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

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ABSTRACT

An assessment and operationalization of the concept of a sustainable air transport system is recognised as an important but complex research, operational and policy task. This paper represents an academic effort to properly address the problem of assessing the sustainability of an air transport system. In particular, the paper presents a methodology for assessment of the sustainability of an air transport system. This methodology is based on an indicator system related to particular dimensions of the air transport system's performance considered from the aspects of particular actors involved. Specific cases are selected to illustrate the application of the proposed methodology.

INTRODUCTION

What is a sustainable system? According to the numerous definitions, this should be a 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, a transport system is an unsustainable system (Daly, 1991; Whitelegg, 1993). Nevertheless, since a transport system also acts as a strong driving force for the economic development and social welfare, the above definition of sustainability,

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particularly in the long-term, needs to be refined by taking into account both the positive and negative impacts of the system. In such context, sustainability of a transport system could be considered as the growth of the differences between the positive and negative effects. Such development seems to be achievable by establishing a balance between the system effects. However, numerous conceptual and practical problems might emerge as barriers. One of the most important conceptual barriers seems to be a rather difficult estimation of the system's full effects mainly due to the diversity of approaches and methodologies. The main practical problem appears to be difficulty in globalising the policies for promoting the concept of sustainable development mainly due to the heterogeneity of performances of the system components and the necessity for permanently compromising the interests of particular actors (ATAG, 2000: 2000a; DETR, 2000, 2001; EC, 1997; ECMT, 1998; Hewett & Foley, 2000; Levison, Gillen, Kanafani & Mathieu, 1996; WCED, 1987).

This paper makes an academic effort in applying a methodology to the assessment of the sustainability of an air transport system (Janic, 2003). This methodology is based on the indicator system of sustainability reflecting the system's operational, economic, social and environmental dimension of performance[1] (FAA, 1996). The indicator system for each dimension of performance contains the individual indicators and their measures defined with respect to the expected objectives and preferences of the 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 the 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 an air transport system with respect to the particular indicators and measures is carried out (EC, 1999).

THE CONCEPT OF SUSTAINABLE AIR TRANSPORT SYSTEM

Basic Principles of Sustainability

In light of the refined definition of sustainability, an air transport system could be considered 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 the sum of the differences

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[1] This is an analogous definition to the definition that a sustainable society is supposed to have three essential dimensions of performance: economic, social, and environmental (United Nations, 1992).

between the positive effects (benefits) and the negative impacts (costs) at different geographical scales such as global (intercontinental), regional (national/continental), and local (community; INFRAS, 2000).

Sustainability at the global scale

At the global scale, the 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 are thought to be useful to drive the system towards sustainable development—that is, to setting up and maintaining trade-offs between the positive effects and negative impacts—as follows (Janic, 2003).

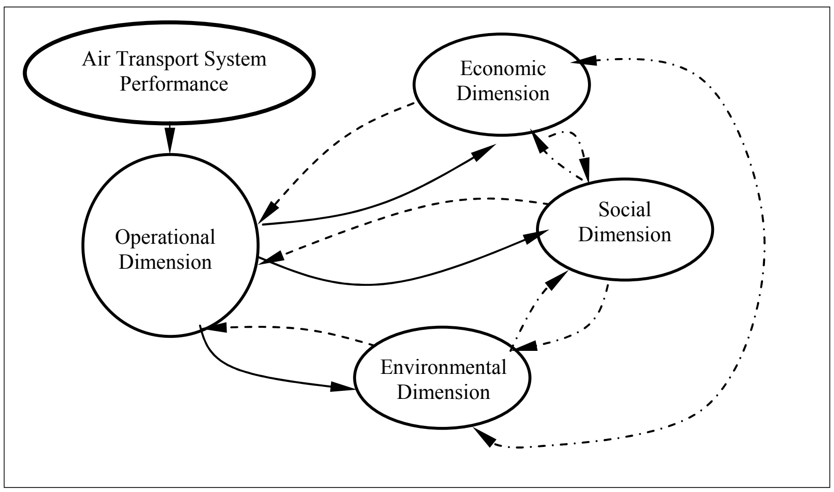
1. *Constraining the system growth at global scale*, which would include setting up an absolute limit to growth of the air transport demand and consequently to growth of the associated negative impacts;
2. *Setting up a cap on the impacts*, which would limit the system's energy consumption, associated air pollution, and thus indirectly the system's growth itself (Hewett & Foley, 2000);
3. *Decoupling the 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
4. *Trading-off between global effects and impacts,* which as a compromise scenario would provide mechanisms for the faster growth of the system's long-term global positive effects than the negative impacts.

Sustainability at the regional scale

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

1. *Affecting regional demand-driving forces*, which would as a controversial scenario discourage further growth of air transport demand by affecting the factors supporting market liberalisation and competition, productivity, and airfares (Boeing, 2001).
2. *Constraining the infrastructure expansion,* which as a do nothing scenario in terms of 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).
3. *More efficient utilisation of the available infrastructure*, which could lead to improvements of utilisation of existing airport and ATM/ATC infrastructure capacity by using innovative technologies and operational procedures, modifications of the airlines' operational practice, and co-operation with other transport modes (particularly railways; Arthur, 2000).

Figure 1: Dimensions of performance of the air transport system and their linkages



Sustainability at the local scale

At the 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):

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

Dimensions of the System Performance

Definition of the indicator system 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's operating revenues, costs and productivity (Hooper & Hensher, 1997).

The social dimension relates to the social effects such as the system's direct and indirect contribution to employment and GDP at the local and regional scale (Button & Stough, 1998; DETR, 1999; 2000). In addition, contributions 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's physical impacts on the people's health and the 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 the Amsterdam Schiphol airport, the government has limited by law the maximum annual number of aircraft movements aimed at controlling the noise. Consequently, in 1998 the maximum number of aircraft movements has been restricted to 380,000 with possible annual increase of 20,000 until 2003 (Boeing, 2001; Offerman & Bakker, 1998).

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

The Actors, Their Objectives and Preferences

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

1. *Users of services,* such as air travellers and shippers of freight and mail constituting the air transport demand;
2. *Air transport operators,* providing the system's services by using the related infrastructure, facilities and equipment such as airports, ATM/ATC, and airlines;
3. *Aerospace manufacturers,* producing the aircraft, ATM/ATC, and airport facilities and equipment;
4. *Local community members,* which is the population living in the vicinity of airports;
5. *The governmental bodies,* playing the role in creation of the institutional regulation for the system's operation at the local (community) and central (national) levels;
6. *Aviation organisations,* co-ordinating the system's development at the global (international) scale;
7. *Lobbies and pressure groups,* articulating the interests of people who may be for or against an expansion of the air transport system infrastructure; and
8. *The public,* temporarily interested 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 system as the methodology for assessment of sustainability.

Sustainability of the air transport system may have different meaning and contents for the particular actors, which are summarised as follows:

1. The *users—air travellers* and *shippers of freight* and *mail—* usually prefer frequent, easily accessible, low cost, punctual, reliable, safe and secure services.
2. The *air transport operators* prefer services according to their business objectives in terms of profitability, safety and security and the users' preferences.
3. The *aerospace manufacturers* prefer smooth selling of their reliable, safe, and profitable products to the system operators.
4. *Local community members* usually tend to maximise the benefits and minimise the costs of an air transport system at the local scale. The employment opportunity and use of efficient air connections to other distant communities or 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 aircraft accidents.

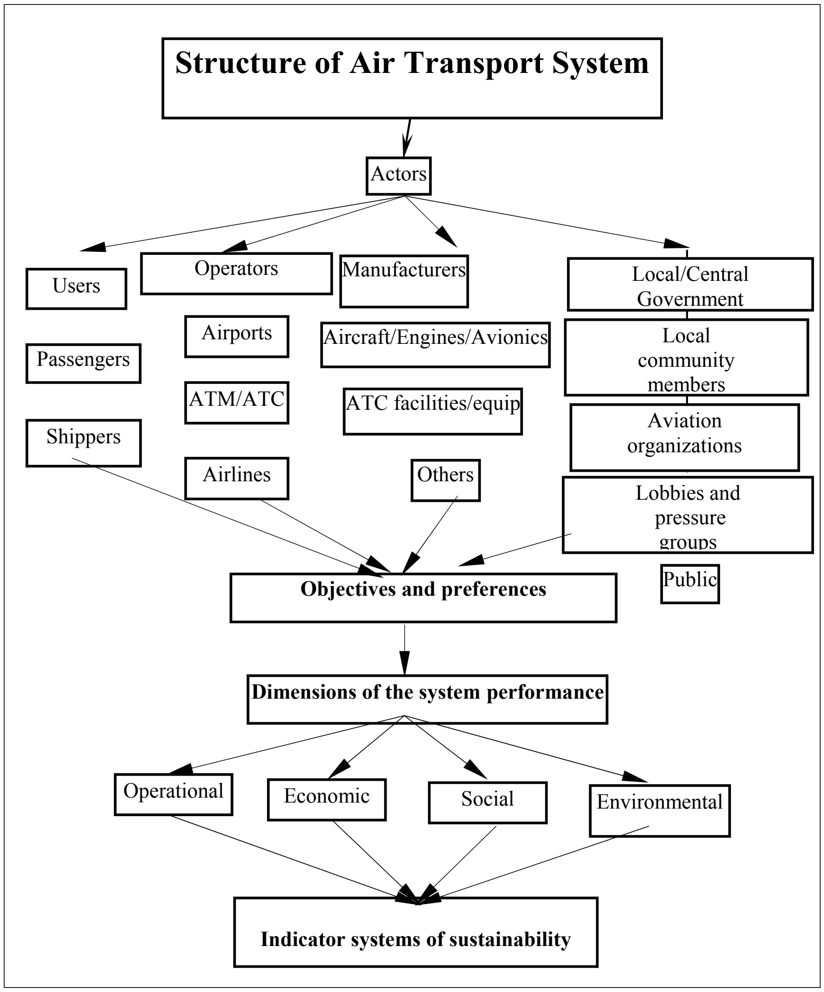
5. *Local* and *central government(s)* are mostly interested in the system's overall benefits and externalities. Direct benefits may include the system's contribution to local and national employment and GDP. Indirect benefits may embrace contributions to internalisation and globalisation of manufacturing, trade, investments and tourism. Externalities may be of interest while creating local and global policies and legislation to protect the people's health and environment.
6. *International aviation organisations* such as International Civil Aviation Organisation (ICAO), International Air Transport Association (IATA), European Civil Aviation Conference (ECAC), Association of European Airlines (AEA) and Airport Council International (ACI) provide the framework and guidelines for coordinated development of the system at both the regional and global scale.
7. *Different lobbies and pressure groups* organise campaigns against globally harmful effects of the polluting systems on the people's health and environment. In this role, they also intend to prevent further contribution of the air transport system to global warming by strong opposition, sometimes together with local community people, to the physical expansion of the system infrastructure, that is, airports.
8. *The public* uses media such as radio, television, the 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, information about the system should be available to public at any time.

THE INDICATOR SYSTEM OF SUSTAINABILITY

General

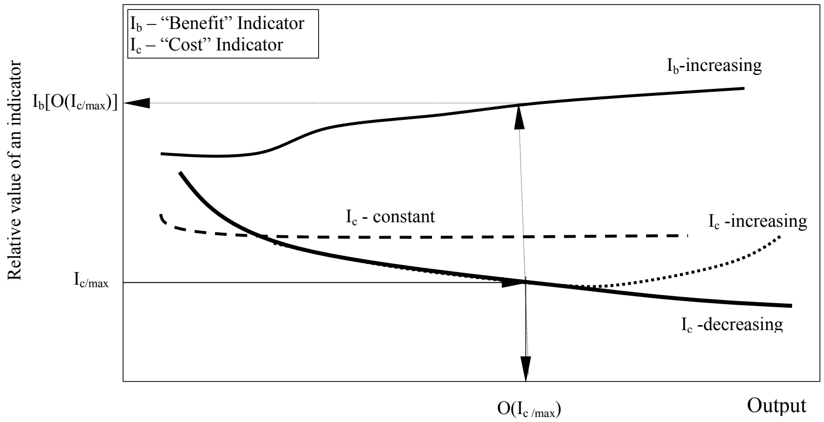
The indicator system of sustainability of an air transport system has been defined to measure the effects (benefits) and impacts (costs), in either absolute or relative monetary or non-monetary terms, as functions of the relevant system output (Janic, 2003). In such a context, the system has been assumed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

Figure 2: Structure of the air transport system for assessment of sustainability



[4] Setting up a limit on the particular indicator may have a 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 between the effects and impacts.

Figure 3: Relationships between the sustainability indicators and the air transport system's output



STRUCTURE OF THE INDICATOR SYSTEM

Different actors might use different indicators for assessment of the system's sustainability with respect to the particular dimensions of the system performance and their specific objectives and preferences. The indicator system consisting of the individual indicators and their measures are valid for the given period of time (day, month, year; Janic, 2003).

Indicators for users–air travellers

The indicator system for users—air travellers—consists of eight individual indicators related to the airports and airlines operated at different scales.

Operational indicators

The indicators of the operational dimension of performance are identified as follows:

1. *Punctuality* of service is measured by the probability that a flight will be on time and the average delay per flight[5] (Headley & Bowen, 1992; USDT, 2001). Users usually prefer

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

the former measure to be as high as possible and the latter one as low as possible with increasing of the number of flights.

2. *Reliability* of service is measured as the ratio between the realised and the total number of flights (USDT, 2001). The measure is preferred to be as high as possible and to increase with increasing of the number of flights.
3. *Ratio of lost/damaged baggage* is expressed as the proportion of the lost (or damaged) baggage compared to the total number of passengers served. This measure is preferred to be as low as possible and to decrease with increasing of the number of passengers.
4. *Safety* is measured as the ratio of the number of deaths (or injuries) per unit of output—Revenue Passenger Kilometer or Revenue Passenger Mile (RPK or RPM). The users prefer this measure to be as low as possible and to decrease with increasing of RPK or RPM.
5. *Security* is measured as the ratio between the number of detected illegal dangerous devices and the total number of passengers screened. It is preferred to be as low as possible and to decrease with increasing of the number of passengers.

Economic indicator

The indicator of the economic dimension of performance is identified as follows:

1. *Economic convenience of service* is measured by the average airfare per passenger, which is preferred by users to be as low as possible[6].

Social indicator

The indicator of the social dimension of performance is identified as follows:

1. *Spatial convenience of service* is 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.

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

Environmental indicator

The indicator of the environmental dimension of performance is identified as follows:

1. *Comfort* and *healthfulness* at airports is measured by the number of passengers per unit of the available space and the average queuing time (Hooper & 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 is used to measure the passenger comfort. The airport measures are preferred to be as low as possible and to decline with increasing of the number of passengers served. The measures while onboard are preferred to be as high as possible.

Indicators for airports

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

Operational indicators

The indicators of the operational dimension of performance are identified as follows:

1. *Demand* has been expressed as the number of passengers and the number of ATMs and is preferred to be as great as possible and to match the available capacity.
2. *Capacity* is measured as the maximum number of passengers and the maximum number of ATMs. Both measures are preferred to be as high as possible and to match growing demand (Janic, 2001).
3. *Quality of service* is measured by the average delay per ATM or per passenger occurring whenever the demand exceeds the capacity. The measure is preferred to be as low as possible and to decrease with increasing of demand (Janic, 2001).
4. *Flexibility of using the available capacity* is measured by the ratio between the number of substituted flights by other transport modes and the total number of flights[8]. This ratio is

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[7] Configuration of the economy class seats on long-haul flights has recently emerged as a matter of concern due to cases of passenger deaths caused by DVT (Deep Vein Thrombosis).

[8] For example, three European super hubs, Frankfurt Main, Paris Charles De Gaulle and Amsterdam Schiphol are connected to a High Speed Rail Network. Partial substitution of short-haul flights has already taken place there (EC, 1998; HA, 1999; IFRAS, 2000). If the air-rail

preferred to be as high as possible and to increase with increasing of the number of flights.

Economic indicators

The indicators of the economic dimension of performance are identified as follows:

1. *Profitability* is measured by the operating profits (the difference between operating revenues and operating costs) per unit of the airport output–an ATM or a passenger (Doganis, 1992). This measure is preferred to be as high as possible and to increase with increase in the airport output.
2. *Labour productivity* is expressed by the number of ATMs, passengers or workload unit per (WLU) employee[9] (Doganis, 1992; Hooper & Hensher, 1997). This measure is preferred to be as high as possible and to increase with increasing of the number of employees.

Social indicators

No indicators of the social dimension of performance are identified.

Environmental indicators

The indicators of the environmental dimension of performance are identified as follows:

1. *Energy efficiency* is measured by the quantity of energy consumed per unit of the airport output–an ATM or a passenger. This measure is preferred to be as low as possible and to decrease with increasing of airport output.
2. *Noise efficiency* is expressed by the area in square kilometres determined by the equivalent noise level in decibels (DETR, 2000; 2001). This indicator is preferred to be as small as possible and to diminish with increasing of the number of ATMs.
3. *Air pollution efficiency* is measured by the air pollutants emitted per an event–landing/take-off (LTO)[10] cycle (EPA, 1999; ICAO, 1993a). This measure is preferred to be as low as

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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.

[9] In many cases, workload unit (WLU) has been used as an equivalent for one passenger or 100 kg of baggage (Doganis, 1992)

[10] ICAO has recommended the landing/take-off (LTO) cycle as a standardised format for quantifying air pollution at airports (ICAO, 1993a)

possible and to decrease with increasing of the number of LTO cycles.

4. *Waste efficiency* is measured by the quantity of waste per unit of the airport output–an ATM or a passenger (BA, 2001). The measure is preferred to be as low as possible and to decrease with increasing of the airport output.
5. *Land use efficiency* is measured in terms of the area of land used for accommodating air transport demand. The measure is preferred to be as low as possible and to increase with increasing of the volume of demand.

Indicators for ATM/ATC

The indicator system for ATM/ATC consists of eight indicators, which might be quantified for a part of the ATM/ATC sector or for the whole system (airspace of a country, a wider region, or continent; Janic, 2003).

Operational indicators

The indicators of the operational dimension of performance are identified as follows:

1. *Demand* is measured as the number of flights demanded to pass through a given ATM/ATC airspace (Janic, 2001). This measure is preferred to be as great as possible.
2. *Capacity* is measured by the maximum number of flights served in a given airspace per unit of time (Janic, 2001). This indicator is preferred to be as great as possible and to increase with increasing demand.
3. *Safety* is 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 are preferred to be as low as possible and to decrease with increasing of the number of flights.
4. *Punctuality of service* is measured by the proportion of flights being on-time and the average delay per delayed flight due to the ATM/ATC restrictions. While the former measure is preferred to be as high as possible and to increase, the latter measure is preferred to be as low as possible and to decrease with increasing of the number of flights.

Economic indicators

The indicators of the economic dimension of performance are identified as follows:

1. *Cost efficiency*[11] is measured by the average cost per unit of output (controlled flight). The measure is preferred to be as low as possible and to decrease with increasing of the number of flights (Janic, 2001).
2. *Labour productivity* is reflected the number of controlled flights per an employee. This measure is preferred to be as high as possible and to increase with increasing of the number of employees.

Social indicators

No indicators of the social dimension of performance are identified.

Environmental indicators

The indicators of the environmental dimension of performance are identified as follows:

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

Indicators for airlines

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

Operational indicators

The indicators of the operational dimension of performance are identified as follows:

1. *Airline size* is expressed by the volume of RTK or RTM, 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

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[11] Cost is considered to be a more relevant indicator than profitability because 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).

(Janic, 2001). The above measures are preferred to be as great as possible and to increase over time and under conditions of sufficient demand.

2. *Load factor* is measured as the ratio between the total RTK or RTM and Available Ton-Kilometre or Available Ton-Mile (ATK or ATM). This measure is preferred to be as great as possible and to increase with increasing of the airline output (Janic, 2001).
3. *Punctuality, reliability* and *safety* of service for airlines are measured and preferred analogously to that of users as described above (Janic, 2001).

Economic indicators

The indicators of the economic dimension of performance are identified as follows:

1. *Profitability* is measured by the average profits (difference between the operating revenues and costs) per unit of output—RTK or RTM. This measure is preferred to be as great as possible and to increase with increasing of the airline output.
2. *Labour productivity* is measured by the average quantity of output—RTK or RTM—per employee. This measure is preferred to be as great as possible and to increase with increasing of the number of employees.

Social indicators

No indicators of the social dimension of performance have been identified.

Environmental indicators

The indicators of the environmental dimension of performance are identified as follows:

1. *Energy* and *air pollution efficiency* are measured by the average quantity of fuel and associated air pollution, respectively, per unit of output—RTK or RTM, distance flown or the number of flying hour. Both measures are preferred to be as low as possible and to decrease with increasing of output.
2. *Noise efficiency* is measured by the proportion of the aircraft of Stages 3 and 4 in an airline fleet. This measure is preferred to

be as great as possible and to increase with expansion of the airline fleet[12] (BA, 2001; ICAO, 1993b).

3. *Waste efficiency* is measured by an average quantity of waste per unit of the airline output—RTK or RTM. This measure is preferred to be as low as possible and to diminish with growing of the airline output (BA, 2001).

Indicators for aerospace manufacturers

The indicator system of the airspace manufacturers consists of eight indicators (Janic, 2003).

Operational indicators

The indicators of the operational dimension of performance are identified as follows:

1. *Aircraft innovations* is measured by technical productivity, resource use and cost efficiency (RAS, 2001). The first measure, preferred to be as high as possible, is expressed as the product between the aircraft speed and capacity product (ton-kilometres per hour or ton-miles per hour). The second measure, preferred to be as low as possible, is expressed by the amount of resources used for installment of a unit of aircraft capacity (i.e., in terms of aircraft weight per seat; Lowson, 2001). The last measure, preferred to be as low as possible, is expressed by the average operating cost per unit of capacity—ATK or ATM (Arthur, 2000; Janic, 2001).
2. *Innovations* of *ATM/ATC* and *airport facilities* is 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 is preferred to be as small as possible and the latter one as high as possible (Arthur, 2000; Janic, 2001).
3. *Reliability of structures* is measured by the rate of failures of the particular components per unit of time. Due to the safety and operational reasons, this measure, is preferred to be as high as possible.

[12] 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.

Economic indicators

The indicators of the economic dimension of performance are identified as follows:

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

Social indicators

No indicators of the social dimension of performance are identified.

Environmental indicator

The indicator of the environmental dimension of performance is identified as follows:

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

Indicators for local community

The indicator system for the local community consists of four indicators of sustainability (Janic, 2003).

Operational indicators

No indicators of the operational dimension of performance are identified.

Economic indicators

Indicators of the economic dimension of performance have not been identified.

Social indicators

The indicator of the social dimension of performance is identified as follows:

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

Environmental indicators

The indicators of the environmental dimension of performance are identified as follows:

1. *Noise disturbance* is measured by the total number of disturbing noise events—ATMs—during a given period of time (day, month, year) and by the number of complaints per noise event—ATM. Both measures are preferred to be as low as possible and to decrease with increasing of the number of ATMs.
2. *Air pollution* is measured as the ratio between the amounts of air pollutants emitted by the air transport system and the total amount of pollutants emitted by all other local sources. This indicator is preferred to be as low as possible and to decrease with increasing of the total air pollution.
3. *Safety* is measured by the number of aircraft accidents per ATM which affect the local community people in terms of damaging their property, making injuries or losing their life. This measure is preferred to be as low as possible and to decrease with increasing of the number of ATMs.

Indicator system for local and central governments

The indicator system for local and central government consists of seven indicators (Janic, 2003):

Operational indicators

No indicators of the operational performance are identified.

Economic indicators

The indicators of the economic dimension of performance are identified as follows:

1. *Economic welfare* is measured by the proportion of GDP obtained by the air transport sector in the total GDP. This measure is preferred to be as great as possible and to increase with increasing of the total GDP.

2. *Internalisation/globalization* is measured by the proportion of trade in terms of the volume and/or value of export and import carried out by the air transport in the total regional (country) trade, and by the ratio between the number of air trips and the total number of trips in a given region (country). These measures are preferred to be as great as possible and to increase with increasing of the volume of trade and the total number of trips, respectively.
3. *Externalities* are measured by the average expense per unit of the system output—RPK or 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; Ying-Lu, 2000). This measure is preferred to be as low as possible and to decrease with increasing of the system output.

Social indicator

The indicator of the social dimension of performance is identified as follows:

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

Environmental indicators

The indicators of the environmental dimension of performance are identified as follows:

1. *Global energy efficiency* us measured by the average amount of fuel consumed per unit of the system output–RTK or RTM. This measure is preferred to be as low as possible and to decrease with increasing of the system output.
2. *Global noise disturbance* is measured by the total number of people exposed to the air transport noise during given period of time (year). The measure is preferred to be as low as possible and to decrease over time.
3. *Global air pollution* is measured by the total emissions of air pollutants per unit of the system output—RTK or RTM. This measure is preferred to be as low as possible and to diminish with increasing of the system output.
4. *Global land use* is measured as the ratio between the land used for installing the air transport infrastructure and the total land

used for installing the infrastructure of the whole transport system of a given region (country). This measure is preferred to be as low as possible and to decrease with increasing of the area of land acquired for transport infrastructure.

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

Actor	Dimension of the System Performance	Indicator
Users		
	Operational	Punctuality
		Reliability
		Lost & damaged baggage
		Security
	Economic	Economic convenience
ATM/ATC		
	Operational	Punctuality
		Reliability
	Economic	Productivity
	Environmental	Energy (fuel) efficiency
Aerospace Manufacturers		
	Operational	Technical productivity
		Efficiency
	Environmental	Fuel efficiency
		Noise efficiency
Local community members		
	Environmental	Noise disturbance
Governments		
	Economics	Economic welfare
		Internalisation/Globalization
	Social	Overall social welfare
	Environmental	Global energy efficiency
		Global noise disturbance
		Global air pollution

APPLICATION OF THE PROPOSED METHODOLOGY

Fifty-eight indicators and sixty-eight measures have been defined in the scope of the indicator system developed for 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. Twenty-six indicators and measures are estimated in order to illustrate existence of the sustainability of an air transport system. The list is given in Table 1.

Data for estimating the particular indicators and their measures are extracted from different secondary sources. The results are shown in Figures 4, 5, 6, 7, 8, 9 and 10. In all these Figures the dots represent empirical data and the lines indicate global direction of development over the mentioned period of time (i.e., trend).

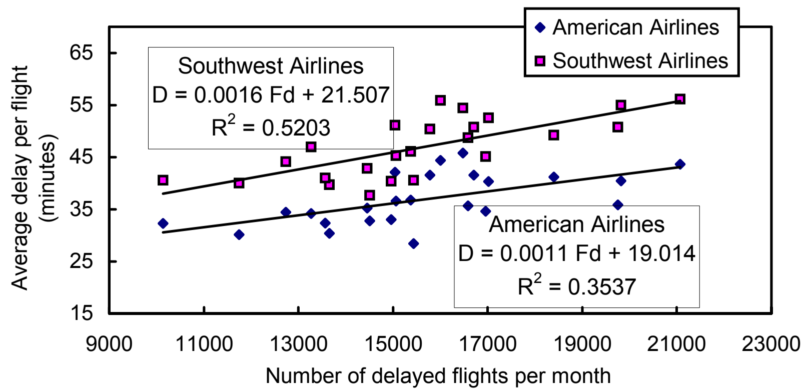
Users

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

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

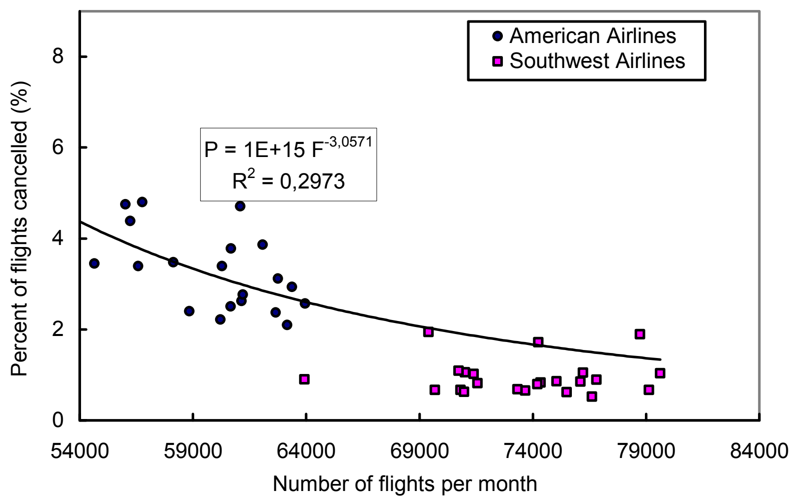
Figure 4c illustrates the ratio of mishandled (lost and damaged) baggage in relation to the total number of domestic passengers accommodated at U.S. airports. As can be seen, this ratio varied between 5.0% and 6.5% and decreased with increasing of the number of passengers up to about 460 million. Above this number, the ratio starts to increase with increasing of the number of passengers, which indicates worsening of the performance. From the users' perspective, according to the variations of this indicator, the system is sustainable with increasing of the number of passengers to a certain limit, and unsustainable beyond that limit.

Figure 4a. Punctuality of some U.S. airlines, 1999-2000



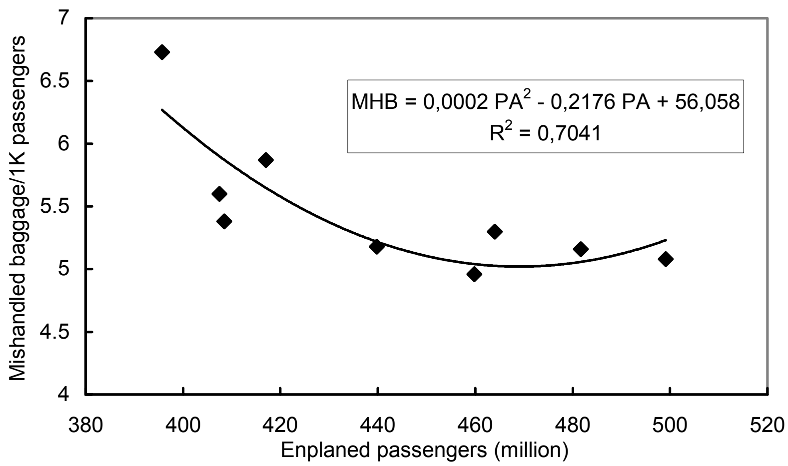
Data compiled from: *Major Airport Flight Delay*. (2001). Washington DC, USA/U.S. Department of Transportation Office of Airline Information.

Figure 4b. Reliability of some U.S. airlines, 1999-2000



Data compiled from: *Major Airport Flight Delay*. (2001). Washington DC, USA/U.S. Department of Transportation Office of Airline Information.

Figure 4c. Lost and damaged (mishandled) baggage for U.S. domestic scheduled services, 1990–1999

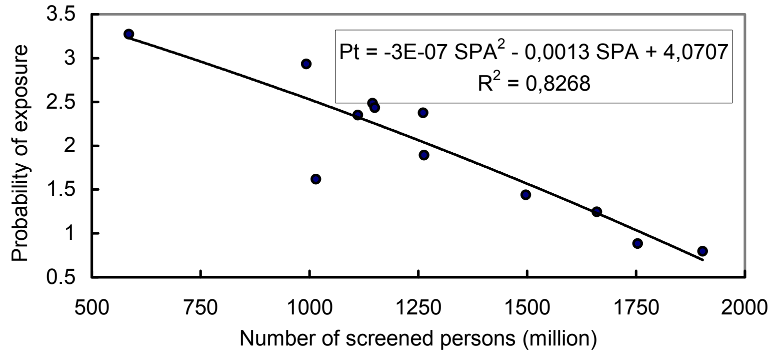


Data compiled from: *Major Airport Flight Delay*. (2001). Washington DC, USA/U.S. Department of Transportation Office of Airline Information.

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

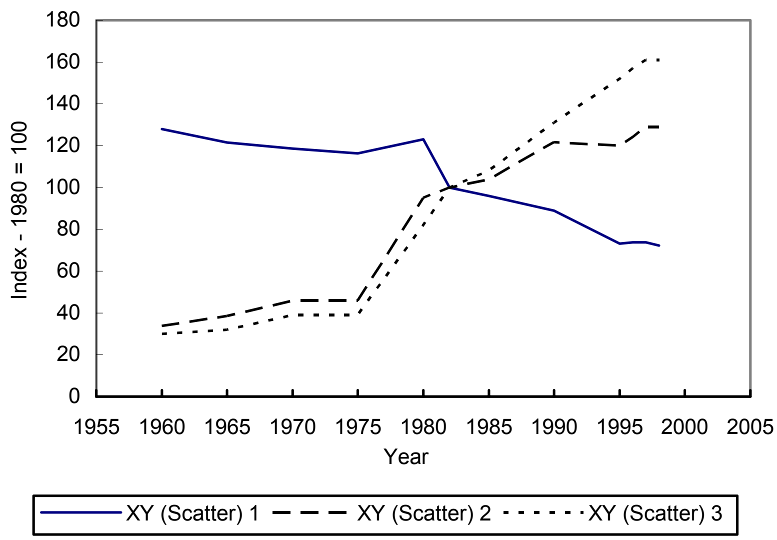
Figure 4e illustrates the economic convenience of air transport services for U.S. air transport system users expressed by average airfares and Consumer Price Index (CPI) during the observed period. As can be seen, two periods have been evident: the first period, between 1960 and 1982, when the index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

Figure 4d. Probability of being exposed to a threat at U.S. airports, 1980–1999



Data compiled from: *Major Airport Flight Delay*. (2001). Washington DC, USA/U.S. Department of Transportation Office of Airline Information.

Figure 4e. Economic convenience of the U.S. air transport system, 1960-1999

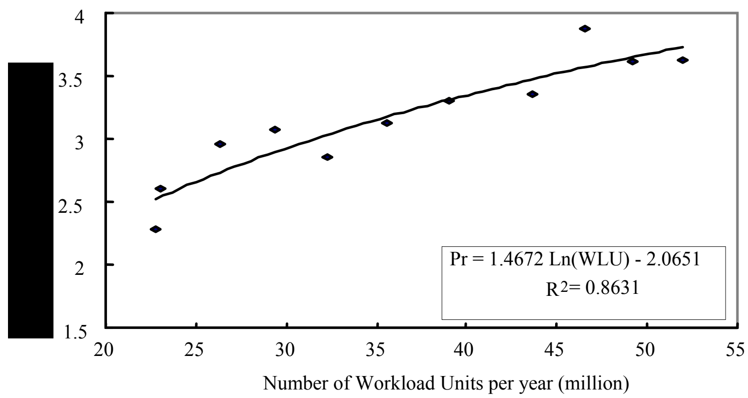


Data compiled from: *Major Airport Flight Delay*. (2001). Washington DC, USA/U.S. Department of Transportation Office of Airline Information.

Airports

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

Figure 5a. Profitability of Amsterdam Schiphol airport, 1990-2000



Data compiled from: *Annual Community Report.* (2000). Schiphol, The Netherlands/Schipol Group.

Figure 5b illustrates labor productivity at Amsterdam Schiphol airport (Netherlands). This productivity is in terms of the number of WLU per employee related to the total number of WLU accommodated at the airport per year. As can be seen, during the observed period, this productivity generally increased with increasing of the number of WLU, but at a decreasing rate, which turned into zero after the number of WLU increased over 45 million per year. Such development indicates how sustainability of the system vanished with respect to this indicator during this period of growth.

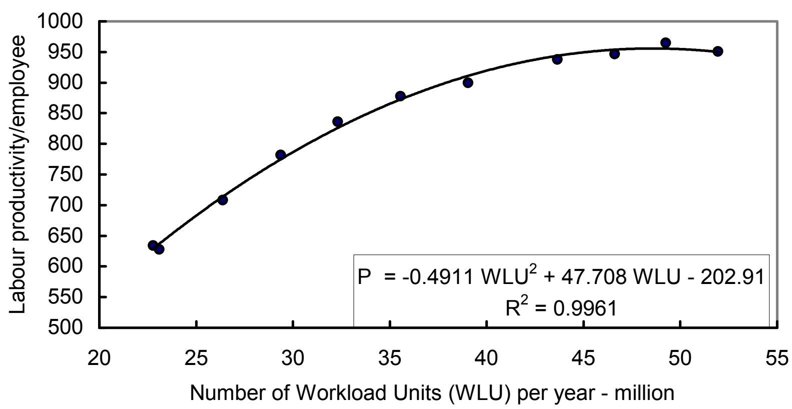
Figure 5c illustrates noise efficiency at Frankfurt airport (Germany) expressed by the area of land covered by the equivalent constant sound level L_{eq} [= 62, 67 and 75 dB(A)] in relation to the annual number of ATMs. As can be seen, for a given number of ATMs, for larger L_{eq} this area was smaller, and vice versa, which was intuitively expected. As well, the area of land affected by given L_{eq} decreased with increasing of the number of

ATMs. Both measures indicate that the area around the airport exposed to a given level of noise generally decreased despite increasing of the traffic volume. This certainly was achieved by replacing noisier aircraft with quieter aircraft and modifications of the operational procedures at and around the airport. Consequently, according to this indicator the airport has developed in a sustainable way.

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

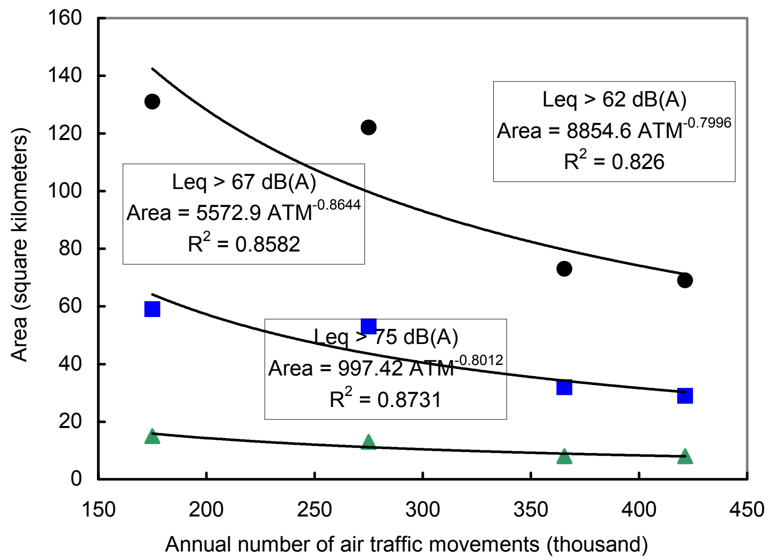
Figure 5e illustrates waste efficiency in terms of the quantity of waste per passenger in relation to the annual number of passengers accommodated at Frankfurt Main (Germany) and three London airports (Heathrow, Stansted, Gatwick, UK). As can be seen, this quantity decreased at Frankfurt Main and increased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

Figure 5b. Labour productivity at Amsterdam Schiphol airport, 1990-2000



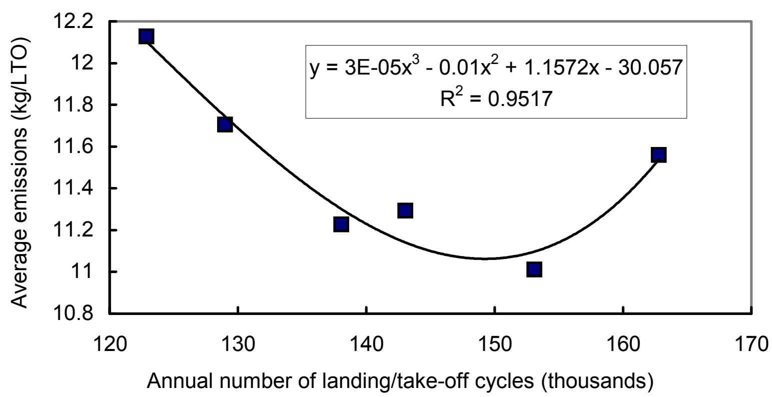
Data compiled from: *Annual Community Report.* (2000). Schiphol, The Netherlands/Schipol Group.

Figure 5c. Noise efficiency at Frankfurt airport. 1987-1999



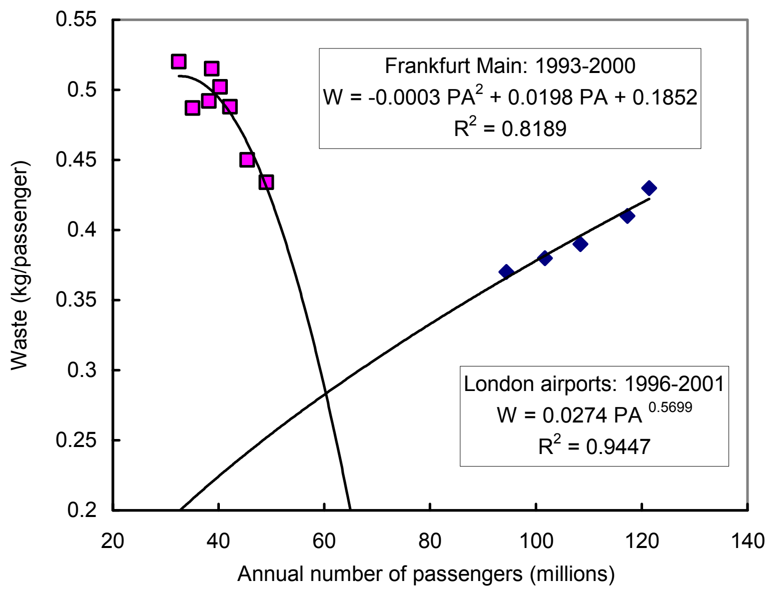
L_{eq} – area of land covered by the equivalent constant sound level
Data compiled from: *Frankfurt Airport: Environment—Noise Reduction.* (2001). Frankfurt, Germany, Fraport.

Figure 5d. Air pollution efficiency at Zurich airport, 1997-2000



Data compiled from: *Environmental Report 2000.* (2001). Zurich, Switzerland/Unique Environmental Services.

Figure 5e. Waste Efficiency at London airports, 1996-2001, and Frankfurt Main airport, 1993-2000



Data compiled from: *Waste Management.* (2001). London, UK/British Airport Authority; *Frankfurt Airport: Environment—Noise Reduction.* (2001). Frankfurt, Germany, Fraport.

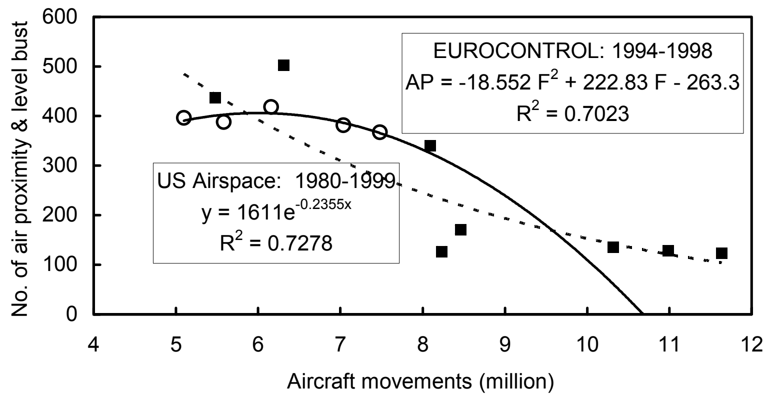
ATC/ATM

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

Airlines

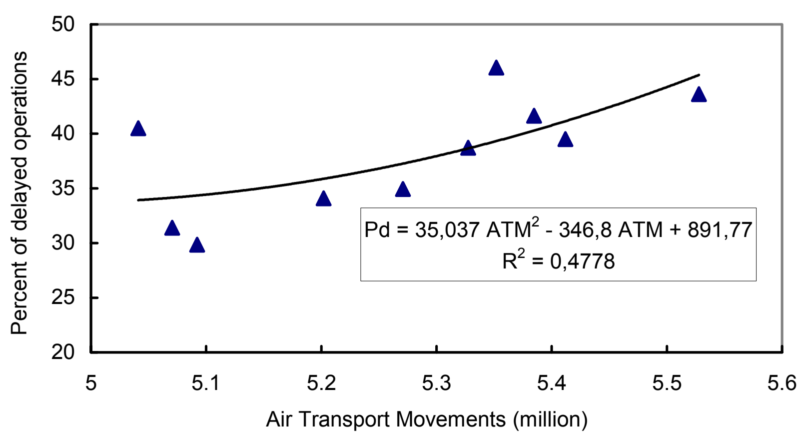
Figure 7a illustrates punctuality of the ten major U.S. airlines. It is expressed as the proportion of the delayed ATMs in relation to the total number of ATMs carried out per year during the period 1988 to 1999. As can be seen, generally, the proportion of cancelled flights generally increased at an increased rate with increasing of the number of the number of ATMs, which implies lack of the system's sustainable development with respect to this indicator.

Figure 6. Safety in European airspace, 1994-1998, and U.S. airspace, 1980-1999



Data compiled from: *National Transport Statistics 2000.* (2001). Washington DC, USA/ U.S. Bureau of Transport Statistics, U.S. Bureau of Transportation; *The Future of Aviation: The Government's Consulting Document on Air Transport Policy.* (2000). London, UK/Department of the Environment, Transport and Regions; *The Creation of the Single European Sky.* (1999). Brussels, Belgium/European Commission.

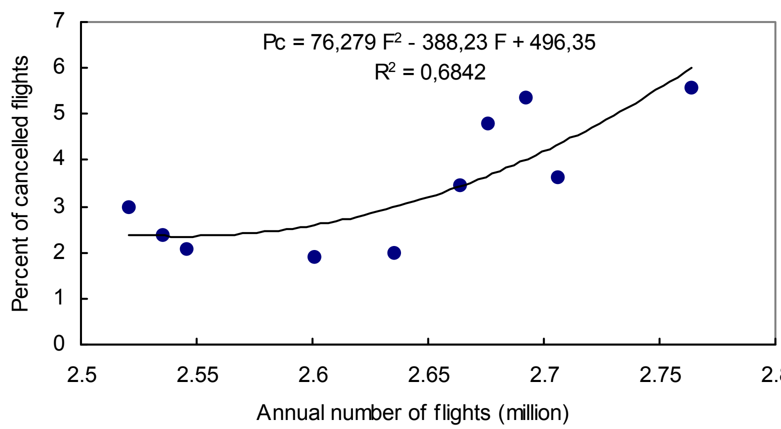
Figure 7a. Punctuality of ten major U.S. air carriers, 1988 – 1999



Data compiled from: *Major Airport Flight Delay.* (2001). Washington, DC, USA./ Office of Airline Information, U.S. Department of Transportation.

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

Figure 7b. Reliability of ten major U.S. air carriers, 1988–1999

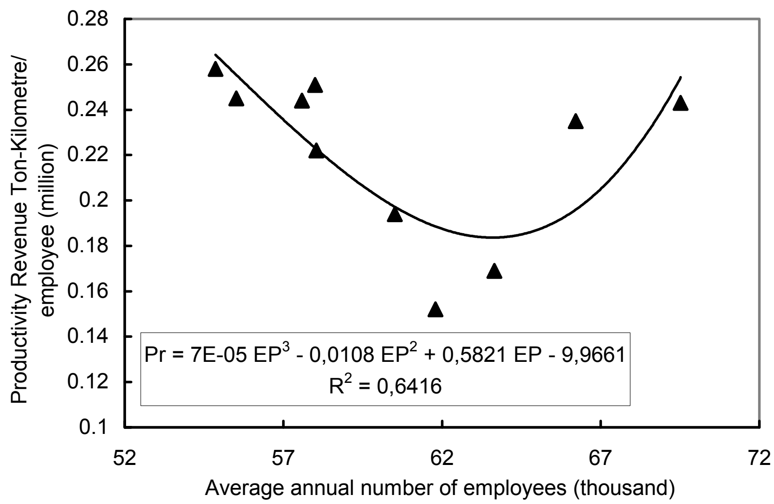


Data compiled from: *Major Airport Flight Delay.* (2001). Washington, DC, USA./ Office of Airline Information, U.S. Department of Transportation.

Figure 7c illustrates productivity at Lufthansa Group (Germany) expressed as RTK per employee in relation to the average annual number of employees. As can be seen, productivity decreased until the number of employees reached about 63 thousands but after that it increased despite that the number of employees continued to rise. This happened due to airline improvements; but the primary cause was the increase of long-haul intercontinental flights. Consequently, according to this indicator the group changed its long-term development trend from unsustainable to sustainable.

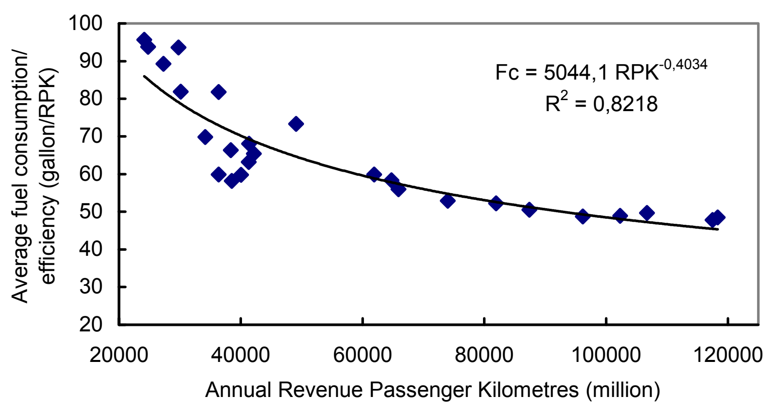
Figure 7d illustrates efficiency of fuel consumption at British Airways during the period 1974-2000. It is expressed in terms of grams of fuel consumed per RPK in relation to the total annual volume of RPK. As can be seen, this consumption generally decreased at a decreasing rate with increasing of the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

Figure 7c. Labour productivity of Lufthansa group, 1991-2000



Data compiled from: *Annual Report 2000: Ten-year Statistics.* (2000). Frankfurt, Germany, Lufthansa (2000).

Figure 7d. Fuel efficiency at British Airways, 1974-2000

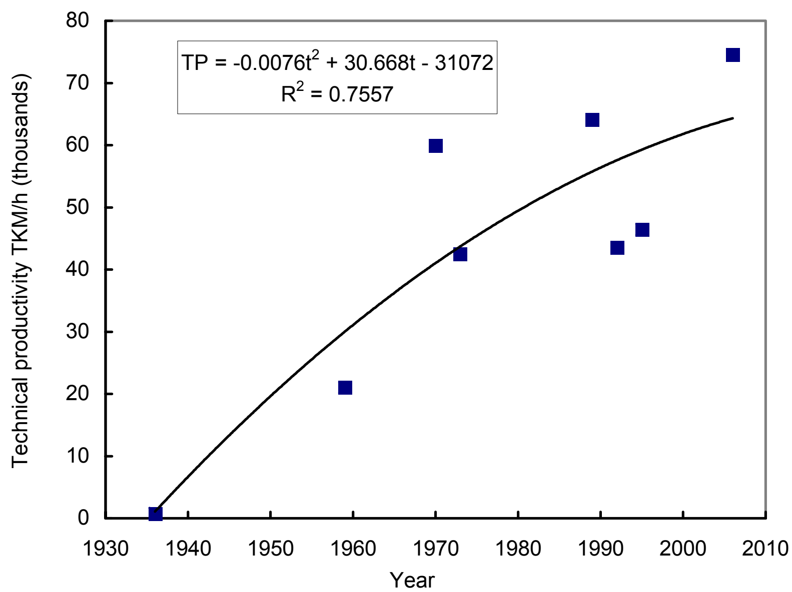


Data compiled from: *From the Ground Up: Social and Environmental Report 2001.* (2001). Wasterside, Middlesex, UK, BA.

Airspace Manufacturers

Figure 8a illustrates the main steps in progress in development of the aircraft technical productivity in terms of the number of TKM/hour. As can be seen, this productivity increased over time thanks to both airlines and their requirements as well as to capabilities of aerospace manufacturers. After introducing the aircraft Douglas DC 3, the rise of technical productivity was achieved by developing the larger aircraft, primarily, and by increasing of the aircraft operating (cruising) speed, secondarily. A culmination of development of this productivity will certainly be reached after introducing the aircraft Airbus A380. In addition, this included development and upgrading of engines in terms of their fuel and air pollution efficiency and sophisticated avionics. Consequently, the system has recorded long-term sustainable development.

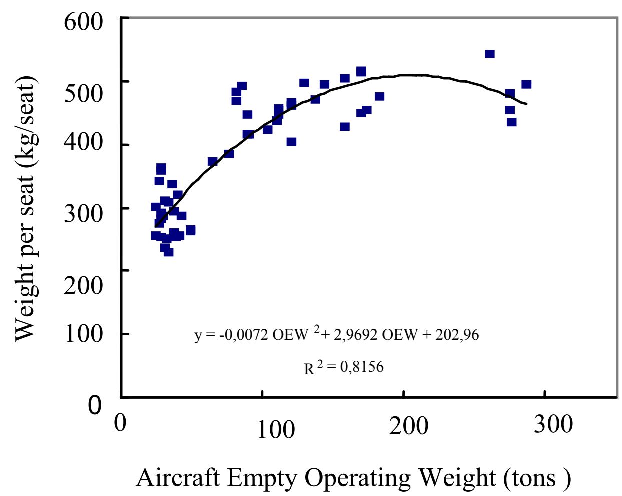
Figure 8a. Aircraft technical productivity since the development of the plane DC3 to present



Data compiled from: "Commercial Aircraft Directory Part I, II." (2001). *Flight International Oct/Nov*; "Regional Aircraft: World Airlines: Part I." (2001). *Flight International, Sept.*

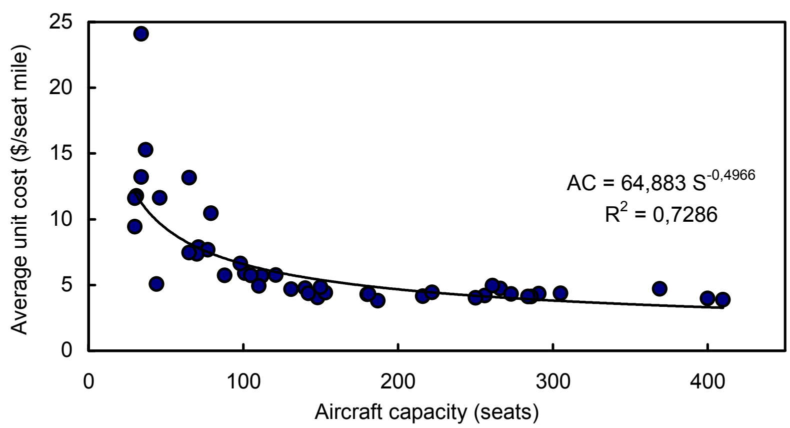
Figure 8b illustrates the use of different materials (resources) for manufacturing aircraft expressed by the average weight per seat. As can be seen, for contemporary aircraft, this weight increased at a decreasing rate with increasing of the aircraft weight. This illustrates achievement of sustainable development with respect to increasing of the aircraft size, that is, for manufacturing larger aircraft less material is used per unit capacity (seat).

Figure 8b. Average weight per seat on aircraft compared to aircraft size



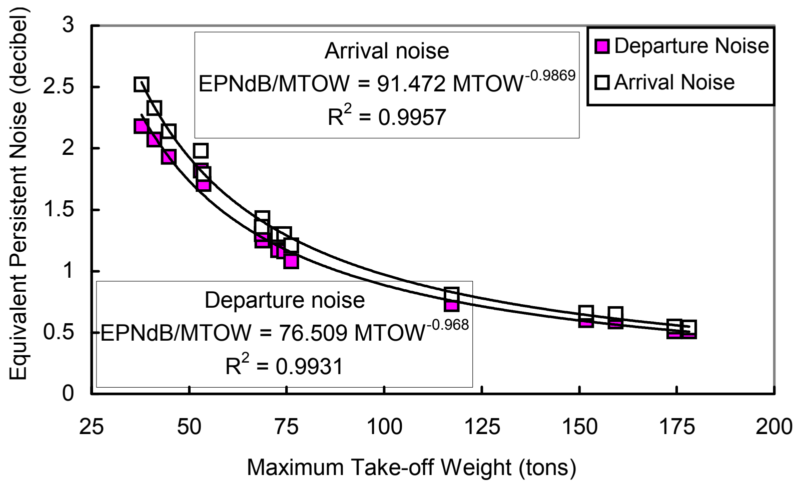
Data compiled from: "Commercial Aircraft Directory Part I, II." (2001). *Flight International Oct/Nov*; "Regional Aircraft: World Airlines: Part I." (2001). *Flight International, Sept.*

Figure 8c. Average cost per seat mile compared to potential number of seats



Data compiled from: *Economic Values for Evaluation of Federal Aviation Administration Investment and Regulatory Decisions.* (1998). Report FAA-APQ-98-8 U.S. Department of Transportation, Federal Aviation Administration, Washington DC, USA.

Figure 8d. Level of noise for aircraft per unit of aircraft's maximum take-off weight compared to its potential maximum take-off weight, for arrivals and departures



Data compiled from: "Commercial Aircraft Directory Part I, II." (2001). Flight International Oct/Nov; Environmental Impact of Air Transport in Comparison with Railways and Transport by Rail in the European Union. (1999). Madrid, Spain: Hera-Amalthea, S.L.; "Regional Aircraft: World Airlines: Part I." (2001). Flight International, Sept.

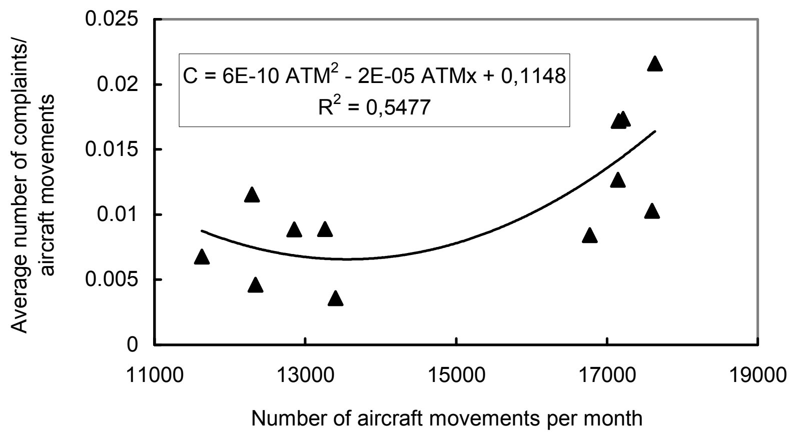
Figure 8c illustrates development of the aircraft efficiency in terms of the average cost per seat mile relative to the aircraft capacity (the number of seats). As can be seen, this cost decreased at a decreasing rate with increasing of the aircraft size thus indicating larger aircraft as being more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

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

Community Members

Figure 9 illustrates noise disturbance at Manchester Airport (UK) expressed by the average number of complaints per ATM in relation to the total number of ATMs carried out during the given period of time. As can be seen, when the average number of movements carried out per month is 13 thousand or less the average number of complaints decreased but when the average number of move increased the average number of complaints increased more than proportionally. This indicates that the airport has grown in an unsustainable way according to the attitudes of local population.

Figure 9. Average number of complaints per air traffic movement compared to total number of air traffic movements, Manchester Airport, 1998-1999



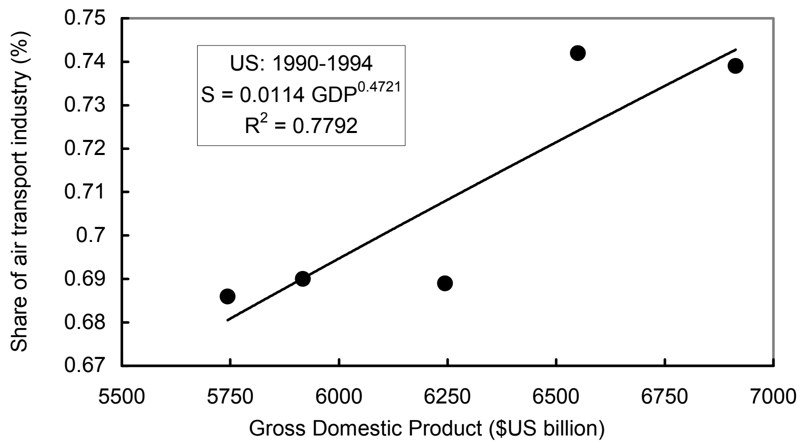
Data compiled from: *Manchester Airport Complaints and Community Disturbance Report: 1998-1999*. (1999). Machester, UK: Manchester Airport PLC.

Governments

Figure 10a illustrates economic benefit obtained by the U.S air transport industry expressed by its share in the total GDP during the limited period 1990 to 1994. As can be seen, this share increased linearly with increasing of the national GDP, which indicates 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 developed in a sustainable way during the observed period with respect to this indicator.

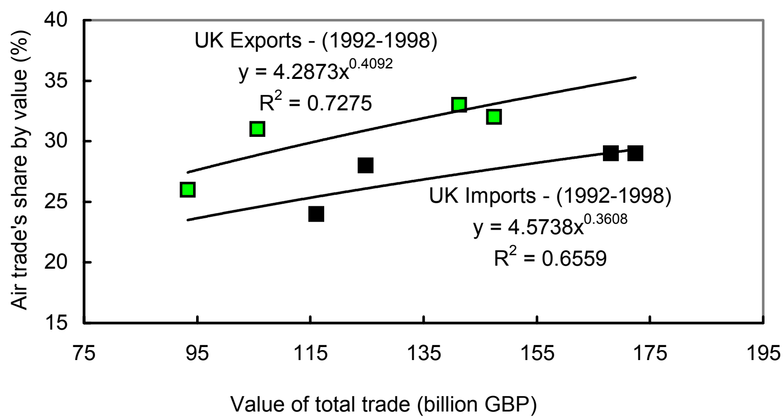
Figure 10b illustrates an example of the contribution of the national air transport system to globalization and internalization of the UK trade sector during the period 1992 to 1998. As can be seen by the country's import and export, the share of air transport by value rose with increasing of the total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

Figure 10a. Economic benefit of the U.S. air transport system, 1990-1994



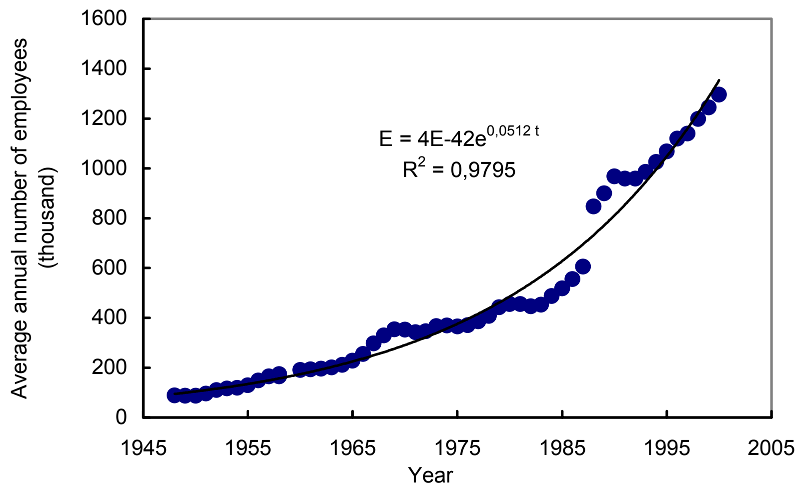
Data compiled from: Han, X. and Fang, B. (1998). "Measuring transportation in the U.S. economy" *Journal of Transportation and Statistics, 93-102.*

Figure 10b. Contribution of UK air transport system to the internalization and globalization of the UK trade sector, 1992-1998



Data compiled from: *UK Air Freight Study Report.* (2001). London UK: Department of the Environment, Transport and Regions.

Figure 10c. Overall number of persons employed by U.S. air transport industry, 1945-2001

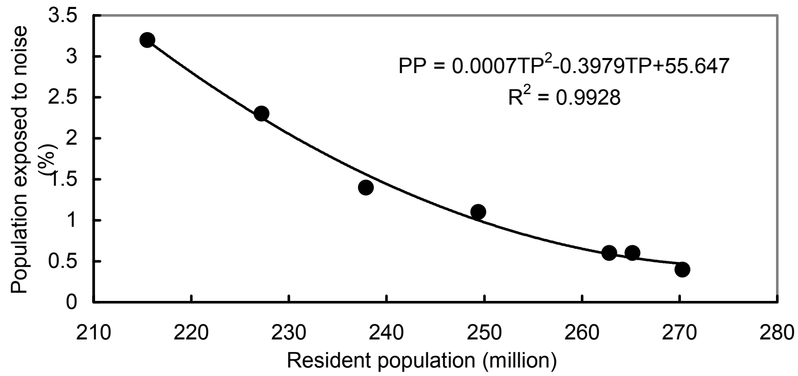


Data compiled from: *National Transport Statistics 2000.* (2001). Washington, D.C., USA: U.S. Bureau of Transport Statistics, U.S. Department of Transportation.

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

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

Figure 10d. Global noise efficiency around 250 largest U.S. airports, 1975-1998

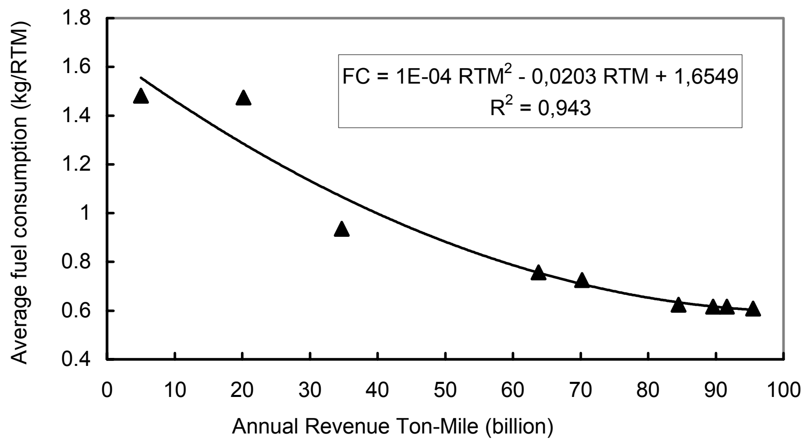


Data compiled from: *National Transport Statistics 2000.* (2001). Washington DC, USA: U.S. Bureau of Transport Statistics, U.S. Department of Transportation.

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

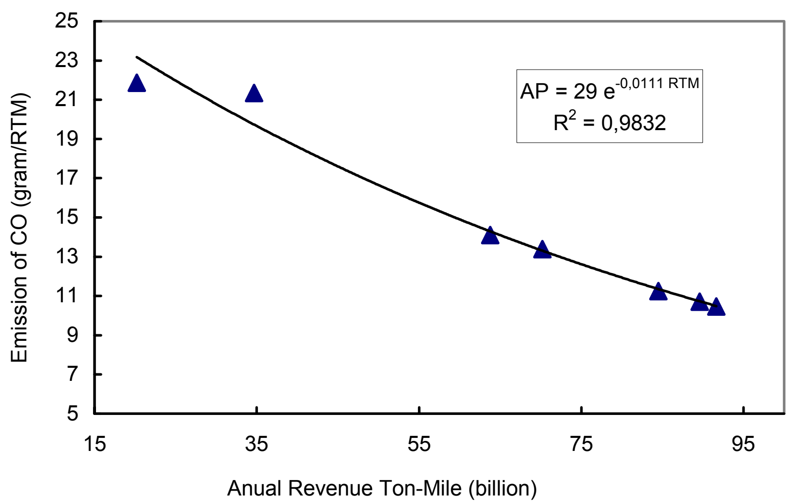
Figure 10f illustrates global air pollution efficiency of the U.S. airline industry. Similar to the fuel consumption case, this efficiency is expressed by the quantity of Carbon Oxide (CO) emitted per RTM in relation to the annual amount of RTMs carried out during the period 1970 to 1998. As can be seen, more than a proportional decrease of this emission, from about 22 grams/RTM to about 10 grams/RTM with increasing of RTMs from about 16 to about 95 billion RTMs per annum, took place. The reasons are the same as in the case of fuel consumption and include improvements of aircraft engines in terms of the quality of burning fuel. Consequently, according to this indicator, the system developed in a sustainable way.

Figure 10e. Global energy efficiency of the U.S. airline industry, 1960-1999



Data compiled from: National Transport Statistics 2000. (2001). Washington DC, USA: U.S. Bureau of Transport Statistics, U.S. Department of Transportation.

Figure 10f. Global air pollution efficiency of the U.S. airline industry, 1970-1998



Data compiled from: *National Transport Statistics 2000.* (2001). Washington DC, USA: U.S. Bureau of Transport Statistics, U.S. Department of Transportation.

CONCLUSIONS

The paper explains the methodology for assessment of the sustainability of an air transport system and its potential application. The methodology consists of an indicator system consisting of individual indicators and their measures. They represent the system's operational, economic, social and environmental performance. The particular indicators and their measures are defined in terms of the system's positive effects and negative impacts and in relation to the system's 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 the public are also included. In total, fifty-eight individual indicators and their sixty-eight measures are defined.

The application of the methodology includes estimation of twenty-six indicators. Due to the structure of the particular indicators and availability of the relevant data, almost all cases relate to the U.S. air transport industry while just a few ones relate to the European air transport industry. The results show (and confirm) that the long-term development of the air transport system and its particular components are sustainable with respect to most indicators of the economic, social and environmental dimension of performance from the aspects of most actors involved. Nevertheless, there are 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 9/11, the operational and economic dimension of performance have become of growing importance illustrating the system and its components' struggle for survival. Questions about the system's future sustainable development as well as its sustainability compared with the sustainability of other transport modes and other sectors of the national and international economy, using the same or modified methodology, still need to be addressed.

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