METHODOLOGY FOR ASSESSING SUSTAINABILITY OF AN AIR TRANSPORT SYSTEM

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ABSTRACT

Assessment and operationalisation of the concept of a sustainable air transport system have been recognised recently as an important but complex research, operational and policy tasks. In the scope of the current academic efforts to properly address these problems, this paper develops methodology for assessing the sustainability of an air transport system. The methodology is based on the indicator systems of sustainability defined for the operational, economic, social, and environmental dimensions of the system performance. The measures are defined for each indicator to express the system effects (benefits) and impacts (costs) for particular actors such as the system users—air travellers, air transport operators, aerospace manufacturers, local community members, local and central government. They are assumed to evaluate the system sustainability with respect to the values of selected indicators. Generally, for all of them the system will be sustainable if the indicators representing effects (benefits) are as high as possible and increase with increasing system output, and the indicators representing impacts (costs) are as low as possible and decrease with increasing system output.

INTRODUCTION

What is sustainability? Different definitions related to sustainable society have been developed. The generic one provided by the Word Commission on Environment and Development (1987), considered a

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sustainable society as one that meets the needs of the present without compromising the ability of future generations to meet their own needs (WCED, 1987, p. 14). This definition has been frequently modified. For example, Daly (1991) defined a physical sustainable society as one proposed to fulfil basic conditions in terms of limiting rates of using renewable and non-renewable resources, and quantities of air pollution emissions. Recently, the United Kingdom (UK) government has defined sustainable development popularly as a better quality of life, now and for generation to come (DETR, 2000, p. 3).

When strictly applied to transport, the above definitions generally indicate that transport (as a system) has not been sustainable primarily due to the permanent and intensive consumption of mostly non-renewable energy resources (fossil fuels) and emissions of greenhouse gases despite the fact that the sector has managed to reduce energy consumption and air pollution rates by using new technologies and alternative energy sources (Whitelegg, 1993). Nevertheless, air transport has acted as a strong driving force of economic development and welfare. Therefore, in order to deal fairly with both aspects of transport influences, the concept of a *sustainable air transport system* has been introduced. In the scope of this concept, *sustainability* has meant continuity of the sector growth combined with limitation (or mitigation) of the harmful effects for both the short- and long-term. Such balanced development has thought to be achieved by establishing inter- and intra-balance (trade-offs) between the full social benefits and costs of the various transport modes. However, numerous theoretical and practical problems have emerged as barriers to operationalisation of this concept. One of the most important theoretical problems has shown to be the complexity of quantifying of the full social benefits and costs of particular transport modes. The main practical problem has shown to be the generalisation and operationalisation of the policies designed to internalise costs of the environmental damages throughout the air transport system worldwide (DETR, 2001; EC, 1997; ECMT, 1998; Hewett & Foley, 2000; Levison, Gillen, Kanfani & Mathieu, 1996).

This paper develops methodology for assessing the sustainability of an air transport system. The methodology is based on definition of indicator systems each consisting of a set of indicators related to different dimensions of the system performance: operational, economic, social and environmental (FAA, 1996). In the scope of each indicator system, separate sub-sets of indicators are defined to express the objectives and sometimes very conflicted interests and preferences of the various actors involved in the system. These actors include air travellers, air transport operators, aerospace manufacturers, local community members, and local and central government. The methodology is expected to be able to scan current and future sustainability of an air transport system and its components with respect to particular indicators (EC, 1999).

In addition to this introductory section, this paper consists of three sections. The second section describes the concept of a sustainable air transport system. The third section develops the methodology for assessing the sustainability of an air transport system in the form of the indicator systems relevant for particular actors involved in dealing with sustainability of the system. The last section contains some conclusions.

THE CONCEPT OF A SUSTAINABLE AIR TRANSPORT SYSTEM

The concept of a sustainable air transport system is based on the identification, analysis and assessment of three linked dimensions of its performance: economic, social, and environmental. As well, they all are linked and highly dependent on the operational dimension of performance, which should also be taken into account. Analysis and assessment of the sustainability of an air transport system can be carried out by developing the indicator systems of sustainability for each dimension of performance. Each such indicator system consists of the sub-sets of individual indicators relevant for particular actors involved in dealing with the air transport system. The indicator systems constitute the methodology for assessing the sustainability of an air transport system.

The objectives of this paper is to develop this methodology through following steps: (a) Understanding the basic principles of sustainability, including identification of particular dimensions of the air transport system performance and groups of actors involved; (b) Designing the indicator systems of sustainability consisting of individual indicators for each group of actors involved and each dimension of the system performance; and (b) Quantification of particular indicators and evaluation of the main directions of their development with respect to the basic principles of sustainability.

The first two steps are presented in this paper. The last step should be the subject of further research. In addition to contributions to the academic research, achieving the above objectives could help in establishing the scientific base for negotiations between particular groups of actors concerning setting up the thresholds or acceptable ranges of values for particular indicators as policy targets, which in turn should provide medium- to long-term sustainable development of an air transport system.

Dimensions of the System Performance

Sustainability of an air transport system can be considered with respect to four dimensions[1] of the system performance: operational, economic, social, and environmental. They are linked and dependent on each other as it is shown in Figure 1. The operational dimension is the basic one. It relates to elements such as demand and capacity, quality of service, and safety and security. The air transport demand has been mostly driven by the external forces, of which the gross domestic product (GDP) has dominated at the global level. Figure 2 shows one such characteristic example. Capacity has been always adjusted (i.e., expanded) in order to satisfy demand at any given level of efficiency and effectiveness (i.e., quality of service). Safety and security have inherently been included in the system planning, operation and management at both the local (i.e., the system component) and global level.

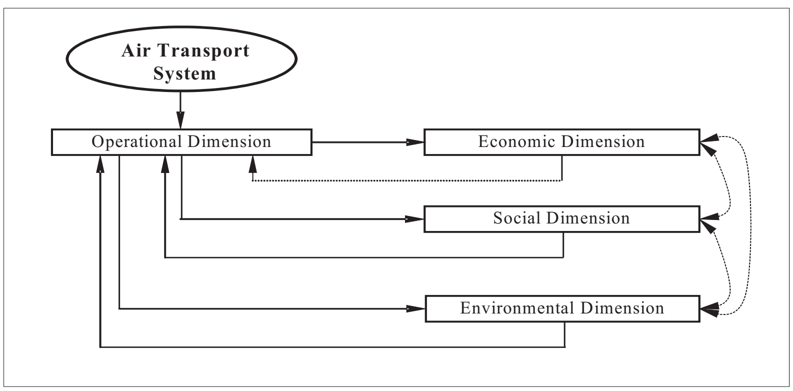

Figure 1. Dimensions of air transport system performance and their linkage

The operational dimension influences the economic dimension, which consists of the elements such as the system operational costs, revenues, profits, and productivity (Hooper & Hensher, 1997). Costs are imposed on the system operators while providing capacity by using inputs, generally in terms of capital, labour and energy, at given prices. The revenues are obtained by charging users for services. Profits are the differences between revenues and costs. The size and scope of the economic dimension mostly depends on the size and scope of the supply (capacity), which is adjusted to present and prospective demand. The economic dimension increases with the increasing of the operational dimension, and vice versa.

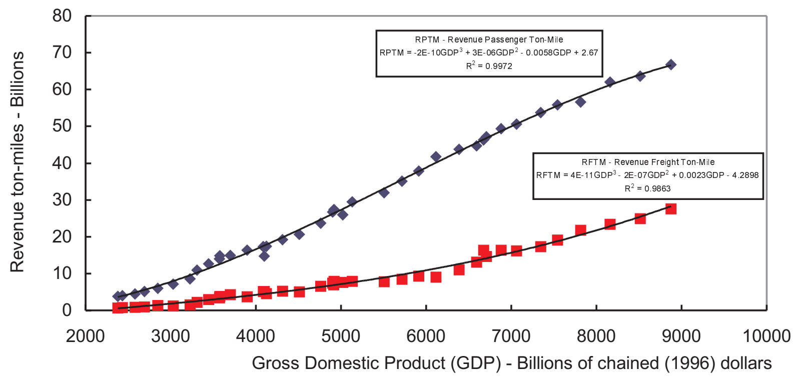

Figure 2. Air transport growth vs. economic growth: development of the U.S. domestic traffic - period 1960-1999 (compiled from BTS, 2001)

The social dimension represents the social effects of the system such as direct, indirect and induced employment at the local and regional level, and contributions to local and regional GDP (Button & Stough, 1998; DETR, 1999, 2000). In addition, contributions to globalisation and internalisation of business and leisure activities (e.g., international trade, investments, tourism) may also be considered in the scope of the social dimension. The social dimension depends on the operational dimension. Generally, the social dimension increases with the increasing of the operational dimension, and vice versa.

The environmental dimension contains the physical impacts on peoples health and the environment. In general, local (airport) and global (airspace) air pollution, airport noise, aircraft accidents, congestion and delay, generation of waste, and land use can be considered as the most common and noticeable impacts. Most of these impacts are directly dependent on the operational dimension, that is, the environmental dimension increases with the increasing of the operational dimension, and vice versa (Janic, 1999).

The economic, social and environmental dimensions of performance also influence each other. For example, implementation of measures for protecting the environment in the scope of the environmental dimension may influence the economic and operational dimension by imposing extra costs on the air transport system operators and by limiting the scale and scope of their activities, respectively. In addition, limitation of activities may affect the system's social dimension through reduction of positive social contributions. On the other hand, favouring of employment as an element of the social dimension may negatively influence the elements of the economic dimension such as profitability and productivity.

Groups of Actors Their Objectives and Preferences

According to the vertical organisation of air transport services, different groups of actors may be involved in dealing with sustainability of air transport system as follows (ATAG, 2000; INFRAS, 2000):

1. Users—air travellers, freight (air cargo) shippers, and mail constitute air transport demand;
2. Air transport operators—airports, Air Traffic Management/Air Traffic Control (ATM/ATC), and airlines constitute the system service (capacity) providers;
3. Aerospace manufacturers produce and deliver the aircraft (airframe, engines, avionics), ATM/ATC and airport facilities and equipment to the system operators;
4. Local community members live in vicinity of airports, and benefit and suffer from air transport operations;
5. Local and central government mainly play roles in creating policies to regulate the system operations at the local (community) and regional (national) level, respectively;
6. Aviation organisations coordinate the system development at the global (international) level;
7. Lobbies and pressure groups organise and articulate the interests of people who usually oppose the expansion of the air transport system infrastructure; and
8. The public is interested in particular aspects of the air transport system from time to time.

Sustainability of an air transport system may have different meanings and contexts for different groups of actors depending on their specific the very often conflicted objectives and preferences.

1. The users—air travellers and freight shippers—usually prefer frequent, easy accessible, relatively cheap, punctual, reliable, safe and secure door-to-door service in which air transport plays the major role.

2. The air transport operators provide services according to their business objectives in terms of profitability and safety on one side, and the users' satisfaction on the other.

3. The aerospace manufacturers prefer business success to be achieved through selling their products. In general, they are mainly focused on the quality of products in terms of reliability, safety, efficiency and profitability.

4. Local community members usually tend to maximise potential benefits and minimise costs of air transport system operation at the local level. Opportunity for direct and indirect employment and use of the efficient air connections to other distant communities can be considered as obvious benefits. The costs are regarded as exposure to airport noise, air pollution, and risk of damage of property, injury or loss of life due to potential aircraft accidents.

5. Local and central governments are mostly interested in the overall benefits and externalities of the system operation. The direct benefits embrace the system's contributions to the GDP. Indirect benefits include contributions to internalisation and globalisation of businesses (international trade and investments) and tourism. Creation and implementation of the policies to protect people's health and the environment at both the local and global level is intended to keep the externalities under control.

6. International aviation organisations [for example, International Civil Aviation Organization (ICAO), International Air Transport Association (IATA), European Civil Aviation Conference (ECAC), Association of European Airlines (AEA), Airports Council International (ACI)] provide the framework and guidelines for sustainable development of air transport systems at both the regional (national) and global (international) level.

7. Different lobbies and pressure groups campaign against global harmful effects of polluting systems on the peoples health and environment. In such context, they also intend to prevent further contribution of air transport to global warming by strong opposition to any further physical expansion of the system infrastructure, that is, airports.

8. The public is informed about the air transport system from media such as radio, television, internet, and newspapers. However, media report mostly about the cases of severe system disruptions such as aircraft accidents, terrorist attacks, congestion (delays), massive cancellation of flights, and significant rises of airfares since such disruptions may directly affect wide population of users and non-users for a long time. Generally, the public wants to be objectively informed.

Figure 3 shows a scheme of the vertical organisation of an air transport system developed for defining the indicator systems of sustainability.

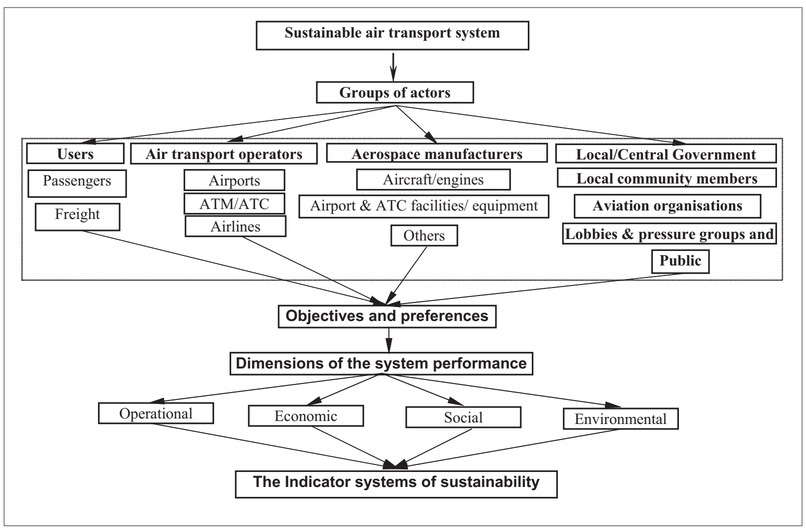

Figure 3. Scheme of the air transport system vertical organisation for developing the indicator systems of sustainability

The Basic Principles of Sustainability

It can be said that an air transport system develops in a sustainable way if the net benefits of its operations expressed either in absolute (total) or relative terms (per unit of output) increase in line with the increasing of the system output. This can be achieved by establishing a balance (i.e., trade-off) between the system's positive effects (benefits) and negative impacts (costs). Generally, such trade-offs may be established at the global (intercontinental), regional (continental, national) and local (community) level (INFRAS, 2000).

Global Trade-off

At the global level, the growth of economy and air transport demand have strongly driven each other with the evident negative consequences such as increased energy consumption and increased emission of greenhouse gases. A trade-off between positive effects and negative impacts of such growth may eventually be established by using one among the following scenarios.

Setting up a cap on the impacts. According to this scenario, a cap on total energy consumption and related air pollution, and consequently growth of air transport demand in absolute terms, would be set up. However, despite a lot of efforts, development and implementation of such a global scenario—based on the worldwide consensus of particular actors involved in air transport operation and business—seems unlikely to take place in the short- to medium-term future (Hewett & Foley, 2000).

Decomposing the growth of air transport demand and the overall economic growth. This scenario consists of weakening the strong links between the air transport demand and the GDP as its main external driving force. Figure 1 shows the very strong dependence. Under such circumstances, it seems that such decomposition can only be carried out by stimulating people to change their habits of using air and other transport modes (EC, 1999). However, this is a long-term process with unpredictable success.

Trading-off between global effects and impacts. In this scenario, long-term conditions to guarantee faster growth of the systems global positive effects rather than the negative impacts should be established. In general, this can be achieved by adequate technological improvements of aircraft and engines, and ATM/ATC procedures, as well as by more sophisticated global use of land for expanding the systems infrastructure. At present, this scenario seems to be the most acceptable. Figure 4 shows a generic scheme

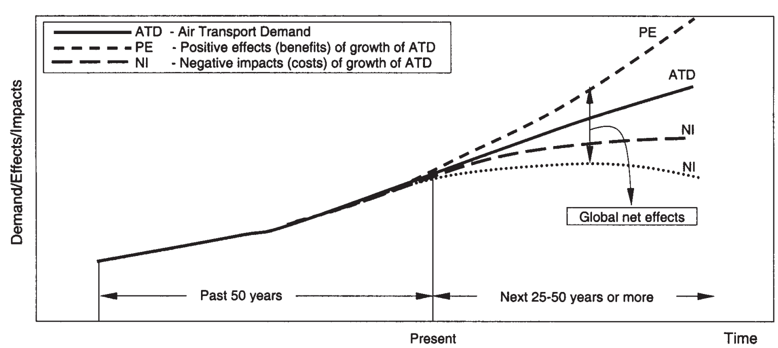

Figure 4. Long-term sustainable development of air transport system according to compromise scenario

of the systems possible long-term development according to a compromise scenario.

Regional Trade-off

At the regional (national, continental) level, particularly in the United States (US) and western Europe, the growth of air transport demand has been driven by liberalisation of already matured air transport markets as well as by higher productivity and lower prices of services. At the same time, this growth has been confronted with the limited capacity of airports and ATM/ATC, which has increased congestion and delays and thus deteriorated the expected quality and efficiency of service. This has given rise to the question of establishing of an appropriate trade-off between demand and capacity at the regional level in order to maintain the desired quality of service and hinder its further deterioration. Three scenarios are available.

Changing regional factors. This scenario assumes changing of the regional factors—liberalisation, market competition, productivity, and airfaresin a way to discourage further growth of air transport demand. If it did happen, previous positive development and progress achieved so far would be annihilated. However, the present trends indicate that this scenario is not likely to take place (Boeing, 2001).

Constraining the infrastructure expansion. This may be called the do-nothing scenario, in terms of further expansion of the air transport infrastructure in some mature markets, for example, those in western Europe and the US. If such a scenario takes place and if air transport demand continues to grow, the system infrastructure will come to saturation, which will cause widespread and severe deterioration of the quality and efficiency of service and thus deter the existing and prospective demand from using the system. Such a scenario has already taken place at some the very congested European airports and airspace, but still without any noticeable evidence of a significant effect on demand (EUROCONTROL, 2001).

Utilising the available resources more efficiently. This scenario consists of more efficient utilisation of the existing air transport infrastructure—airports, ATM/ATC—and aircraft. This can be achieved by using new technologies and innovative operational procedures, appropriate modification of the airline hub-and-spoke practice, and cooperation with other transport modes (particularly railways) through provision of integrated services. Some elements of this scenario have already been implemented at particular congested European airports (Arthur, 2000).

Local Trade-off

At the local level, trade-offs between the positive effects and negative impacts of airport growth on the local community and environment may eventually be established by using two scenarios:

Constraining the airport growth. This scenario assumes that the growth of a particular airport should be limited to the capacity of the existing infrastructure, both airside and landside. On one side, such limits will prevent further escalation of the negative impacts on local people and the environment in terms of noise, local air pollution, and acquisition of land. On the other, it will constrain the positive direct and indirect effects on the local economy. This scenario has already taken place at particular congested airports in Europe.[2]

Managing the airport growth. This seems to be a reasonable scenario for development of most airports under present circumstances, which assumes that their growth will be managed to provide higher rates of benefits than costs to the local area.

Figure 5 shows how this scenario would work at London Heathrow airport. As can be seen, under conditions of growing demand and current use of two parallel runways (alternating mode) to mitigate noise, the airport will come to saturation in the near future with negative consequences such as severe congestion and delays. In order to reduce these negative social consequences and to increase the positive economic and the environmental consequences of previous development, different options for increasing the runway system capacity should be considered. One of the options consists

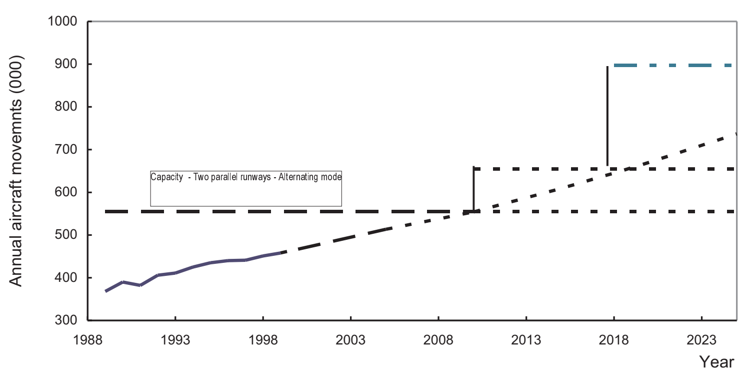

Figure 5. Options for increasing of airside capacity at London Heathrow airport

of more efficient utilisation of the existing runway system, which can be carried out by changing the present mode of runway use from alternating to mixed (BA, 2001). Another option consists of building a third parallel runway. However, both options will likely increase aircraft noise and air pollution. Therefore, a trade-off between these two effects should be established and evaluated.

METHODOLOGY – THE INDICATOR SYSTEMS OF SUSTAINABILITY

Assumptions

Development of the indicator systems of sustainability of an air transport system is based on various assumptions introduced to easier define, understand and quantify the individual indicators of sustainability. These assumptions are as follows:

1. The indicator systems of sustainability are developed for particular groups of actors involved in dealing with the sustainability of an air transport system. Thus, the number of these systems corresponds to the number of different groups of actors involved. Each indicator system consists of four sub-systems corresponding to different dimensions of the system performance (operational, economic, social, environmental). The particular sub-system of indicators consists of the individual indicators and their measures.

2. The individual indicators are defined to measure the effects (benefits) and impacts (costs) of an air transport system operation in either absolute or relative monetary or non-monetary terms, as functions of the relevant system output. Within the same sub-system of indicators, if a benefit indicator increases and a cost indicator decreases or is constant with the increasing of the relevant output, the system will be considered as sustainable. Otherwise, the system will be considered as unsustainable. When a threshold value is set up for an indicator, it can be used as a target value for achieving sustainability. Figure 6 shows a generic example.[3]

3. For all individual actors within the same group, the indicator system and sub-systems are unique.

4. The individual indicators are assumed to be independent across given indicator systems and sub-systems.

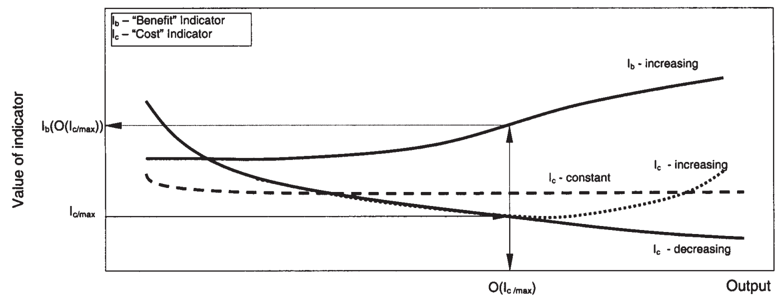

Figure 6. Generic relationships between indicators of sustainability and the system output

5. The particular indicators should be sufficiently convenient to be applied either to the system as a whole or to its individual components. As well, they should be easily transformable to be applied to other transport modes for comparative purposes.
6. The indicator systems should be updateable depending on the specific objectives and preferences of particular groups of actors.
7. Indicators should be convenient for an initial assessment of the direction of the system's development with respect to sustainability.
8. The data for quantifying particular indicators should be available from existing statistical databases. Regression least-square technique seems to be the most appropriate analytical technique for estimating dependence of particular indicators on the system output. In such a case, the value (i.e., measure) of the indicator is assumed to be the dependent variable and the relevant system output is the independent variable.

Definition of the Indicator Systems

According to their specific objectives and preferences, different actors may use different indicator systems for assessing sustainability of an air transport system. Therefore, separate indicator systems are defined to express each systems specific objectives and preferences with respect to the four dimensions of system performanceoperational, economic, social, and environmental. Tables 1A-7A in the appendix provide list of these systems.

The Indicator System for Users

The indicator system for users, that is, the air travellers, consists of eight individual indicators. Five indicators are defined for the operational dimension and one indicator each for the economic, social and environmental dimensions of performance. These indicators mainly relate to airline and airport services and can be quantified for individual airlines, routes and/or airports, as well as for the airline industry and airport network of the region as the whole (see Table 1A).

Operational Indicators of the User Indicator System

The five indicators of operational performance are experienced punctuality of service, experienced unreliability of service, lost and damaged baggage, safety and security.

Experienced punctuality of service refers to the users' perceptions of a chosen airline's ability to carry out flights and services on- time. This assessment can be carried out either by experience or by using airline information. In the later case, two measures may be convenient. First is the probability that an airline flight is on time. This probability can be calculated as the ratio between the number of on-time flights and total number of flights carried out for a given airline during a given period of time. Another measure is the average delay per flight, which may include arrival delay, departure delay or both. Both measures are relevant when choosing the airline, air route and air transport mode itself, and are components of the Airline Quality Rating system (AQR) in the US (Headley & Bowen, 1992; BTS, 2001). Users usually prefer the probability of on-time flights to be as high as possible and average delay per flight to be as low as possible under conditions of increasing number of flights.

Experienced unreliability of service reflects the users' perception of a chosen airline's ability to fulfill the schedule. This indicator can be assessed either by experience or by using airline information. In the later case, the number of cancelled (or diverted) flights to total number of flights during a given period of time ratio can be used as a measure. This measure is also a component of the AQR in the US (BTS, 2001). Independent of the causes of cancellations or diversions of flights, it is preferred the ratio be as low as possible and to decrease with an increase in the number of flights.

Lost and damaged baggage expresses potential loss or damage of the users' baggage while within the air transport system. In addition to experience, information from a chosen airline can be used to assess this indicator. This indicator is also a component of the AQR. The number of lost (or damaged) baggage to total number of passengers served during a given period of time ratio can measure it. The ratio is preferred to be as low as possible and to decrease with an increase in the number of passengers served.

Safety emerges as a relevant indicator for users while choosing one airline among the other airlines as well as while choosing the air transport mode itself among the other alternative transport modes. This indicator measures perceived risk of death or injury of an individual while onboard. Again, in addition to subjective judgements, airlines and/or the national and international aviation authorities can provide information about this measure, which is usually expressed by the number of deaths (or injuries) per unit of output as measured by revenue passenger kilometer or revenue passenger mile (RPK/RPM). The users prefer this ratio to be as low as possible and to decrease with an increase in system output.

Security relates to the perceived risk of an individual's exposure to threat from illegally carried weapons or other dangerous devices (e.g., bombs, firearms, and guns) while at an airport or onboard. Airport security services can provide information on this indicator for individual airports or for an airport network. The number of detected illegal dangerous devices to the total number of passengers screened ratio can measure this indicator. Users prefer this ratio to be as low as possible and to, independent of the causes,[4] decrease with an increase in the number of screened passengers.

Economic Indicator of the User Indicator System

Economic convenience of air travel is the economic indicator important to an air traveller while choosing the air transport mode among the alternative transport modes (Janic, 2001). This indicator reflects the total generalised cost of a door-to-door trip. Air transport generally has the highest cost as compared to other travel modes. The average airfare per passenger can be used as convenient measure. Users always prefer airfares be as low as possible and to decrease over time.

Social Indicator of the User Indicator System

Spatial convenience is the only social indicator relevant for users. It reflects the users' opportunity to travel from a given airport by a selected airlines to other medium and long distant places. The number of destinations served from an airport (or region) by a given airline can be used as a measure. In addition, connectivity by non-stop, one-stop or multi-stop flights with respect to trip purpose (business, leisure) can be considered to refine this measure. Recently, this measure has become a global competitive tool of both airlines and airports. In general, users prefer the number of opportunities to be as high as possible and to increase over time.

Environmental Indicator of the User Indicator System

Comfort and health is the user's indicator for the environmental dimension. Air transport users consider travelling comfort and healthiness of the airport and aircraft environment while assessing the quality of the transport environment. This indicator relates to the users' feeling of comfort while at an airport terminal and onboard. Different measures can be used. At an airport, in addition to a subjective judgement, passenger density (the number of passengers per unit of space) and the average queuing time can be used to measure passenger comfort and discomfort as a component of the airports quality of service. In addition to the individual experience, the airport operator can provide information on these measures (Hooper & Hensher, 1997; Janic, 2001). Configuration and size of seats in economy class and the quantity of fresh air delivered to the aircraft passenger cabin per unit of time seem to be the most relevant measures of passenger comfort and healthiness of the environment while onboard. The measures of airport comfort and discomfort are preferred to be as low as possible and to decline with an increase in the number of passengers served. Both measures of comfort while onboard are preferred to be as high as possible and to increase over time.

The Indicator System for Airports

The indicator system for airports consists of eleven indicators. Four indicators are defined for the operational dimension, two for the economic dimension, and five for the environmental dimension of airport performance. There are no indicators for the social dimension. The indicators can be quantified for the individual airport or the airport network as the whole (see Table 2A).

Operational Indicators of the Airport Indicator System

Demand, capacity, quality of service and integrated service are regarded as the main airport operational dimension indicators.

Demand indicates the scale of an airport operation. The number of passengers and Air Transport Movements (ATM) measured by arrivals and departures, and the volume of freight accommodated during a given period of time can measure this indicator. Sometimes, it is more convenient to use Workload Unit (WLU) where one unit equals one passenger or 100 kg of freight (Doganis, 1992). The airport operator prefers these measures to increase over time.

Capacity reflects the maximal physical capability of an airport to accommodate demand during a given period of time. Commonly, two measures are used: airside capacity in terms of the maximum number of ATM, and landside capacity in terms of the maximum number of WLU. Both measures are preferred to be as high as possible and to increase over time in order to cope with increasing demand.

Quality of service reflects the relationship between airport demand and capacity. Generally, the average delay per ATM or WLU during a given period of time can be used as a measure. This delay occurs whenever demand exceeds capacity. The measure is preferred to be as low as possible and to decrease with an increase in demand.

Integrated service is when an airport has the opportunity to improve utilisation of their capacity by substitution of some short-haul flights with adequate surface transport, usually high-speed rail services, and by using such freed slots for more profitable long haul services.[5] A measure of this indicator can be the ratio between the number of substituted flights and total number of feasibly substitutable flights carried out during a given period of time. Airport operators prefer this ratio to be as high as possible and to increase with an increase in the number of feasibly substitutable flights.

Economic Indicators of the Airport Indicator System

In addition to the operational dimension, airports, as business enterprises look strictly after the economic dimension of their performance. Profitability and labour productivity are defined as the most convenient indicators of the economic dimension.

Profitability usually reflects the airports financial success. It can be measured by operating profits (the difference between operating revenues and operating costs) per output measured by WLU (Doganis, 1992). This measure is preferred to be as high as possible and to increase with an increase in airport output.

Labour productivity reflects the efficiency of labour use at an airport. The output in terms of the number of WLU (or ATM) carried out during a given period of time per employee can be used as a measure of this indicator (Doganis, 1992; Hooper & Hensher, 1997). Only direct employment is taken into account. This measure is preferred to be as high as possible and to increase with an increase in the number of employees.

Environmental Indicators of the Airport Indicator System

Five indicators—energy inefficiency, noise inefficiency, air pollution inefficiency, waste inefficiency and land use inefficiency—are defined to represent the environmental dimension of airport performance. These indicators relate to the physical impacts of an airport on the health of the local people and the environment and get relevance while undertaking mitigation measures.

Energy inefficiency relates to the quantity of energy used by an airport for day-to-day operation of the airport itself. This energy obtained from different sources is used for lighting, heating, and other airport infrastructure. A measure for this indicator can be the quantity of energy consumed per unit of WLU accommodated during a given period of time. The measure is preferred to be as low as possible and to decrease with an increase in the volume of output.

Noise inefficiency relates to the noise energy generated by the number of ATM during a given period of time. A measure for this indicator can be the area determined by a certain equivalent long-term noise level (L_{eq}) expressed in decibels [dB(A)]. The affected area is expressed in square kilometres (DETR, 2000, 2001). This indicator is preferred to be as low as possible and to diminish with an increase in output.

Air pollution inefficiency relates to total air pollution generated by an airport during a given period of time. The quantity of all or specific air pollutants can be considered. In addition to that from air traffic-aircraft, the air pollution from landside airport road traffic and by airport handling operations can be taken into account (EPA, 1999). Generally, the quantity of air pollutants per polluting event—defined by ICAO (1993a) as a landing/take-off (LTO) cycle—can be used as a measure of this indicator. Airport operators prefer this quantity to be as low as possible and to decrease with an increase in the number of LTO cycles.

Waste inefficiency relates to waste generated by an airport excluding airline in-flight waste (BA, 2001). A convenient measure can be the quantity of waste generated per WLU during a given period of time. This measure is preferred to be as low as possible and to decrease with an in crease in the airport output.

Land use inefficiency relates to utilisation of land taken for building the airport infrastructure—both airside and landside. Once the infrastructure has been constructed, the intensity of use of land where it is accommodated is dependent on the demand. However, this intensity is always limited by the capacity of the infrastructure. A convenient measure for this indicator can be WLU accommodated during a given period of time per unit of acquired airport land. This measure is preferred to be as high as possible and to increase with an increase in land taken by the airport infrastructure.

The Indicator System for Air Traffic Management/Air Traffic Control (ATM/ATC)

The indicator system for Air Traffic Management/Air Traffic Control (ATM/ATC) consists of eight indicators of performance: four for the operational dimension, two for the economic dimension, and two for the environmental dimension. There are no social indicators defined for this system. These indicators can be quantified for a part of the ATM/ATC sector or for the whole system (e.g., airspace of a country or continent) (see Table 3A).

Operational Indicators of the ATM/ATC Indicator System

Demand, capacity, safety and punctuality of service are defined as the operational indicators of the ATM/ATC indicator system.

Demand is measured by the number of flights accommodated (i.e., controlled) in a given ATM/ATC airspace during a given period of time (Janic, 2001). This measure is preferred to be as high as possible and to increase over time.

Capacity expresses the maximum capability of ATM/ATC providers to serve demand under given conditions. It can be 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 over time to cope with the increase in demand.

Safety expresses probability of occurrence of an air traffic accident because of ATM/ATC operational error. This accident may take place at an airport or in airspace and while an aircraft is on the ground or airborne. Some convenient measures of this indicator can be the number of individual aircraft accidents or the number of Near Midair Collisions (NMAC) per unit of the ATM/ATC output measured by the number of controlled flight. These measures are preferred to be as low as possible and to decrease with an increase in the number of flights.

Punctuality of service is a surrogate for the quality of service provided by ATM/ATC to its users—flights and aircraft. This indicator can be measured for a given period of time by two measures: percent of non-delayed flights due to the ATM/ATC restrictions, and the average delay per delayed flight. The percent of non-delayed flights is preferred to be as high as possible and to increase with an increase in the number of flights. The average delay per delayed flight is preferred to be as low as possible and to decrease with an increase in the number of flights.

Economic Indicators of the ATM/ATC Indicator System

Two indicators are defined to reflect economic dimension of performance of ATM/ATC providers: cost efficiency and labour productivity.

Cost efficiency[6] relates to the ATM/ATC operating costs. It is measured by the average cost per unit of output—controlled flight—for a given period of time. This measure is preferred to be as low as possible and to decrease with an increase in the number of controlled flights (Janic, 2001).

Labour productivity reflects efficiency of the ATM/ATC providers in terms of labour use. A convenient measure can be the number of controlled flights per employee. This indicator is preferred to be as high as possible and to increase with an increase in the number of employees.

Environmental Indicators of the ATM/ATC Indicator System

Two indicators are defined to express the environmental dimension of ATM/ATC performance: energy efficiency and air pollution efficiency.

Energy efficiency relates to the extra fuel consumption due to deviations of flights and aircraft from the prescribed (fuel-optimal) trajectories dictated by the ATM/ATC safety requirements. This indicator can be measured by the average extra fuel consumption per flight. The measure is preferred to be as low as possible and to decrease with an increase in the number of flights.

Air pollution efficiency relates to the extra emission of air pollutants due to extra fuel consumption resulting from deviations of flight and aircraft from prescribed trajectories. The indicator is measured by the average quantity of emitted pollutants per flight. It is preferred to be as low as possible and to decrease with an increase in the number of flights.

The Indicator System for Airlines

The indicator system for airlines consists of eleven indicators: five for the operational dimension, two for the economic dimension, and four for the environmental dimension of performance. There are no social indicators for airlines. These indicators can be quantified for an individual airline, an airline alliance or the whole airline industry of the region (see Table 4A).

Operational Indicators for the Airline Indicator System

Airline size, load factor, operational punctuality, unreliability of service, and safety are defined as indicators of airline operational performance.

Airline size reflects the volume of airline output carried out during a given period of time. Several measures can be used to quantify this indicator: total number of passengers, total volume of freight and total volume of Revenue Ton-Kilometre or Revenue Ton-Mile (RTK/RTM) (Janic, 2001). As well, RPK/RPM and Freight Ton-Kilometre or Freight Ton-Mile (FTK/FTM) can be used separately instead of the aggregate RTK/RTM. In addition, the size of available resources in terms of the number of aircraft and staff deployed to carry out the output can be used to measure the airline size. All of these measures are preferred to be as high as possible and to increase over time.

Load factor indicates dynamic utilisation of the airline capacity during a given period of time. Usually, it is measured in aggregate form as total RTK/RTM to Available Ton-Kilometre or Available Ton-Mile (ATK/ATM) ratio. As well, load factor can be determined separately for passengers and freight. In each case, this measure is preferred to be as high as possible and to increase with the increase in airline output (Janic, 2001).

Operational punctuality and *unreliability of service*, and *safety* indicators for the airline indicator system are analogous to those same indicators of the users indicator system in terms of how they are measured and their preferences. The airlines use them as competitive tools when applied to the user indicator system and as indicators of operational efficiency when applied to their own system (Janic, 2001).

Economic Indicators of the Airline Indicator System

Two indicators are defined to express the economic dimension of airline performance: profitability and labour productivity.

Profitability relates to the airlines financial success. It is measured by the average profits, defined as the difference between operating revenues and costs, per unit of output measured by RTK/RTM. This indicator is preferred to be positive, as great as possible, and to increase with an increase in airline output.

Labour productivity reflects the airlines efficiency in using its workforce. It is measured by the average output, measured by RTK/RTM, per employee for a given period of time. The preference for this measure is to be as great as possible and to increase with an increase in the number of employees.

Environmental Indicators for the Airline Indicator System

Four indicators are defined to express the environmental dimension of airline performance: energy efficiency, air pollution efficiency, noise efficiency and waste efficiency.

Energy efficiency and *air pollution efficiency* relate to the rate of modernisation and efficiency of utilisation of the airline fleet in terms of energy and fuel consumption and associated emissions of air pollutants. These indicators are measured during a given period of time by the average quantity of fuel and air pollution, respectively, per unit of output measured by RTK/RTM, distance flown (D) or flying hour (FH). Both measures are preferred to be as low as possible and to decrease with an increase of airline output.

Noise efficiency indicates the rate of modernisation of an airlines fleet in terms of the use of aircraft of the Stage 3 and Stage 4 type, rather than older Stage 2 type (ICAO, 1993; BA, 2001). Once an airlines fleet is completely modernized by replacing all aircraft of Stage 2 type by aircraft of Stage 3 and Stage 4 type, this indicator will become irrelevant. This indicator can be measured by the proportion of the aircraft of Stage 3 and Stage 4 type in the airlines fleet. This proportion is preferred to be as great as possible and to increase with the growth of the airline fleet.

Waste efficiency indicates generation of airline in-flight waste (BA, 2001). This indicator can be measured by the average quantity of in-flight waste per unit of airline output measured by RTK/RTM (BA, 2001). This measure is preferred to be as low as possible and to diminish with an increase in airline output.

The Indicator System for Aerospace Manufacturers

The indicator system for aerospace manufacturers consists of eight indicators: three for the operational dimension, two for the economic dimension, and three for the environmental dimension of performance. There are no social dimensions. These indicators can be quantified for an individual manufacturer or for the sector as a whole (see Table 5A).

Operational Indicators of the Aerospace Manufacturer Indicator System

Innovations of aircraft, innovations of ATM/ATC and airport facilities and equipment, and reliability of structures are defined as indicators of the operational dimension.

Innovations of aircraft reflect the technological progress in terms of aircraft speed, capacity and cost efficiency (RAS, 2001). The progress in speed and capacity can be measured by technical productivity measured by the product of ton-kilometres or ton-miles per hour. Technical productivity of commercial aircraft has generally increased by introducing larger aircraft flown at higher subsonic speeds (Arthur, 2000). Aircraft cost efficiency is usually measured by the average operating cost per unit of capacity measured by Aircraft Seat-Kilometre or Aircraft Seat-Mile (ASK/ASM). This cost generally decreases with an increase in aircraft capacity (Janic, 2001).

Innovations of ATM/ATC and airport facilities and equipment express technical and technological progress in developing avionics, ATM/ATC and airport facilities and equipment. Progress in developing avionics and ATM/ATC equipment can be measured by the cumulative navigational error of aircraft position, which has significantly reduced over time (Arthur, 2000). This has brought gains in airspace capacity and safety. Progress in development of airport facilities and equipment can be measured by increased capacity of processing units in both airport airside and landside areas (Janic, 2001). This measure is preferred to be as high as possible and to increase over time.

Reliability of structures reflects the feature of the particular system components to operate without unexpected failures. This indicator can be separately measured for different components, but, in any case, the average number of failures per unit of operating time for a given period of time can be used as a measure. Because of safety and operational reasons, this measure, independent of the indicator system, is preferred to be as high as possible and to improve with technological progress over time.

Economic Indicators of the Aerospace Manufacturer Indicator System

Profitability and labour productivity are defined as indicators of the economic dimension of performance of aerospace manufacturers.

Profitability, similarly as in the airport and airline indicator systems, expresses financial success or failure of an aerospace manufacturer. It is measured by the average operating profits measure by the difference between operating revenues and costs per unit sold. As with any type of manufacturer, this measure is preferred to be as great as possible and to increase with an increase in the number of sold units.

Labour productivity expresses the efficiency of aerospace manufacturers in using workforce. Like in case of airlines, airports and ATM/ATC providers, the average number of units produced per employee can be used as a measure. This measure is preferred to be as high as possible and to increase with an increase in the total number of employees.

Environmental Indicators of the Aerospace Manufacturer Indicator System

Three indicators are defined for the environmental dimension of performance. They primarily relate to performance of new aircraft and engines in terms of energy efficiency, air pollution efficiency and noise efficiency.

Energy efficiency, *air pollution efficiency* and *noise efficiency* reflect reductions of fuel consumption, associated air pollution and noise energy generated by new aircraft and engines, respectively, in both absolute and relative terms. They can be measured by the absolute or relative decrease in the quantity of fuel consumption, air pollution and noise energy, respectively, per unit of engine power or aircraft operating weight. These measures are preferred to be as low as possible and to decrease with the increase in the engine power and/or aircraft operating weight.

The Indicator System for Local Community Members

People living permanently or temporarily in tourist residential areas near the airports represent the group of local community members. Usually, they are mostly interested in the social and environmental dimension of the air transport system performance. The indicator system for local community member is assumed to consist of four indicators: one for the social dimension and three for the environmental dimension of performance (see Table 6A). There are no indicators for the operational dimension or the economic dimension.

Social Indicators for the Local Community Member Indicator System

Social welfare is the only defined indicator of the social dimension of performance for the local community member group. This indicator relates to the opportunity of local community members to get a job either directly or indirectly as a result of the local air transport system (DETR, 1999). A convenient measure can be the ratio between the number of community members employed by the air transport system and total number of employed community members. This measure is preferred to be as high as possible and to increase with an increase of employment in the local community.

Environmental Indicators of the Local Community Member Indicator System

Noise disturbance, air pollution and safety are defined as indicators of the environmental dimension of performance.

Noise disturbance reflects the annoyance of local people by noise from ATM. This annoyance depends on both subjective and objective factors. Subjective factors reflect individual sensitivity to noise. In such case, any noise being equal or exceeding a given individuals threshold is considered annoying. The most important objective factors include the amount of noise energy generated by aircraft flying over the affected area, the distance between residential location and aircraft flight path, and the quality of houses with respect to noise isolation. Bearing in mind both types of factors, two measures can be measured. First is the total number of complaints about aircraft noise by local community members during a given period of time. Second is the ratio of complaints per ATM during a given period of time. Both measures are preferred to be as low as possible and to decrease with an increase in the number of ATM.

Air pollution relates to the exposure of local community members to the harmful impacts of air pollution generated by the local air transport system. This indicator can be measured as the ratio between the quantities of air pollution generated by the local air transport system and total air pollution generated by all local air polluting sources. This indicator is preferred to be as low as possible and to decrease with an increase of total air pollution.

Safety relates to perceived risk of death or injury, or damage or loss of local property due to aircraft accidents. It can be measured by the number of aircraft accidents per ATM carried out during a given period of time. This measure is preferred to be as low as possible and to decrease with an increase in the number of ATM.

The Indicator System for Local and Central Government

Usually, local and central government are not directly interested in the operational dimension of air transport system performance except in cases of significant disruptions. Particular disruptions appear as aircraft incidents or accidents, and significant reduction of punctuality and reliability of air services. These disruptions may deteriorate the overall air transport system performance, other dependent socio-economic activities, and consequently the quality of life. Otherwise, the local and central government are primarily focused on the economic, social and environmental dimensions of the system performance. The indicator system consists of seven indicators: three for economic, one for social and three for the environmental dimension of performance (see Table 7A). There are no operational indicators.

Economic Indicators for the Local and Central Government Indicator System

Economic welfare, globalization and internalisation, and externalities are defined to express the economic dimension of the system performance.

Economic welfare relates to contributions of the air transport system to the local and regional welfare. A measure can be a proportion of the GDP carried out by air transport system compared to the total GDP of the region. This measure is preferred to be as great as possible and to increase with an increase in total GDP.

Internalisation and globalization relates to contribution of the air transport system to the internationalisation of local and regional business—trade, investments, and tourism. Three measures can be used to quantify this indicator. First is the proportion of trade carried out by air transport in relation to total regional trade. Trade can be expressed by the volume and/or value of export and import. Second is the ratio between the number of long-distant business trips carried out by air transport mode related to the total number of long-distant trips carried out by all transport modes from or to the region during a given period of time. Third is the ratio between the number of long-distant tourist trips by air transport mode compared to the total number of long-distant tourist trips by all transport modes in the region during a given period of time. All three measures are preferred to be as great as possible and to increase with an increase in the total amount of trade or number of business or tourist trips, respectively.

Externalities relate to the costs of air transport noise, air pollution, and air incidents or accidents. Sometimes congestion cost is also included (Janic, 1999; Levison et. al, 1996). Local and central governments are both interested in these costs because of their responsibility for creating a healthy and environmentally friendly society and their responsibility for implementing policies that really change particular impacts (DETR, 2001; EC, 1997). Once such appropriate policies are introduced, the operators (airlines and airports) and end-users (air travellers as the actual payers of the externalities) will become more interested in these aspects of the air transport system operation. The externalities can be measured by the average expenses per unit of the system output measured by RPK/RPM used for either preventing or remedying air transport noise, air pollution and air incidents and accidents (Ying-Lu, 2000). This measure is preferred to be as low as possible and to decrease with an increase in the system output.

Social Indicators of the Local and Central Government Indicator System

Overall social welfare is the only defined indicator of the social dimension of performance for the local and central government. This indicator represents benefits gained by total direct and indirect employment by the air transport system at the local and regional level. Total annual number of people employed by the air transport system can be used as a measure of this indicator, which is preferred to be as high as possible and to increase over time.

Environmental Indicators of the Local and Central Government Indicator System

Four indicators are defined for the environmental dimension of performance: global energy efficiency, global noise disturbance, global air pollution, and global land use.

Global energy efficiency relates to the total energy consumed by the air transport industry of the country or region in question during a given period of time. This indicator emerges as particularly important for the central government while planning the energy budget of the country. Nevertheless, for the purpose of assessing sustainability, a convenient measure of this indicator can be expressed in relative terms by the average amount of fuel consumed per unit of the system output measured by RTK/RTM carried out during a given period of time. This measure is preferred to be as low as possible and to decrease with an increase in the volume of system output.

Global noise disturbance relates to global exposure of local and regional people to noise generated by the air transport system. This indicator can be measured by the total number of people exposed to the air transport noise during a given period of time. The measure is preferred to be as low as possible and to decrease over time.

Global air pollution relates to global emissions of air pollutants by the air transport system. This indicator can be measured by total emissions of air pollutants per unit of output measured by RTK/RTM. In this case, total air pollution consists of air pollution during the LTO cycle, and climb, cruise, and descent phases of flight (EC, 1998). This measure is preferred to be as low as possible and to decrease with an increase in total system output.

Global land use relates to the total area of land used for the local and regional air transport infrastructure. An appropriate measure for this indicator seems to be the ratio between the total area of land and total volume of output. In such case, the measure reflects the intensity of land use. This measure is preferred to be as low as possible and to decrease with an increase in air transport system output.

The Indicator System for Others

Other actors such as international aviation organisations, the environmental lobbies and pressure groups and public can use the same indicator systems and individual measures as the other actors. However, because of diversity of the objectives and preferences, interpretation of the particular indicators and measures will likely be different.

DISCUSSIONS AND CONCLUSIONS

This paper has provided a methodology for assessing sustainability of an air transport system. The methodology has been based on the indicator systems of sustainability defined to represent the objectives and preferences of different groups of actors with respect to the air transport system's operational, economic, social and environmental dimensions of performance.

The indicator systems have been developed with respect to the basic principles and rules regarding their generality, transparency and applicability of the individual indicators. Consequently, they are able to measure the system performance in both absolute and relative terms, and independent of its output, which is assumed to generally increase over time. In addition, they are able to assess sustainability of the system as a whole or of its particular components at the global, regional and local level. Fifty-eight individual indicators and sixty-eight measures have been defined in the scope of the indicator systems corresponded to seven groups of actors. Table 1 summarises the relevant statistics. An explanation of particular indicators and their measures is provided in the appendix.

As can be seen, the indicators reflecting the operational dimension of the system performance are the most numerous followed by the number of those reflecting the economic and environmental dimensions. Evidently,

Table 1. Statistics on the Indicator Systems and Measures of Sustainability of Air Transport System

Group of actors	***Dimensions of performance***				
	Operational	*Economic*	*Social*	*Environmental*	
	Number of the individual indicators/measures				***Total***
1. Users air travellers	5/6	1/1	1/1	1/3	8/11
2. Airports	4/6	2/2	-	5/5	11/13
3. ATM/ATC	4/5	2/2	-	2/2	8/9
4. Airlines	5/8	2/2	-	4/4	11/14
5. Airspace manufacturers	3/3	2/2	-	3/3	8/8
6. Local community members	-	-	1/1	3/4	4/5
7. Local/central government	-	3/3	1/1	4/4	8/8
Total	**21/28**	**12/12**	**3/3**	**21/24**	**58/68**

the environmental indicators are relevant for all actors. They relate to the fuel consumption and associated air pollution, noise, waste, and land use. Operational indicators are relevant for users, air transport operators, and aerospace manufacturers. Air travellers, airports, ATM/ATC service providers and airlines indictors reflect demand, capacity, quality of service, safety and security. Local and central government, the system users and operators, and aerospace manufacturers are interested in the economic indicators. Users consider the costs of their trip. The local and central governments are mostly interested in contributions of the air transport system to the GDP, internalisation and globalisation of local and regional economy in terms of trade, investments and tourism, and local and global externalities. Airlines, airport operators and aerospace manufacturers primarily look after profitability and productivity of their business. Indicators of social dimension of performance reflecting overall social welfare in terms of local and regional direct and indirect employment are relevant only for local community members and local and central governments.

Quantification of indicators in the scope of the particular indicator systems and evaluation of sustainability of an air transport system and its components with respect to their values should be the matter of further research.

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APPENDIX

Table 1A. The Indicator System for Users

Dimension of performance	Indicator	Explanation	Measure—dependent variable	Independent variable
Operational	*Experienced punctuality of service*	- Flights carried out on time - Delay of air trip	- Percent of flights on time - Average delay per flight	-Total number of flights per period of time -Total number of flights per period of time
	Experienced unreliability of service	- Cancellation and/or diversion of flights	- Percent of cancelled (or diverted) flights	-Total number of flights per period of time
	Lost and damaged baggage	- Lost and/or damage of baggage	- Average number of lost (or damaged) baggage per passenger	- Total number of passenger served per period of time
	Safety	- Perceived risk of death (or injury) during air trip	- Average number of deaths (injuries) per RPK/RPM	- Total RPK/RPM per period of time
	Security	- Perceived risk of treat by illegal dangerous devices	- Average umber of detected dangerous devices per passenger	- Total number of screened passengers per period of time
Economic	*Economic convenience*	- Generalised travel cost	- Average airfare per passenger	- Period of time
Social	*Spatial convenience*	- Number of destinations served by an airline from given airport	- Number of destinations per airport and airline	- Period of time
Environmental	*Comfort and health*	- Comfort at airport terminal crowding (passenger density)	- Average number of passengers per unit of terminal area - Average queuing time per passenger	- Total number of passengers served per period of time - Total number of passengers served per period of time - Period of time
		- Quality of air in aircraft - Seat configuration in aircraft	- Quantity of fresh air delivered to aircraft cabin per unit of time - Average number and size of seats in economy class	- Period of time

RPK/RPM — Revenue Passenger Kilometre or Revenue Passenger Mile

Table 2A. The Indicator System for Airports

Dimension of performance	Indicator	Explanation	Measure —dependent variable	Independent variable
Operational	*Demand*	- Number of WLU - Number of ATM	- Number of WLU accom-modated per period of time - Number of ATM accom-modated per period of time	- Period of time - Period of time
	Capacity	- Maximum number of WLU - Maximum number of ATM	- Maximum number of WLU per unit of time	- Period of time
		- Delay of ATM or WLU	- Maximum number of ATM per unit of time	- Period of time
	Quality of service	- Substitution of air services by adequate surface services	- Average delay per ATM (WLU)	- Total number of ATM or WLU per period of time
	Integrated service		- Percent of substituted flights	- Total number of shot haul flights per period of time
Economic	*Profitability*	- Operating profits	- Average earnings per WLU	- Total WLU per period of time
Social	*Labour productivity*	- Output per employee	- Average number of WLU or ATM per employee	- Total number of employees per period of time
Environmental	*Energy inefficiency*	- Energy consumption for airport operation	- Average quantity of energy per WLU	- Total WLU per period of time
	Noise inefficiency	- Generation of long-term noise level	- Total area determined by given long-term noise level - L_{eq}	- Total number of ATM per period of time
	Air pollution inefficiency	- Emission of air pollutants by polluting events	Average quantity of air pollution per LTO cycle	- Total number of LTO cycles per period of time
	Waste inefficiency	- Generation of waste	- Average quantity of waste per WLU	- Total WLU per period of time
	Land use inefficiency	- Land taken for airport infrastructure and its utilisation	- Number of WLU carried out per unit of land	- Total surface of land taken

WLU Workload Unit; ATM Air Traffic Movement (arrival or departure); LTO Landing/Take-Off

Table 3A. The Indicator System for Air Traffic Management/Air Traffic Control (ATM/ATC)

Dimension of performance	Indicator	Explanation	Measure dependent variable	Independent variable
Operational	*Demand*	- Number of flights	- Number of controlled flights per period of time	- Period of time
	Capacity	- The maximum number of flights	- Maximum number of controlled flights per unit of time	- Period of time
	Safety	- Perceived risk of air traffic accident	- Average number of aircraft accidents or near midair collisions per flight	- Total number of flights per period of time
	Punctuality of serviceEconomic	- Traffic (flights) not delayed due to ATM/ATC restrictions - ATM/ATC delays	- Percent of non-delayed flights - Average delay per delayed flight	- Total number of flights per period of time - Total number of flights per period of time
Environmental	*Cost efficiency*	- Operating cost of ATM services	- Average cost per controlled flight	- Total number of flights per period of time
	Labour productivity	- Output per employee	- Average number of controlled flights per employee	- Total number of employees per period of time
	Energy efficiency	- Extra energy (fuel) consumption	- Average extra fuel consumed per flight	- Total number of flights per period of time
	Air pollution efficiency	- Extra air pollution	- Average extra emission of pollutants per flight	- Total number of flights per period of time

Table 4A. The Indicator System for Airlines

Dimension of performance	Indicator	Explanation	Measure—dependent variable	Independent variable
Operational	*Airline size*	- Total transport work carried out	- Volume of output—RTK/RTM—per period of time	- Period of time
		- Number of passengers served	- Number of passengers per period of time	- Period of time
		- Volume of freight transported	- Volume of freight per period of time	- Period of time
	Load factor	- Utilisation of available capacity	- RTK/RTM or ATK/ATM	- Total ATK/ATM per period of time
	Operational punctuality	- On-time flights	- Percent of on-time flights	- Total number of flights per period of time
		- Length of delays	- Average delay per flight	- Total number of flights per period of time
	Unreliability of service	- Cancelled (or diverted) flights	- Percent of cancelled (or diverted) flights	- Total number of flights per period of time
	Safety	- Risk of aircraft accident/incident	- Average number of aircraft accidents or incidents per RTK/RTM or FH	- Total RTK/RTM or FH per period of time
Economic	*Profitability*	- Operating profits	- Average earnings per RTK/RTM	- Total RTK/RTM per period of time
	Labour productivity	- Output per employee	- Average number of RTK/RTM per employee	- Total number of employees per period of time
Environmental	*Energy efficiency*	- Energy (fuel) consumption	- Average fuel consumption per RTK/RTM, D, or FH	- Total RTK/RTM, D, or FH per period of time
	Air pollution efficiency	- Emission of air pollutants	- Average air pollution per RTK/RTM, D or FH	- Total RTK/RTM, D, or FH per period of time
	Noise efficiency	- Use of aircraft of Stage 3 and 4 in the fleet	- Percent of aircraft of Stage 3 and 4 type in the fleet	- Total number of aircraft in the fleet per period of time
	Waste efficiency	- Generation of in-flight waste	- Average quantity of in-flight waste per RTK/RTM	- Total RTK/RTM per period of time

RTK/RTM Revenue Ton-Kilometre or Revenue Ton-Mile;; ATK/ATM Available Ton-Kilometre or Available Ton-Mile; D Distance flown; FH Flying Hours

Table 5A. The Indicator System for Aerospace Manufacturers

Dimension of performance	Indicator	Explanation	Measure—dependent variable	Independent variable
Operational	*Innovations of aircraft*	- New aircraft in terms of technical productivity and cost efficiency	- Average technical productivity per aircraft - Average cost per unit of capacity–ASK/ASM	- Period of time - Aircraft capacity seats
	Innovations of ATM/ATC and airport facilities and equipment	- New ATM/ATC and airport facilities and equipment	- Cumulative aircraft position error - Capacity of airport facilities and equipment	- Period of time - Period of time
	Reliability of structures	- Failures of the system components	- Average number of failures per unit of time	-Total operating time
Economic	*Profitability*	- Operating profits	- Average earnings per unit sold	- Total number of units sold per period of time
	Labour productivity	- Output per employee	- Average number of units produced per employee	- Total number of employees per period
Environmental	*Energy efficiency*	- Reduction of fuel consumption of new engines and aircraft	- Percent of reduction of fuel consumption per unit of engine power or aircraft operation weight	- Total engine power or aircraft operating weight
	Air pollution efficiency	- Reduction of air pollution of newengines and aircraft	- Percent of reduction of air pollution per unit of engine power or aircraft operating weight	- Total engine power or aircraft operating weight
	Noise efficiency	- Reduction of noise of new engines and aircraft	- Percent of reduction of noise per unit of engine power or aircraft operating weight	- Total engine power or aircraft operating weight

ASK/ASM Aircraft Seat Kilometre or Aircraft Seat Mile

Table 6A. The Indicator System for Local Community Members

Dimension of performance	Indicator	Explanation	Measure—dependent variable	Independent variable
Social	*Social welfare*	- Relationship between employment by ATS and total local employment	- Proportion of ATS employees in total local employment	
Environmental	*Noise disturbance*	- Annoyance of local people by noise	- Total number of complaints to noise by community people per period of time	- Total number of local employees per period of time
			- Average number of complaints per ATM	- Total number of ATM per period of time
	Air pollution	- Exposure of local people to air pollution generated by ATS	- Proportion of ATS air pollution in total air pollution in the community	- Total number of ATM per period of time - Total air pollution in the region per period of time
	Safety	- Perceived risk of death or injury and/or damage or loss of community property due to aircraft accident	- Average number of air accidents per ATM	- Total number of ATM per period of time

ATM Air Transport Movement (arrival or departure); ATS Air Transport System

Table 7A. The Indicator System for Local and Central Government

Dimension of performance	Indicator	Explanation	Measure—dependent variable	Independent variable
Economic	*Economic welfare*	- Contribution of ATS to GDP	- Proportion of GDP by ATS in total GDP	- Total GDP per period of time
	Internalisation and globalisation	- Use of ATS for long- distance business (trade and trips) and tourism	- Proportion of business trips (or trade) by ATS by total number of long- distance business trips (or total trade)	- Total number of long-distance business trips (total trade) per period of time
			- Proportion of tourist trips by ATS in total number of long- distance tourist trips	- Total number of long- distance tourist trips per period of time
	Externalities	- Total cost of the environmental damage (noise, air pollution, congestion, accidents and incidents)	- Average expenses per period of time	- Period of time
Social	*Overall social welfare*	- Total direct and indirect employment	- Total number of the ATS employees per period of time	- Period of time
Environmental	*Global energy efficiency*	- Total energy consumption by ATS	- Average energy consumption per RTK/RTM	- Total RTK/RTM per per period of time
	Global noise disturbance	- Peoples exposure to ATS noise in the region or country	- Total number of exposed people to ATS noise per period of time	- Period of time
	Global air pollution	- Global air pollution in the region or country	- Total ATS air pollution per period of time	- Period of time
	Global land use	- Land used for regional and/or national ATS infrastructure	- Area of land for ATS infrastructure per RTK/RTM	- Total RTK/RTM per per period of time

RTK/RTM Revenue Passenger Kilometre or Revenue Passenger Mile; ATS Air Transport System