unit of the system output–RPK (RPM) due to either preventing or remedying the particular impacts such as noise, air pollution, air incidents/accidents, and sometimes congestion (DETR, 2001; EC, 1997; Janic, 1999; Levison et. al, 1996; Yang-Lu, 2000). This measure has been preferred to be as low as possible and to decrease with increasing of the system output.

iii) Social indicators

The indicators of the social dimension of performance have been as follows:

- *Overall social welfare* has been measured as the ratio between the number of employees within air transport sector and the total number of employees in a region (country). This measure has been preferred to be as high as possible and to increase with increasing of the total employment.

iv) Environmental indicators

The indicators of the environmental dimension of performance have been as follows:

- *Global energy efficiency* has been measured by the average amount of fuel consumed per unit of the system output–RTK (RTM). This measure has been preferred to be as low as possible and to decrease with increasing of the system output.
- *Global noise disturbance* has been measured by the total number of people exposed to the air transport noise during given period of time (year). The measure has been preferred to be as low as possible and to decrease over time.
- *Global air pollution* has been measured by the total emissions of air pollutants per unit of the system output – RTK (RTM) (EC, 1998b). This measure has been preferred to be as low as possible and to diminish with increasing of the system output.
- *Global land use* has been measured as the ratio between the land used for air transport infrastructure and the total land used for infrastructure of the whole transport system of a given region (country). This measure has been preferred to be as low as possible and to decrease with increasing of the area of land acquired for transport infrastructure.

4 AN APPLICATION OF THE METHODOLOGY

Fifty-eight indicators and sixty-eight measures have been defined in the scope of the indicator systems corresponded to seven groups of actors – users-air travellers, the system operators – airports, airlines and ATM/ATC, airspace manufacturers, local community members, and local and central government. For particular actors twenty-six selected indicators are estimated in order to illustrate existence of the sustainability of air transport system. Their list is given in Table 1.

Table 1: Indicators estimated for assessment of the sustainability of air transport system

Actor	*Dimension of the system performance*	*Indicator*
Users	• Operational • Economic • Social • Environmental	o *Punctuality* o *Reliability* o *Lost & damaged baggage* o *Security* o *Economic convenience* o — o —
Airports	• Operational • Economic • Social • Environmental	o — o *Profitability* o *Labour productivity* o — o *Air pollution efficiency* o *Noise efficiency* o *Waste efficiency*
ATM/ATC	• Operational • Economic • Social	o *Safety* o — o —

	• Environmental	o -----
Airlines	• Operational • Economic • Social • Environmental	o *Punctuality* o *Reliability* o *Productivity* o ---- o *Energy (fuel) efficiency*
Aerospace manufacturers	• Operational • Economic • Social • Environmental	o *Technical productivity* o *Efficiency* o ---- o ---- o *Fuel efficiency* o *Noise efficiency*
Local community members	• Operational • Economic • Social • Environmental	o ---- o ---- o ---- o *Noise disturbance*
Governments	• Operational • Economic • Social • Environmental	o ---- o *Economic welfare* o *Internalisation/Globalisation* o *Overall social welfare* o *Global energy efficiency Global noise disturbance* o *Global air pollution*

Data for estimating the particular indicators and their measures are extracted from different secondary sources. The results are given in Figure 4, 5, 6, 7, 8, 9 and 10.

i) Users

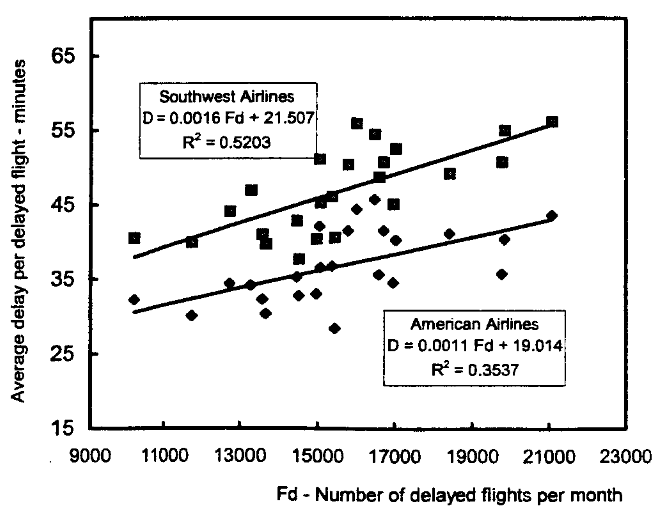

Figure 4a Punctuality of some U.S. airlines: period 1999-2000 (Compiled from USDT, 2001)

Figure 4a illustrates punctuality of American and Southwest Airlines (U.S). As can be seen, at both airlines the average delay per delayed flight has increased with increasing of the number of delayed flights. As well, the average delay of a Southwest flight has been longer than the average delay of an American flight, independently on the number flights carried out. Consequently, users might have better perception of punctuality of American than Southwest Airlines, but in general, they both have been unsustainable according to this indicator.

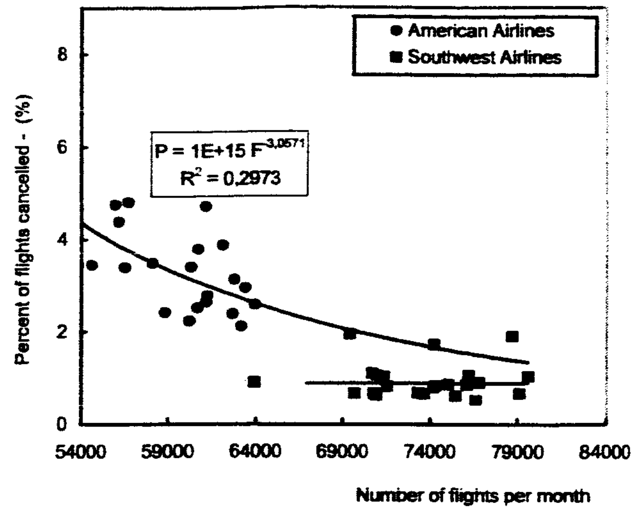

Figure 4b Reliability of some U.S. airlines: period 1999-2000 (Compiled from USDT, 2001)

Figure 4b illustrates reliability of two U.S. airlines, American and Southwest, as proportion of the cancelled flights dependent on the total number of flights carried out per month. As can be seen, in given example, at American this proportion has varied between 2% and 6% and generally decreased with increasing of the number of flights. At Southwest, it has varied between 0.5% and 2% and has been nearly constant with increasing of the number of flights. As well, Southwest has performed greater number of flights than American. From the above example, it seems that the airlines with a greater number of flights have also tend to provide a higher reliability of services, which according to the users' perception have made them more sustainable.

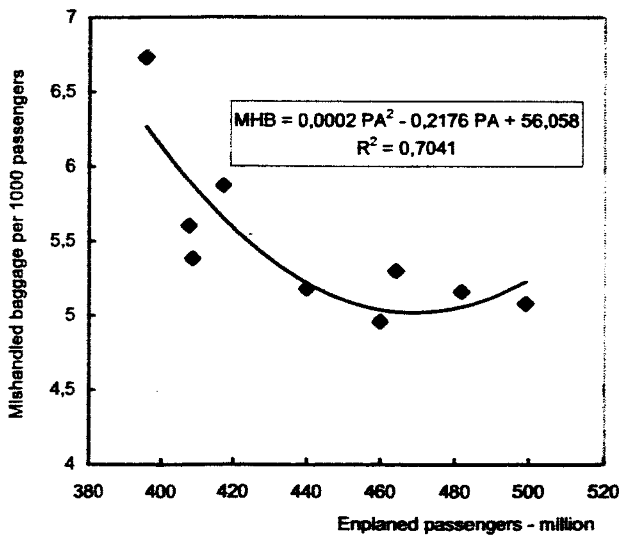

Figure 4c Llost and damaged (mishandled) baggage at U.S. domestic schedule services: period 1990–1999 (Compiled from USDT, 2001)

Figure 4c illustrates a ratio of mishandled (lost and damaged) baggage in dependence on the total number of domestic passengers served at the U.S. airports. As can be seen, this ratio has varied between 5 and 6.5% and decreased with increasing of the number of passengers up to about 460 million. Above this number, the ratio has started to increase with increasing of the number of passengers, which has indicated worsening of the performance. From the users' prospective, according to the variations of this indicator, the system has been sustainable under condition of rising of the number of passengers to a certain limit, and unsustainable beyond that limit.

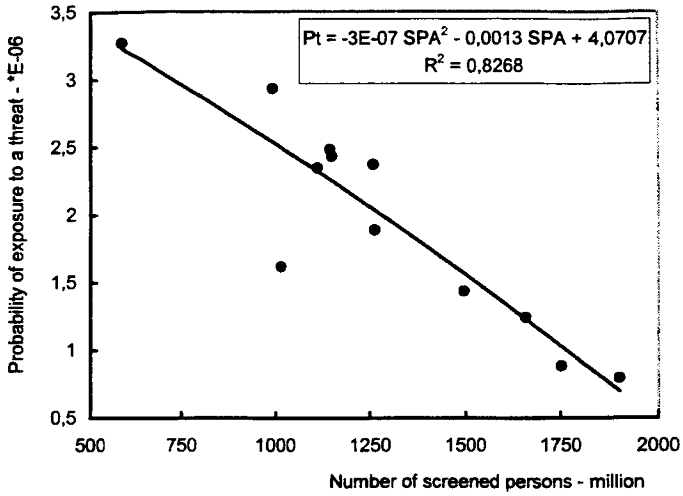

Figure 4d Security at U.S. airports – period 1980–1999 (Compiled from BTS, 2001)

Figure 4d illustrates security at the U.S airports expressed by the probability of being exposed to the threat of illegally carried dangerous devices in dependence on the number of passengers screened per year. As can be seen, this probability has decreased with increasing of the number of screened passengers. This has indicated the system long-term sustainability with respect to this indicator. Nevertheless, one has to be cautious with this measure since also the very low risk has hidden a virtual threat with a potential to materialize into the events with serious consequences such as, for example, September 11 (2001) terrorist attack on the U.S.

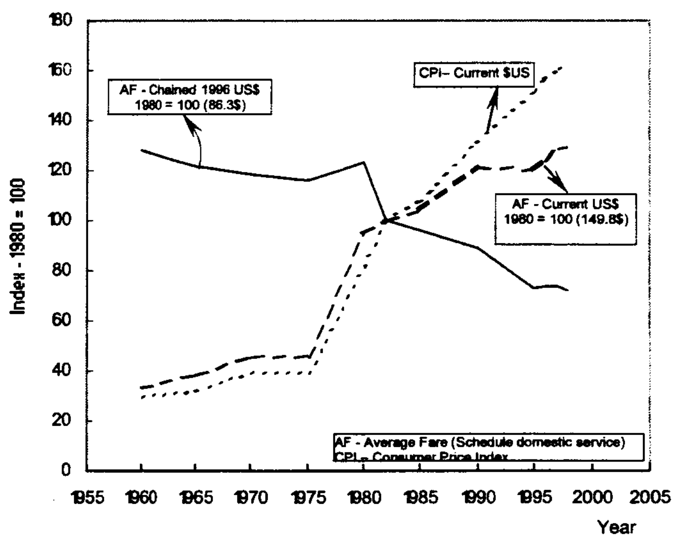

Figure 4e Economic convenience of the U.S. air transport system (Compiled from BTS, 2001)

Figure 4e illustrates economic convenience of air transport services for users of the U.S. air transport system expressed by changing of the average airfares and Consumer Price Index (CPI) during the observed period. As can be seen, two periods have been evident: first, it has been the period between 1960 and 1982 when the index of airfares had been above the index of CPI; second, it ahs been the period from 1983 on, when the index of CPI has been below than that of airfares. The main forces of such change have consisted of the positive developments in the U.S. aviation market after deregulation (1978) on the one hand and an overall socio-economic progress on the other. In addition, in an absolute sense, airfares have been more or less permanently decreasing, particularly after the year 1983, which might illustrate the long-term system sustainability according to this indicator.

ii) Airports

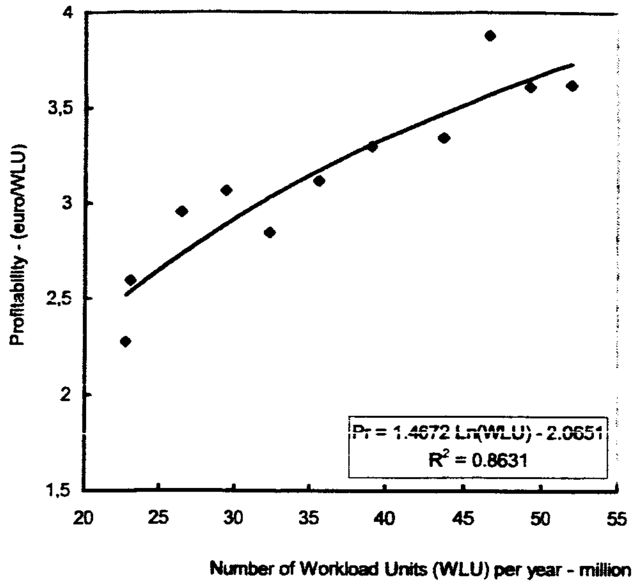

Figure 5a Profitability of Amsterdam Schiphol airport: period 1990-2000 (Compiled from Schiphol Group, 2000)

Figure 5a illustrates profitability of Amsterdam Schiphol airport (Netherlands). The profitability as the difference between revenues and costs in terms of EURO per WLU (Work Load Unit) has been related to the total annual number of WLU accommodated at the airport. As can be seen, this profitability has increased with increasing of the number of WLU at a decreasing rate. In given example, existence of the long-term airport sustainability has been indicative with respect to this indicator.

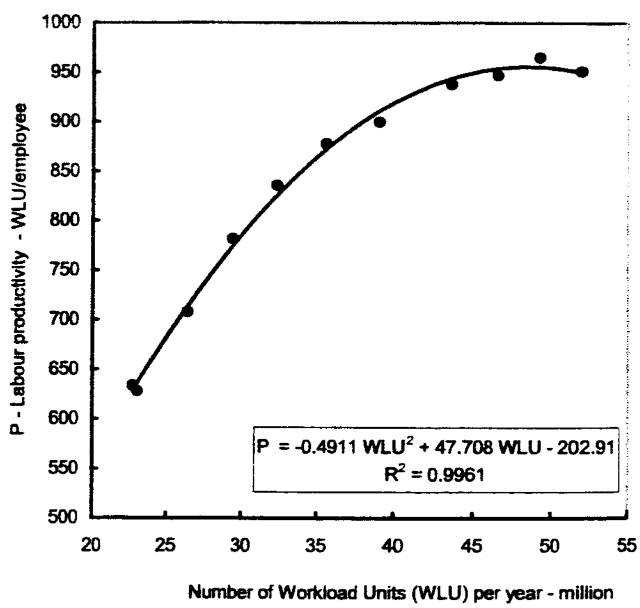

Figure 5b Labour productivity at Amsterdam Schiphol airport – period 1990-2000 (Compiled from Schiphol Group, 2000)

Figure 5b illustrates labor productivity at Amsterdam Schiphol airport (Netherlands). This productivity in terms of the number of WLU per employee has been related to the total number of WLU accommodated at the airport per year.

As can be seen, during the observed period, this productivity has generally increased with increasing of the number of WLU, but at a decreasing rate, which has turned into zero after the number of WLU has increased over 45 million per year. Such development has indicated how sustainability of the system has vanished with respect to this indicator during the period of growth.

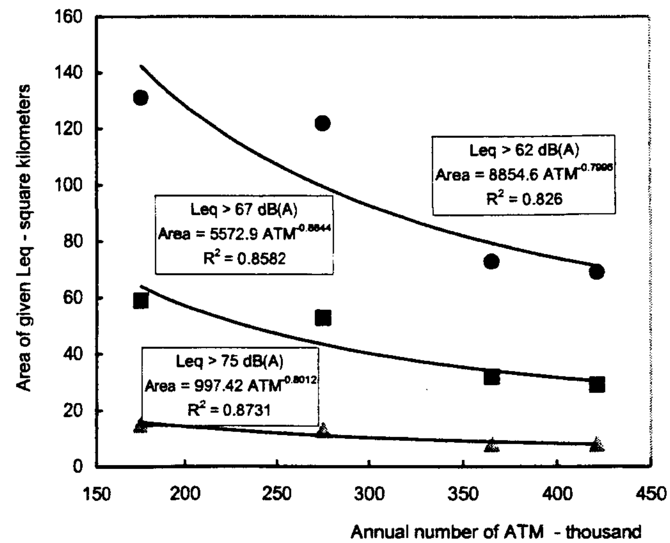

Figure 5c Noise efficiency at Frankfurt Airport – period 1987 – 1999 (Compiled from Fraport, 2001)

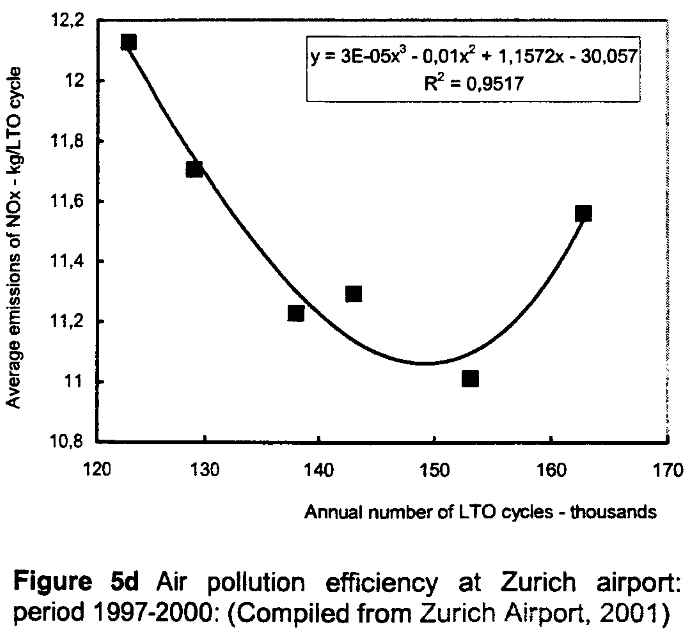

Figure 5d Air pollution efficiency at Zurich airport: period 1997-2000: (Compiled from Zurich Airport, 2001)

Figure 5c illustrates noise efficiency at Frankfurt airport (Germany) expressed by the area of land covered by the equivalent constant sound level L_{eq} (= 62, 67 and 75 dB(A)) in dependence on the annual number of ATM (Air Transport Movements). As can be seen, for given number of ATM, for larger L_{eq} this area has been smaller, and vice versa, which has been intuitively expected. As well, the area of land affected by given L_{eq} has decreased with increasing of the number of ATM. Both measures has indicated that the area around the airport exposed to the given level of noise has generally squeezed despite increasing of the traffic volume. This certainly has been achieved by replacing noisier with quieter aircraft and modifications of the operational procedures at and around the airport. Consequently, according to this indicator the airport has been developing in a sustainable way.

Figure 5d illustrates air pollution efficiency of Zurich airport (Switzerland) expressed by the quantity of N_{ox} per LTO cycle in dependence on the number of LTO cycles carried out. As can bee seen, this efficiency has been achieved by decreasing of this emission despite increasing of the number of LTO cycles, primarily through modernization of the aircraft fleet. However, this emission has started to increase when the number of LTO cycles has exceeded 150 thousands, primarily due to more intensive use of the larger aircraft. This has clearly indicated compromising of the already achieved sustainability trend.

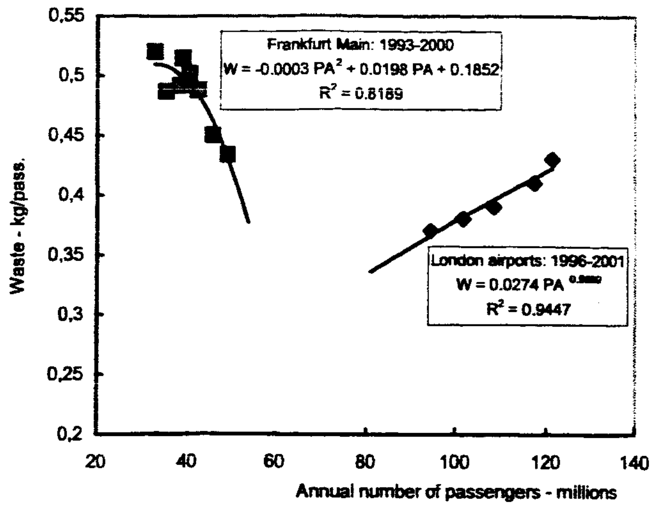

Figure 5e Waste efficiency at European airports (Compiled from Fraport, 2001; BAA, 2001)

Figure 5e illustrates waste efficiency in terms of the quantity of waste per passenger in dependence on the annual number of passengers accommodated at Frankfurt Main (Germany) and three London airports (Heathrow, Stansted, Gatwick) (UK).
As can be seen, this quantity has decreased at Frankfurt Main and increased at London airports with increasing of the annual number of passengers, which has indicated their sustainable and unsustainable development, respectively, with respect to this indicator.

iii) ATC/ATM

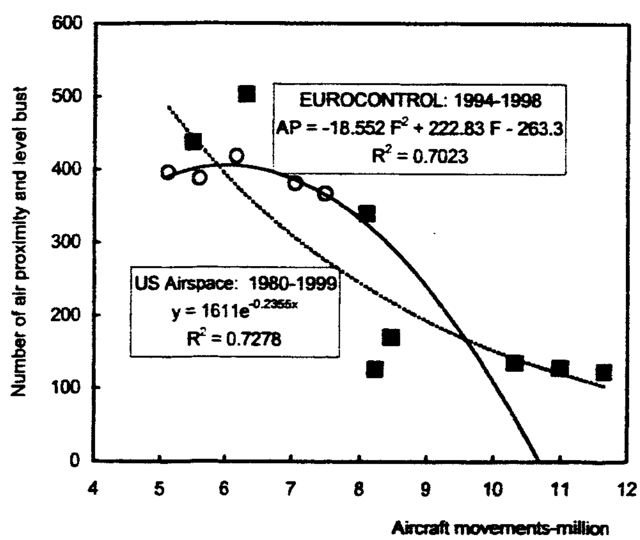

Figure 6 Safety in European and U.S. airspace (Compiled from EC, 1999a; DETR, 2000; BTS, 2001)

Figure 6 illustrates safety of the air traffic control system in terms of the number of air proximities and level busts dependent on the annual number of aircraft movements in the airspace of Europe and U.S. As can be seen, in both regions, this indicator has generally decreased with increasing of the number of aircraft movements, but the rates of decrease have been different. Nevertheless, both systems have been developed in a sustainable way according to this indicator, i.e., flying has been less and less with a risk of air proximities with increasing of traffic density.

iv) Airlines

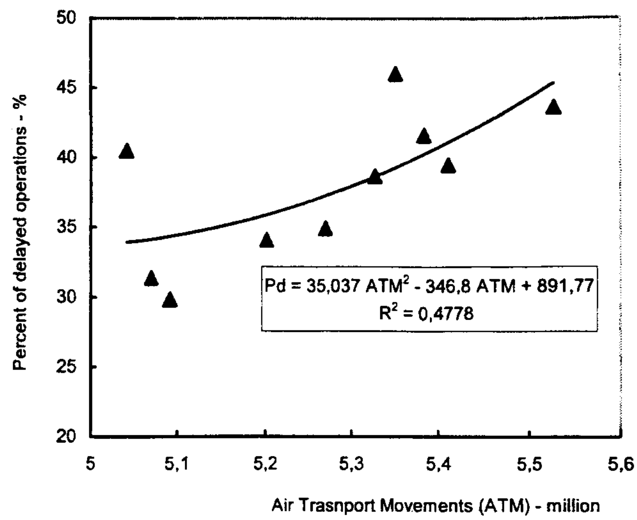

Figure 7a Punctuality of Major ten U.S. air carriers: period 1988 – 1999 (Compiled from USDT, 2001)

Figure 7a illustrates punctuality of the ten major U.S. airlines. It has been expressed as the proportion of the delayed ATM (Air Transport Movements) in dependence on the total number of ATM carried out per year during the period 1988-1999. As can be seen, generally, the proportion of cancelled flights has generally increased at an increased rate with increasing of the number of the number of ATM, which has implied lack of the system sustainable development with respect to this indicator.

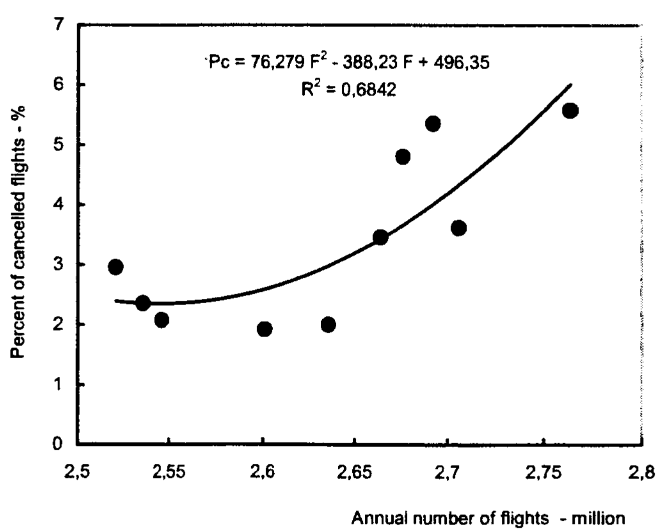

Figure 7b Reliability of Major ten U.S. air carriers: period 1988–1999 (Compiled from USDT, 2001)

Figure 7b illustrates reliability of the ten U.S. major airlines in terms of the proportion of cancelled flights dependent on the total number of flights carried out per year. All reasons for cancellations, from bad weather to technical failures, have been included. As can be seen, similarly as punctuality, this proportion has increased at an increasing rate with increasing of the totals number of flights. Such relationship has implied a lack of sustainability of the system development with respect to this indicator.

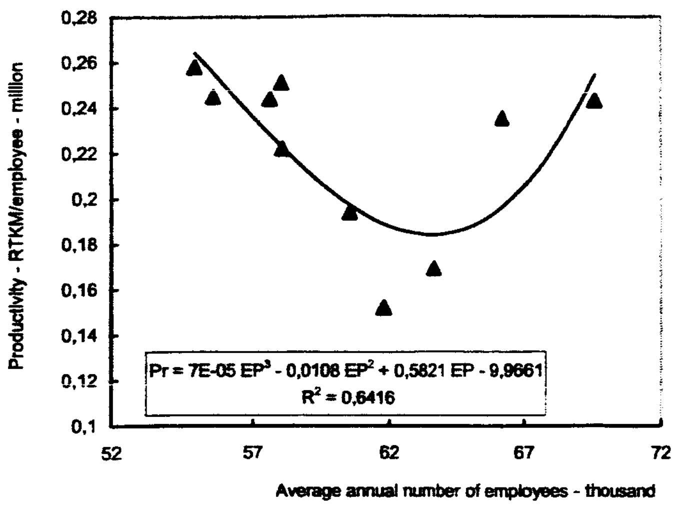

Figure 7c Labour productivity of Lufthansa group: period 1991-2000 (Compiled from Lufthansa, 2000)

Figure 7c illustrates productivity at Lufthansa Group (Germany) expressed as RTK per employee in dependence on the average annual number of employees. As can be seen, productivity has decreased until the number of employees has reached about 63 thousands but after that it has increased despite the number of employees has continued to rise. On the one hand this has happened due to the airline improvements. On the other, the strong force has been intensification of the long-haul intercontinental flights. Consequently, according to this indicator the group has changed its long-term trend of development from unsustainable to sustainable.

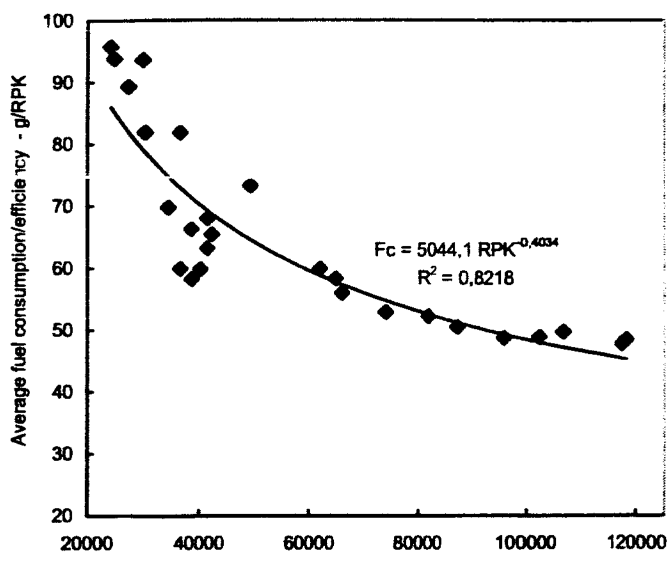

Figure 7d Fuel efficiency at British Airways: period 1974-2000 (Compiled from BA, 2001)

Figure 7d illustrates efficiency of fuel consumption at British Airways during the period 1974-2000. It has been expressed in terms of grams of fuel consumed per RPK (Revenue Passenger Kilometer) in dependence on the total annual volume of RPK. As can be seen, this consumption has generally decreased at a decreasing rate with increasing of the volume of RTK, which has also meant decreasing of the associated air pollution. Such undoubtedly long-term sustainable development has been achieved because the airline has permanently modernized its fleet on the one hand and been provided with more effective services by ATM/ATC during operations over its air route network on the other.

v) Airspace manufacturers

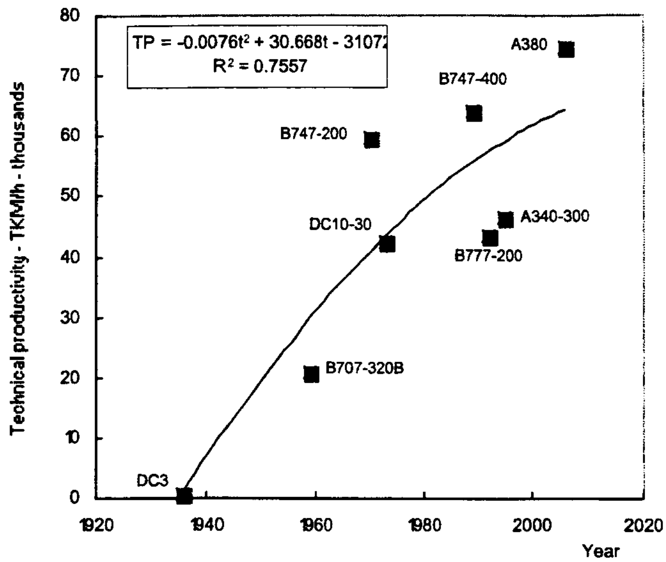

Figure 8a Aircraft technical productivity (Compiled from FI, 2000, 2001)

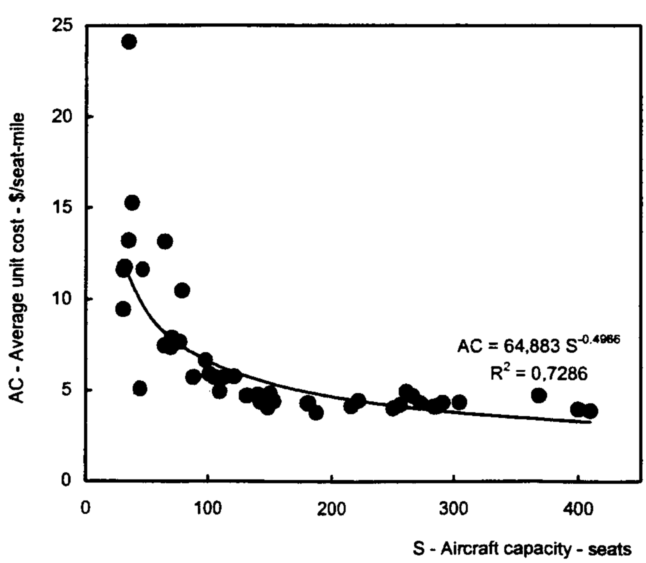

Figure 8b Aircraft eefficiency (Compiled from FAA, 1998)

Figure 8a illustrates the main steps in progress in development of the aircraft technical productivity in terms of the number of TKM/h (Ton Kilometers per Hour). As can be seen, this productivity has been increasing over time thanks to both airlines and their requirements as well as to capabilities of aerospace manufacturers. After DC 3, the rise of technical productivity has been primarily achieved by developing the larger aircraft and much less by increasing of the aircraft operating (cruising) speed. A culmination of development of this productivity will certainly be reached after introducing A380. The development of aircraft capacity has simultaneously included development and upgrading of engines (jet engines after DC3) in terms of their fuel and air pollution efficiency on the one hand and sophisticated avionics on the other. Consequently, the system has recorded the long-term sustainable development.

Figure 8b illustrates development of aircraft efficiency in terms of the average cost per seat mile dependent on the aircraft capacity (the number of seats). As can be seen, this cost has decreased at a decreasing rate with increasing of the aircraft size thus indicating the larger aircraft as being more efficient in relative terms. If development of bigger aircraft has been an objective in terms of sustainability, then such development has been sustainable in the long term.

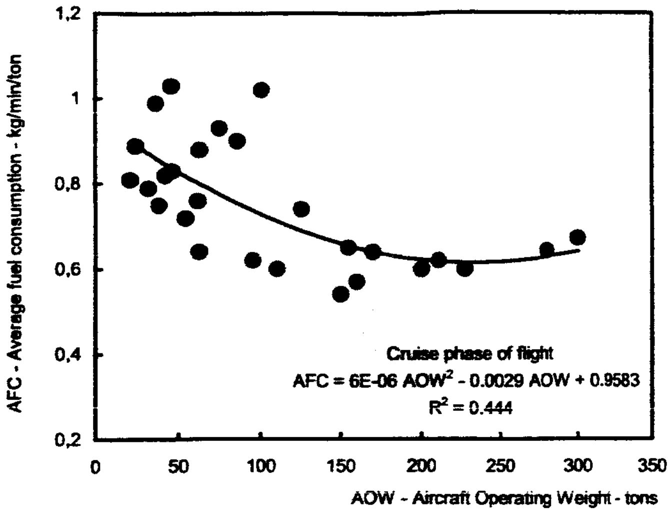

Figure 8c Fuel efficiency (Compiled from EUROCONTROL, 1998)

Figure 8c illustrates the aircraft fuel efficiency in terms of the average fuel consumption per unit of time and per unit of weight dependent on the aircraft operating weight. As can be seen, this consumption has decreased at a decreasing rate with increasing of the aircraft weight, which has implied higher relative fuel efficiency of the larger aircraft up to the weight of about 250 tons. For heavier aircraft, this advantage has disappeared and they have even shown to be less fuel-efficient. Consequently using larger aircraft up to a certain size has seemed to be more sustainable with respect to this indicator then otherwise.

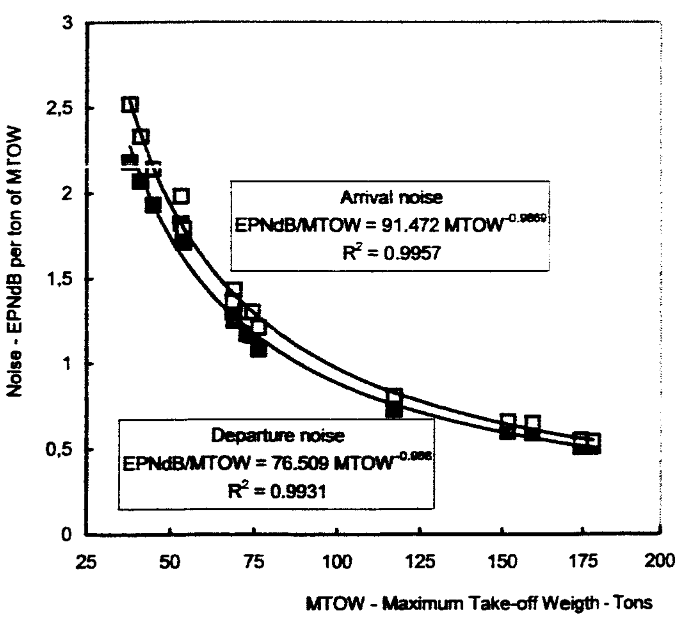

Figure 8d Noise efficiency (Compiled from HA, 1999; FI, 2000; 2001)

Figure 8d illustrates the aircraft noise efficiency expressed as the level of noise in terms of EPNdB (Equivalent Persistent Noise in Decibels) per unit of the aircraft maximum take-off weight in dependence of this weight. As can be seen, the relative level of noise has decreased more than proportionally with increasing of the aircraft maximum take-off weight for both aircraft arrivals and departures. The arrival noise has been slightly higher than the departure noise. Again, if development of bigger and relatively quieter aircraft has been an objective, the progress has been sustainable with respect to this indicator.

vi) Community members

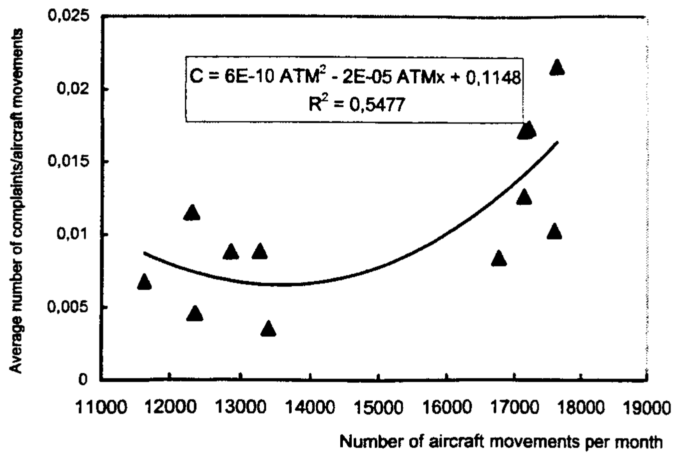

Figure 9 Noise disturbance (Compiled from MA, 1999)

Figure 9 illustrates noise disturbance at Manchester Airport (UK). This is expressed by the average number of complaints per ATM (Air Transport movement) in dependence on the total number of ATM carried out during given period of time. As can be seen, up to about 13 thousand movements carried out per month, the average number of complaints has decreased but after that it has been increasing more than proportionally. This has indicated that the airport has grown in an unsustainable way according to the attitudes of local population.

vii) Governments

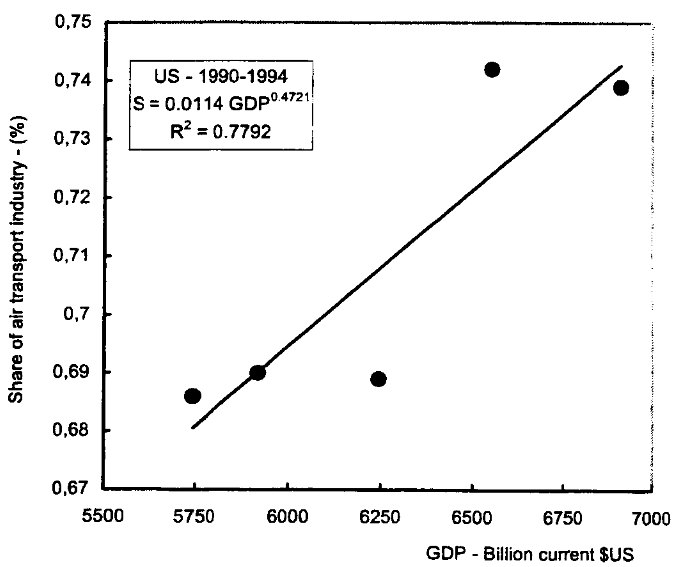

Figure 10a Economic welfare: U.S. air transport system: period 1990-1994 (Compiled from Han X., Fang, B., 1998)

Figure 10a illustrates economic welfare obtained by the U.S air transport industry expressed by its share in the total GDP (Gross Domestic Product) during the limited period 1990-1994. As can be seen, this share has increased linearly with increasing of the national GDP, which has indicated the industry's ability to permanently upgrade its contributions to the national economy (from 0.68% in 1990 to 0.74% in 1994 in the total GDP).

Consequently, the industry has developed in a sustainable way during the observed period with respect to this indicator.

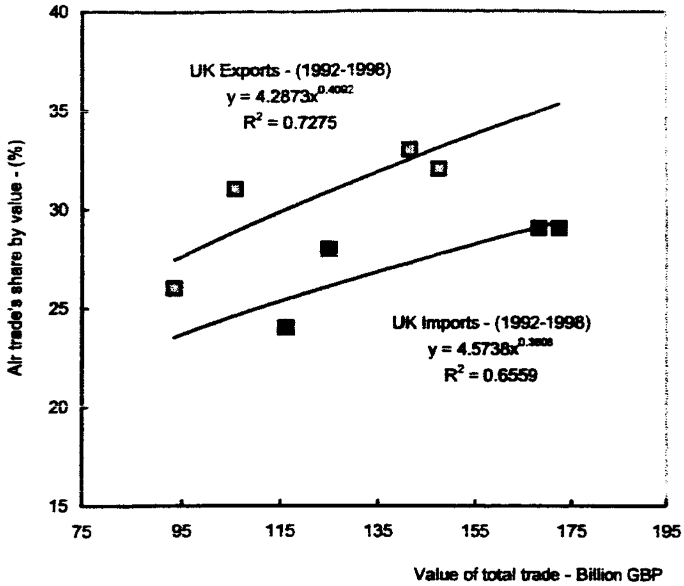

Figure 10b Internalisation & globalization of UK Trade: Period 1992-1998 (Compiled from DETR, 2000c)

Figure 10b illustrates an example of contribution of the national air transport system to globalization and internalization of the UK trade sector during the period 1992-1998. As can be seen, in the country's import and export, the share of air transport by value has been rising with increasing of the total value of trade. This has indicated the system ability to gain more expensive shipments, which in turn has meant its sustainable development with respect to this indicator.

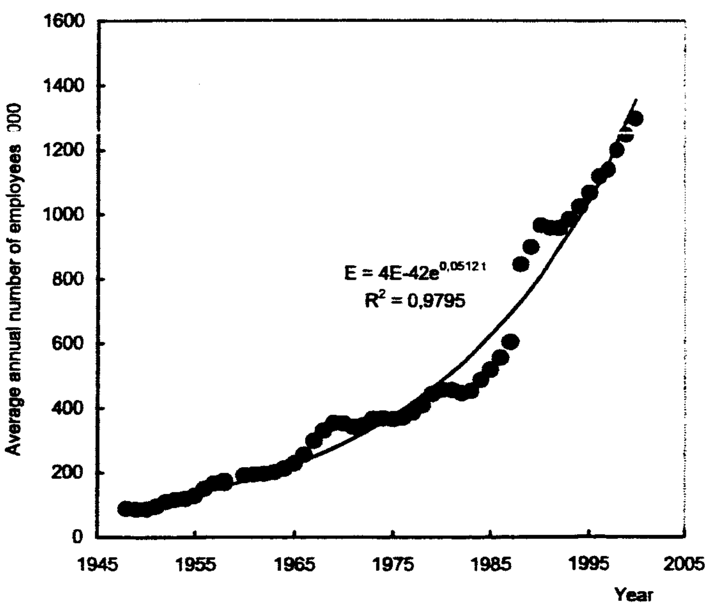

Figure 10c Overall employment at U.S. air transport industry (Compiled from BEA, 2001)

Figure 10c illustrates development of employment in the U.S. air transport industry during the period i945-200i. As can be seen, the long-term growth of the number of employees has been approximately exponential. It has started approximately from one hundred thousands in the year 1945 and reached about one million and four hundred thousands in the year 2001, which has been fourteen-times increase. There have been the variations around the general trend indicating restructuring of the sector after deregulation of the airline industry in the year 1978 and global crisis before and after the Gulf war in 1991. Nevertheless, in the long term, according to this indicator, the system has been developing in the sustainable way.

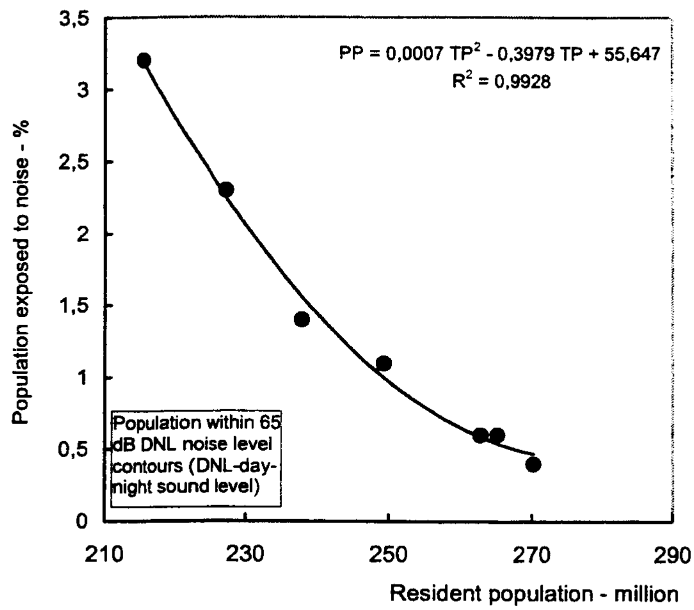

Figure 10d Global noise efficiency around 250 largest U.S. airports: period 1975-1998 (Compiled from BTS, 2001)

Figure 10d illustrates global noise efficiency at 250 U.S. main airports. This efficiency has been expressed as the proportion of population exposed to the air transport noise in dependence on the total resident population. As can be seen, during the period 1975-1998, this proportion has been decreasing more than proportionally with increasing of population, from 3% to less than a half percent. Certainly, such long-term trend has been achieved by improvements of airport and land use planning resettlement of population previously lived close to these airports, improvements of aircraft operational procedures and modernization of aircraft fleet. Consequently, according to this indicator the system has been developing in a sustainable way.

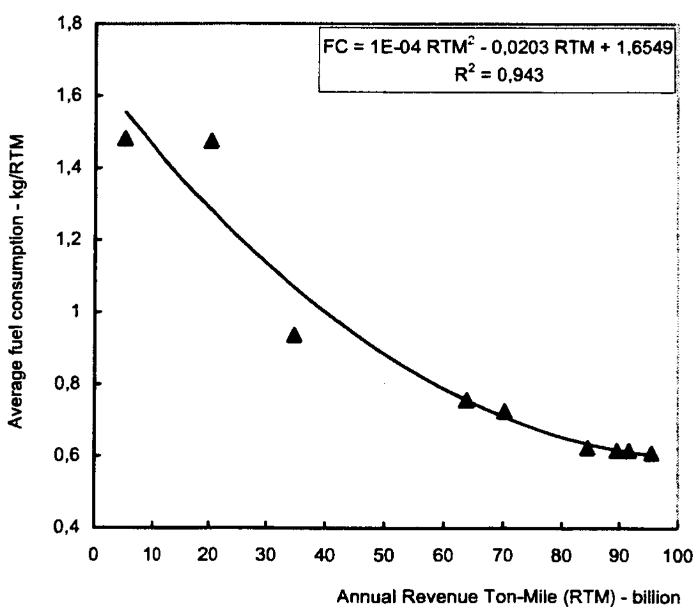

Figure 10e Global energy efficiency of the U.S. airline industry: period 1960-1999 (Compiled from BTS, 2001)

Figure 10e illustrates global energy efficiency of the U.S. airline industry expressed by the average fuel consumption per RTM (Revenue Ton Mile) in dependence on the total annual amount of RTM. As can bee seen, this consumption has decreased more than proportionally with increasing of the total amount of RTM, from about 1.6 kg/RTM to just about 0.6 kg/RTM (~2.7 times). At the same time the annual amount of RTM has increased for about five times. The main influencing factors have been improvements in the aircraft design and fleet use. Consequently, with respect to this indicator, the system has developed in a sustainable way during the observed period.

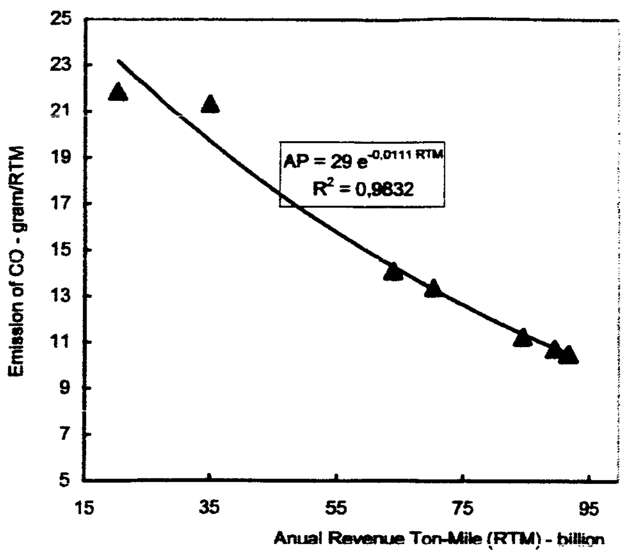

Figure 10f Global air pollution efficiency of the U.S. airline industry: period 1970-1998 (Compiled from BTS, 2001)

Figure 10f illustrates global air pollution efficiency of the U.S. airline industry. Similarly as at the fuel consumption case, this efficiency has been expressed by the quantity of CO emitted per RTM (Revenue Ton Mile) in dependence on the annual amount of RTM carried out during the period 1970-1998. As can be seen, more than proportional decrease of this emission, from about 22g/RTM to about 10 g/RTM, with increasing of RTM, from about 16 to about 95 billion RTM per annum, has taken place. The reasons have been the same as in case of fuel consumption including also improvements of aircraft engines in terms of the 'quality of burning' fuel. Consequently, according to this indicator, the system has been developing in a sustainable way.

5 CONCLUSIONS

The paper has explained the methodology for assessment of the sustainability of air transport system and its potential application. The methodology has consisted of the indicator systems consisted of the individual indicators and their measures. They have represented the system operational, economic, social and environmental performance. The particular indicators and their measures have been defined in terms of the system positive effects and negative impacts and in dependence on the system output, in both monetary and non-monetary terms. Their relevance for different actors such as users (air travellers), air transport operators, aerospace manufacturers, local communities, governmental authorities at different scales (local, national, international), international air transport associations, pressure groups and public have been also included. In total, fifty-eight individual indicators and their sixty-eight measures have been defined.

The application of the methodology has included estimation of twenty-six indicators. Due to the structure of the particular indicators and availability of the relevant data, almost all cases have related to the U.S. air transport industry while just a few ones have related to the European air transport industry. The results have shown (and confirmed) that the long-term development of the system and its particular components has been sustainable with respect to the most indicators of the economic, social and environmental dimension of performance from the aspects of the most actors involved. Nevertheless, there have been still some doubts about unsustainable indicators of the operational dimension of performance such as

punctuality and reliability of service at airports and airlines, indicators of the environmental dimension of performance such as air pollution, waste efficiency and noise disturbance at airports, and indicators of the economic dimension of performance such as labour productivity of airlines.
Generally, based on the analysed cases, it can be said that the air transport system, with few exceptions, has shown sustainable development under given circumstances and during observed period. Stable sustainable trends have been established. However, after September 11 terrorists' attack on the U.S. (2001), the operational and economic dimension of performance have become of the growing importance illustrating the system and its components' struggle for survival. The questions about the system future sustainable development as well as comparison of its with the sustainability of other transport modes as well as other sectors of the national and international economy by using the same or modified methodology are waiting for reply.

6 REFERENCES

Arthur D. L., (2000), Study into Impact of Changes in Technology on the Development of Air Transport in the UK, Arthur D., Little Limited, Science Park, Cambridge, UK

ATAG (2000), Aviation & the Environment, Air Transport Action Group, Geneva, Switzerland

ATAG, (2000a), The Economic Benefits of Air Transport, Air Transport Action Group, Geneva, Switzerland

BA, (2001), From the Ground Up: Social and Environmental Report 2001, British Airways Plc., Waterside, (HBBG), Middlesex, UK

BAA, (2001), Waste Management, British Airport Authority, London, UK

BEA (2002), NIPA Tables, Bureau of Economic Analysis US Department of Commerce, USA

Boeing, (2001), Current Market Outlook – 2001, The Boeing Company, USA

BTS, (2001), National Transport Statistics 2000, US Bureau of Transport Statistics, US Department of Transportation, USA

BTS, (2001a), Number of Pilot Reported Near Midair Collisions, U.S. Bureau of Transport Statistics, US Department of Transportation, USA

Button, J. K., Stough, R., (1998), The Benefits of Being a Hub Airport City: Convenient Travel and High-Tec Job Growth, Report, Aviation Policy Program, George Mason University, Fairfax, Virginia, USA

Daly, H., (1991), Steady State Economics, Inland Press, Washington D.C., USA

DETR, (1999), Oxford Economic Forecasting: The contribution of the Aviation Industry to the UK Economy, Department of the Environment, Transport and Regions, London, UK

DETR, (2000), The Future of Aviation, The Government's Consulting Document on Air Transport Policy, Department of the Environment, Transport and Regions, London, UK

DETR, (2000a), UK Air Freight Study Report, Department of the Environment, Transport and Regions, London UK

DETR, (2000b), "Aircraft Proximity (AIRPROX): Number of Incidents 1988-1998", Transport Statistics Great Britain 2000 Edition, Department of the Environment, Transport and the Regions, UK

DETR, (2000c), UK Air Freight Study Report, Department of the Environment, Transport and Regions, London UK

DETR, (2001), Valuing the External Cost of Aviation, Department of the Environment, Transport and Regions, London, UK

Doganis, R., (1992), The Airport Business, Rutledge, London, UK

EC, (1997), External Cost of Transport in ExternE, European Commission, Non Nuclear Energy Programme, IER Germany, Germany

EC, (1998), Interaction between High-Speed Rail and air Passenger Transport, Final report on the Action COST 318, EUR 18165, European Commission, Luxembourg

EC, (1999), Policy Scenarios of Sustainable Mobility – POSSUM, European Commission, 4th Framework Programme, EURES, Brussels, Belgium

EC, (1999a), The Creation of the Single European Sky, European Commission, COM (1999), 614, final, Brussels, Belgium

ECMT, (1998), Efficient Transport for Europe: Policies for Internalization of External Costs, European Conference of Ministers of Transport, OECD-Organization of Economic Co-operation and Development, Paris, France

EPA, (1999), Evaluation of Air Pollutant Emissions from Subsonic Commercial Aircraft, EPA420-R-99-013, Environmental Protection Agency, Ann Arbor, Michigan, USA

EUROCONTROL, (1998), Aircraft Performance Summary Tables for the Base of Aircraft Data (BADA): Revision 3.1, ECC Note No. 27/98, EUROCONTROL, Brussels, Belgium

EUROCONTROL, (2001), ATFM Delays to Air Transport in Europe - Annual Report 2000, EUROCONTROL, Brussels

FAA, (1996), Aviation System Indicators, 1996 Annual Report Federal Aviation Administration, US Department of Transportation, USA

FAA, (1998), Economic Values for Evaluation of Federal Aviation Administration Investment and Regulatory Decisions, Report FAA-APQ-98-8 US Department of Transportation, Federal Aviation Administration, Washington DC, USA

FI, (2000), "Commercial Aircraft Directory Part I, II", Flight International, Oct/Nov, UK;

FI, (2001), "Regional Aircraft: World Airlines: Part I", Flight International, Sept. UK

Fraport, (2001), Frankfurt Airport: Environment – Noise Reduction, Fraport AG, Frankfurt, Germany

HA, (1999), Environmental Impact of Air Transport in Comparison with Railways and Transport by Rail in the European Union, Intermediate Report, Hera - Amalthea, S.L., Madrid, Spain

Han X., Fang, B., (1998), "Measuring Transportation in the U.S. economy", Journal of Transportation and Statistics, pp. 93 - 102

Headley, E. D., Bowen, D.B., (1992), Airline Quality Issues: Proceedings of the international Forum on Airline Quality, NIAR Report 92-10, NIAR – National Institute for Aviation Research, The Wichita State University, Wichita, Kansas, USA

Hewett, C., Foley, J., (2000), Plane Trading: Policies for Reducing the Climate Change Effects of international Aviation, IPPR – The Institute for Public Policy Research, London, UK

Hooper, P.G., Hensher, D.A., (1997), "Measuring Total Factor Productivity at Airports", Transportation Research – E, Vol. 33, No. 4, pp. 249-259

ICAO, (1993a), Aircraft Engine Emissions, Environmental Protection, Annex 16, Vol. 2, International Civil aviation Organization, Montreal, Canada

ICAO, (1993b), Aircraft Noise, Environmental Protection, Annex 16, Vol. 1, International Civil Aviation Organization, Montreal, Canada

INFRAS, (2000), Sustainable Aviation, Pre-Study, MM-PS, Zurich, Switzerland

Janic, M., (1999), "Aviation and Externalities: The Accomplishments and Problems", Transportation Research D, Vol. 4, pp, 159-180

Janic, M., (2001), Air Transport Systems Analysis and Modeling, Gordon & Breach Science Publishers, Amsterdam, The Netherlands

Janic, M., (2003), "Methodology for Assessing Sustainability of Air Transport System", Journal of Air Transportation, Vol. 8, No. 1, pp. 115-152

Levison, D., Gillen, D., Kanafani, A., Mathieu, J. M., (1996), The Full Cost of Intercity Transportation – A Comparison of High-Speed Rail, Air and Highway Transportation in California, Institute of Transportation, University of California, Berkeley, Research Report, UCB-ITS-RR-96-3, USA

Lufthansa, (2000), Annual Report 2000: Ten-year Statistics, Lufthansa, Frankfurt-Main, Germany

MA (1999), Manchester Airport Complaints and Community Disturbance: Report: 1998-1999, Manchester Airport PLC, Manchester, UK

Offerman, H., Bakker, M, (1998), "Growing Pains of Major European Airports", 2nd USA/Europe Air Traffic Management R&D Seminar, Orlando, USA, 1/4th Dec., p. 10

RAS, (2001), Air Travel – Greener by Design – The Technology Challenge, Royal Aeronautical Society, Report of Greener by Design Steering Group, London, UK

Schiphol Group (2000), Annual Community Report, Schiphol Group, Schiphol, The Netherlands

USDT, (2001), Major Airport Flight Delay, U.S. Department of Transportation, Office of Airline Information, Washington DC, USA

WCED, (1987), Our Common Future, The Word Commission on the Environment and Development (The Bruntland Report), Oxford University Press, Oxford, UK

Whitelegg, J., (1993), Transport for a Sustainable Future, Belhaven Press. London, UK

Ying Lu, C.H., (2000), Social Welfare Impacts of Environmental Charges on Commercial Flights, PhD Thesis, College of Aeronautics, Canfield University, UK

Zurich Airport, (2001), Environmental Report 2000, Unique Environmental Services, Zurich, Switzerland