# Healthy Airports

# A proposal for a comprehensive set of

# Airport environmental health indicators

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Universiteit Maastricht, Department of Health Risk Analysis and Toxicology

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This report is also available at http://home.planet.nl/~wfpas/mtr02.htm

Cover Photograph: 'Tower mit Kirschblüten' (Flughafen München)
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# Contents

# Preface

The present report is the outcome of the project 'Developing environmental health indicators for large airport systems in Europe' that was part of the EU-programme on pollution-related diseases.[1] The project application responded to the year 2000 call for proposals[2] and was granted by the EU under No SI2.292344 (2000CVG2-606).

The project's focus is the environmental health impacts of operations of large airports. As stated in the project proposal the aims are:

to develop environmental health indicators to monitor trends in local health impacts resulting from exposures to environmental risk factors related to the operations of large airports in Europe.

The applicants considered the definition of a set of environmental health indicator a first and necessary step for the implementation of a monitoring programme to be used as guidance for public health policy vis-à-vis the airport and airport-related operations. Furthermore, validated indicator sets might be used for deciding between alternative options for airport development and for comparing the environmental health impacts of major airports in Europe.

The research consortium that carried out the project and is responsible for the present report encompassed scientists from Germany, Italy, the Netherlands, Poland, and the United Kingdom (see Annex A). It was co-ordinated and administered by affiliates of the Universiteit Maastricht, the Netherlands.

With this report the project is successfully completed in the sense that a set of environmental health indicators has been derived and that this set is founded on a sound scientific basis. However, its merits have to be demonstrated in actually implementing the indicator set in monitoring programmes. Before implementation is possible, at many airport systems barriers to efficient data collection have to be removed. Also indicators do not need a scientific underpinning only, but have to be supported by the users, in the present case the airport operators, the local and national authorities and representatives of population living near an airport. Stakeholder consultation is a prerequisite for successful implementation of indicators in an effective and efficient monitoring programme.

I would like to thank the various people that contributed to the project. Especially the participants at the workshop in Baarn, the Netherlands (March 2002) with backgrounds in research, government and public health policy, and airport operations were instrumental in reaching the proposals presented in the present report. The researchers consider these proposals as a contribution to sustainable airport development.

Maastricht, August 2002
Wim Passchier, project co-ordinator

# Executive summary: Airport environmental health indicators

In September 1999 an international committee of experts, convened by the Health Council of the Netherlands, concluded in its report on the public health impact of large airports:

Given the many parties involved in an airport operations system and given the interactions between different measures to reduce public health effects, the committee recommends that all developments are monitored and assessed on their public health consequences in an integrated manner.

Environmental health indicators may be part of such a monitoring programme. This motivated a group of scientists from Germany, Italy, the Netherlands, Poland and the UK to propose a research project entitled

Developing environmental health indicators for large airport systems in Europe

The project was funded by the European Commission as part of the programme on pollution-related diseases. The present report presents as a result a set of environmental health indicators that is thought to be useful in monitoring public health at large airports.

## Airport operations system

It is not too difficult to identify a large airport. The aviation industry is developing into a global network with major airports at the network nodes or 'hubs'. A few conglomerates of airline companies transport passengers and freight from hub to hub and from there to and from secondary destinations. Present day hub airports annually serve several 10s of millions of passengers with several 100s of thousands of aircraft landing and departures. The four major European airports in terms of passengers and aircraft movements are London Heathrow Airport, Frankfurt Airport, Aéroport Charles de Gaulle and Amsterdam Airport Schiphol. Heathrow is among the top five airports world wide in terms of passengers, and all four European airports are in the global top twenty range.

However, an airport is more than arriving and departing aircraft, fuel services, passengers and freight. A major airport attracts a variety of businesses, requires road and rail infrastructure for passenger and freight access and needs housing for the multitude people employed at the airport and the businesses near the airport. Therefore the present project defined an *airport operations system* qualitatively as the airport zone of influence encompassing airport, business developments, infrastructure and residences. In geographical terms one could think of an area with a 20 km radius around the airport, encompassing the zones with serious impact of aircraft noise.

## The indicator set

The proposed set of indicators consists of *health indicators*, *exposure indicators* and *throughput indicators*. The indicators are:

| Indicator | Definition |
|---|---|
| *Health indicators* | |
| Complaints | Number of spontaneous complaints per year about noise and odour related to airport activities |
| Annoyance | Number of people highly annoyed by air traffic noise stratified to age (15-25, 25-60, 60+) |
| Cardiovascular disease | Prevalence of cardiovascular disease in the 45-65 age group |
| Respiratory disease | Prevalence of respiratory disease in the 4-12 age group |
| Sleep disturbance | Number of people highly sleep annoyed by air traffic noise stratified to age (15-25, 25-60, 60+) |
| *Emission/exposure indicators* | |
| Aircraft noise | Fraction of population exposed to aircraft noise with Lden of <55, 55-60, >60 dB(A) |
| Nighttime aircraft noise | Fraction of population exposed to aircraft noise with LAeq,23-7h of <40, 40-50, >50 dB(A) |
| Particulates | Annual emissions of PM10 from air traffic, road traffic and other sources |
| | Mean annual concentration of PM10 |
| Hydrocarbons | Annual emissions of gaseous hydrocarbons from air traffic, road traffic and other sources |
| | Mean annual concentration of gaseous hydrocarbons |
| Nitrogen oxides | Annual emissions of nitrogen oxides (NOx) from air traffic, road traffic and other sources |
| | Mean annual concentration of nitrogen oxide (NO2) |
| *Throughput indicators* | |
| Number of aircraft | Arriving and departing aircraft per year (scheduled flights, chartered flights and 'general aviation') |
| Number of aircraft at night | Arriving and departing aircraft per year during 23-07 h (scheduled flights, chartered flights and 'general aviation') |
| Passengers | Number of arriving and departing passengers per year |
| | Number of transfer passengers per year |
| Freight and mail | Freight and mail loaded and unloaded per year (tons) |
| Public transport | Fraction of passengers going to and from the airport using public transport |
| Geography | Area of the airport |

## What is an indicator?

A comprehensive set of indicators can be compared with a clinical thermometer. If the thermometer performs well, changes in the thermometer reading reflect changes in the health status of the patient. However, a thermometer reading does not provide you with a diagnosis, because it is not a substitute of a medical examination, but may signal the need for such examination. Likewise a 'reading' of a set of environmental health indicators may signal the necessity of further assessment of the environmental health impact of the activity to which the indicator set is related. Registering the readings in the course of time ('monitoring') may indicate that the impact of airport and related developments on the health of the citizens living in the vicinity of the airport is progressing satisfactory or may signal the need of in depth assessment.

## Criteria

What is a good indicator? The first two follow-up questions to be asked are:

- What issues should the indicator address?
- Who are the potential users of the indicator?

In the present case the issues are the positive and negative influences on health and well being of the citizens living in the vicinity of the airport. The potential users are the airport operator, the local and national authorities and representatives of citizen groups. As the indicators need to address the issues of concern to the users, implementing the indicator set in a monitoring programme requires stakeholder consultation. The indicator set proposed in the present project is thought to be a minimum set for implementation at a specific airport. It was specified after a limited consultation of representatives of local authorities, citizen groups and airport operators.

From research into and experience with indicators for different purposes, the following criteria have emerged. Indicators should be:

- Interpretable
- Measurable
- Useful.

Although these criteria appear to be self evident, it is not easy to satisfy them in practice. This is due to theoretical problems (e.g. how do increasing emissions caused by increased transportation of passengers to and from the airport relate to health effects of the local population?), practical problems (do hospital admission data reflect the health status of the population in the airport operations system?) and policy questions with difficult answers (does a decrease in complaints reflect a better performance of the airport or just 'fatigue' of the affected population?).

The indicators were derived applying the criteria mentioned. Although on average the score could be qualified as 'fair', it is clear that further experience and additional research is required to develop the present proposal into a more ideal set. The scores are:

| Indicator | Score (- difficult, 0 fair, + good) | | |
|---|---|---|---|
| | Interpretability | Measurability | Utility |
| *Health indicators* | | | |
| Complaints | - | 0 | + |
| Annoyance | -/0 | 0 | + |
| Cardiovascular disease | - | + | + |
| Respiratory disease | 0 | + | + |
| Sleep disturbance | 0 | 0 | + |
| *Emission/exposure indicators* | | | |
| Aircraft noise | 0 | + | + |
| Nighttime aircraft noise | + | + | + |
| Particulates emission and immission | 0 | 0 | + |
| Hydrocarbons emission and immission | - | 0 | + |
| Nitrogen oxides emission and immission | 0 | 0 | + |
| *Throughput indicators* | | | |
| Number of aircraft<br>Number of aircraft at night<br>Passengers<br>Freight and mail<br>Public transport<br>Geography | + | + | 0 |

## Science behind the indicators

### *Health indicators*

Health indicators represent most directly the issue of primary concern: public health. However, because they are downstream the cause (airport and airport related activities) to effect (public health impact) chain, their relationship with the 'causes' is inherently uncertain. What is the cause of an indicator change (or the absence of such a change)?

The health indicators selected have a low level of integration: complaints, aircraft noise and odour annoyance, respiratory and cardiovascular disease, and sleep disturbance. The relationship of these effects with airport and related activities is scientifically well established, be it that other factors may influence the occurrence of these effects as well (causing the uncertainty just mentioned). Respiratory disease is associated with air pollution with children as a vulnerable group. Cardiovascular disease is associated with exposure to air pollutants and noise; in this case middle-aged people are thought to be the vulnerable group.

*Exposure indicators*

Exposure indicators (emissions and ambient concentrations) are intermediate between activities and health effects. Gathering data for these indicators through a combination of computations and measurements follows well-established techniques. Unfortunately dedicated measurement programmes are often lacking and with respect to noise harmonisation of noise metrics has still some way to go. On a European level this harmonisation need is addressed and the recent EU directive on environmental noise is a step forward in this respect.

The exposure indicators elected are full day noise levels, nighttime noise levels and emission and concentrations of particulates, gaseous hydrocarbons and nitrogen oxides. The noise indicators are in line with the new European requirements. With respect to air pollutants prominent major pollutants related to use and combustion of fossil fuel have been chosen. The scientific basis for aggregate exposure indices of indicators for specific groups of substances, e.g. carcinogenics, was though to be insufficient for inclusion of these indicators in the proposed set; they would probably also be not sensitive enough to serve in a monitoring programme.

*Throughput indicators*

The throughput indicators related to airport activities are fairly straightforward. Aircraft activity during the day and at night, numbers of passengers, tons of freight, airport area and passengers access clearly reflect the airport's 'temperature'. Indicators related to other activities in the airport operations system, like extent of economic activity, people employed within the airport operations system, traffic flows, etcetera, are either difficult to 'measure' or to interpret or both.

*Other developments*

Socio-economic indicators, landscape indicators and aggregate measures are lacking in the recommended set. The researchers propose further study of these quantities to assess their scores on the main selection criteria. With respect to socio-economic indicators the possibility of using income date for standardisation of other indicators (e.g. hospital admission) should be studied. In Europe landscape quality is being registered on a very detailed level in the so-called Corine project database. A linkage with environmental health indicators is worth studying. Apart from exploring the robustness of aggregate indicators for air pollutants it is worthwhile to study the significance of house price changes as a health indicator.

### The way ahead

'The proof of the pudding is in the eating', as the English say. The same applies here. The indicators should prove their merits in actual monitoring programmes. In the Netherlands such a programme will be implemented at Amsterdam Airport Schiphol; it includes the majority of the indicators proposed in the present project.

Apart from 'real life' tests, several subjects have been identified to be elaborated further also in view of harmonisation on a European scale. Such harmonisation is important for comparing environmental health performance among European airports. The case studies at Heathrow, Malpensa and Schiphol, that were part of the present project, indicated barriers for effective and efficient implementation. A major point of concern is data access. The relevant data reside with various data holders and matching of the various databases will not be easy, neither in terms of data definition, spatial resolution, registration frequency etcetera, nor in willingness to cooperate in linkage and harmonisation efforts.

For several of the indicators, especially the health indicators, periodic surveys are recommended. Such surveys are carried out at the airports studied but not always with the required frequency and the required format. The researchers propose annual telephone surveys with more extensive surveys every five years to calibrate the annual data.

From the case studies it appeared that many data reside with either the airport operator or the national statistics bureau. The researchers suggest that setting up a separate office attached to either one with stakeholder oversight might guarantee the required continuity and transparency of the monitoring programme.

### Sustainable development

The results of the case studies demonstrate a willingness among airport operators to place their policies under the heading of 'sustainable development'. Although the various parties in the public and policy debate on airport development would probably define 'sustainability' differently it would at least make agreement on principles possible. On a European level this 'trend' parallels the policies of the Commission and the Council.[6]

Indicator sets as studied and proposed in the present project could be part of an approach towards sustainable operation of airports and airport operations systems. It might be feasible to supplement the set with other performance indicators covering other aspects of sustainable operations apart from impacts on public health and the environment.

# 1 Introduction

## 1.1 Background

Civil aviation represents a growing industry. It is developing into a truly global industry, with a few conglomerates of airlines serving a worldwide network of large 'hub' airports, from which passengers and freight can be further transported to their final destination at a secondary airport. In 1999 the scheduled airlines carried 1.6 billion passengers and 28 million tons of freight.[3] Large airports in Europe have several hundred thousands aircraft movements (landings and takeoffs) and at least a few tens of million passengers (arriving, departing or transferring) per year (Table 1 in Chapter 2). A further growth is still expected, although—given the present political situation worldwide—less than the forecast of seven per cent annually of a few years ago.[4]

Business air travel and airfreight are cornerstones of the global economy and air transport is a key factor in international tourism. Air travel is valued by many, because it generates income for a considerable number of people and produces social benefits, such as providing people with useful goods. However, there is evidence that the operation of large airports affects the health of the population in the vicinity of the airport.[5] The impacts of environmental degradation on public health do not primarily involve mortality risks or serious loss of life expectancy, but modify the incidence and severity of common diseases and affect quality of life in a broader sense. These negative effects of airports on public health and the environment at present and in the future are not fully taken into account in transport tariffs.[6,7]

Attributing health effects to airport and airport related operations is a complex matter. The areas around large airports usually develop in a dynamic way. Even when airports are originally located in remote areas, the airport region tends to become more and more urbanised over the years, as the airport attracts economic activities. Some of the impacts of these activities on public health are uniquely linked to the airport system, such as aircraft noise, kerosene odour and aircraft crash risk. Other effects such as air pollution, landscape changes by transport infrastructure, and road traffic and industrial noise are also encountered in other urbanised and industrialised settings. At the same time, the economic activity generated by airports brings jobs and prosperity to the region surrounding the airport. This development may have an impact on public health in an indirect way.

## 1.2 Aims and objectives

The possibility that airport development and operations result in public health impacts calls for monitoring tools to support public decision making now and in the future. The present study aims to develop environmental health indicators to monitor trends in local health impacts resulting from environmental risk factors related to the operation of large airports in Europe. The proposed environmental health indicators should be instrumental to guide public health policy at the regional and national level. A longer-term objective is to make the health indicators suitable for deciding between alternative options for developments within an airport operations system.

If it turns out to be possible to develop a generic set of indicators for the health impacts of airport operations, this set could later be of use in European Union-wide comparison of health impacts of large airports.

## 1.3 Methodology

The project's objectives have been pursued in various ways. First of all, desk studies have been carried out, considering issues such as:

- Current procedures of monitoring activities with an emphasis on airports and airport related activities
- Evaluation of environmental health indicator projects
- Developing a methodology (framework) for deriving airport related environmental health indicators
- Designing a pilot study of a few European airports.

The desk studies provided the material for a list of environmental health indicators. The intention was to evaluate this set of environmental health indicators at four European airports (Amsterdam Schiphol Airport, Malpensa Airport, Munich Airport Franz Josef Strauss, Heathrow Airport). Due to practical problems in collecting the data, data sets have only been composed for Schiphol, Heathrow and Malpensa. The results of both desk studies and case studies were evaluated at a workshop in March 2002. At the workshop, bringing together scientists and stakeholder representatives, a harmonised set of indicators was identified, as well as gaps in existing knowledge.

## 1.4 Structure of the report

The present report focuses on the framework that is needed to develop environmental health indicators related to large airports in Europe. Issues that are discussed include the criteria, possibilities and limitations of indicator selection, as well as the actual choice of indicators.

Setting up an indicator framework presupposes some background knowledge about airport systems and their environmental health impacts. Therefore, this report includes a brief review of the international literature in this field.

The structure of the present report is as follows. Part I, consisting of Chapters 2-5, provides an overview of the current state of scientific knowledge of health impacts of large airports. In part II, consisting of the Chapters 6-10, questions are addressed of why and how to develop health indicator frameworks for airport development. Some general thoughts behind indicator selection are first discussed separately and subsequently applied to the case of airports.

The results from the pilot studies at Schiphol, Heathrow and Malpensa are presented and discussed in part III, Chapter 11. These findings are then confronted with the objectives and the theoretical framework to yield some preliminary findings and recommendations in the concluding chapter (12).

# Part I

# Airports and health

# 2 Airports and health: an overview

## 2.1 Environment and health

For the assessment of the potential health effects related to large airports, a common understanding of the notion of health is indispensable. We use the term public health to denote health and quality of life of individuals and groups. The concepts of health and quality of life differ from era to era and from region to region. They reflect changes or differences in social and cultural beliefs, in medical technology, and economic conditions.

Major airports are situated in countries with a relatively high standard of living. In these countries the impacts of environmental degradation on public health do not primarily include mortality risks or serious loss of life expectancy. Rather, they influence aspects of the quality of life in a broader sense.[5]. Examples are aggravation of pre-existing disease symptoms like asthma, cardiovascular disorders, severe annoyance and sleep disturbance, and feelings of insecurity and perceived danger of large accidents. Likewise improving environmental quality affects health similarly but in an opposite direction.

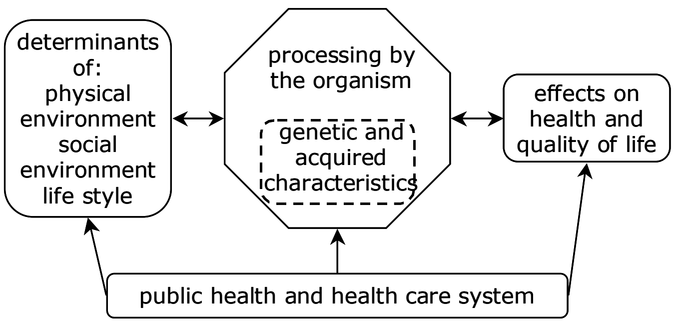


*Figure 1 Model describing the relationship between the environment and health and quality of life.*

Figure 1 illustrates the fact that effects on health and quality of life cannot be linked mechanically to changes in the physical environment (nor to changes in the social environment and life style). Rather, the effects are the outcome of the way in which human beings process changes in their environment. This processing may be of a physiological nature, e.g. detoxification processes that operate after inhalation or ingestion of toxic substances, or it may be psychologically determined as in the case of the enjoyment of a natural landscape or the annoyance from noise; it may also encompass both mechanisms. The physiological and psychological control mechanisms lead to coping behaviour, either to reduce or avoid the exposure, or to partly adapt to the environmental stressors.

The process of coping is influenced by each individual's unique genetic and acquired characteristics. Furthermore the public health and health care system modifies each of the links in the causal chain depicted in the figure.

The variety of factors that play a role in the pathway from exposure to effect may explain why the response to environmental exposures varies substantially from one individual to another and from one population group to another. Aspects of lifestyle or behaviour may largely determine exposure to factors from the physical environment such as noise and air pollutants.

It is well known that there is a strong association between socio-economic and environmental conditions; take for example the geographic association between socio-economic status and residential environmental quality in the vicinity of airports, freeways, and industrial areas. This makes detection of environmental health effects by epidemiological methods quite difficult and often impossible.[5] Detection is also problematic for effects that emerge only after long-term cumulative exposure, including a latency period. In such cases, it is difficult to trace a change in disease incidence back to its original cause, if the change in incidence is detected at all.

## 2.2 The level of analysis and the 'airport operations system'

For the assessment of health effects of airports, the selection of the level of analysis is of crucial importance. Some argue that only the effects of air traffic on people in the immediate surroundings of airports should be monitored. Others endeavour to look at the health effects from a broader perspective, taking into account other forms of mobility and economic activity directly and indirectly related to the airport operations. The latter level of analysis is more appropriate from a public health point of view as health is affected by a combination of environmental factors in a cumulative way.

In the present study we followed the view of an international group of experts convened by the Health Council of the Netherlands in taking the *airport operations system* as the level of analysis.[5] By their very nature airports generate ground transport and attract businesses that rely on good connectivity. In their turn, these businesses generate further activity. An airport and the accompanying economic activity together form a complex system, including many actors, such as airport authorities, local, national and supranational authorities, air companies, passengers, ground personnel, population of nearby areas and companies located at or near the airport. This extra mobility and economic activity cannot be separated from the primary airport activities, directed at facilitating air traffic, and should therefore be included in health assessment and monitoring.

The parties involved in the airport system do not act independently from each other. On the contrary, the quality of the interactions between the various stakeholders co-determines the reliability of the airport operations system, as well as its environmental and public health impacts. As several stakeholders are supra-national organisations, measures to control the public health impacts of airports have an international dimension.

The current project focuses on large airports, the nodes or 'hubs' of the global aviation network. Most of the larger airports in the world are located in the United States, but there are also several European hubs. Table 1 lists the top four European airports according to estimates of the number of passengers, movements and cargo for the year 2000: Heathrow (London), Frankfurt, Charles de Gaulle (Paris) and Schiphol Airport (Amsterdam).[8]

*Table 1 Number of total passengers (arriving + departing), total aircraft movements (arriving + departing) and total cargo (loaded and unloaded) in 2000 at the top four European airports.*

| Airport | Passengers | Movements | Cargo (tons) |
|---|---|---|---|
| London (LHR) | 64 606 826 | 466 815 | 1 402 089 |
| Frankfurt (FRA) | 49 360 630 | 458 731 | 1 709 942 |
| Paris (CDG) | 48 246 137 | 517 657 | 1 610 484 |
| Amsterdam (AMS) | 39 606 925 | 432 480 | 1 267 385 |

Two of the airports in Table 1—Heathrow and Schiphol—were included in our pilot study.

## 2.3 Public health in an airport operations system

An airport operations system has economic, ecological and human welfare aspects. Air pollution, odour, noise and accident risk are the more prominent environmental factors that may more or less directly affect health in a negative sense. Other environmental factors operate more indirectly: water and soil pollution, particularly in relation to de-icing, the spread of infectious diseases ('airport malaria'), disruption of nature habitats and landscape changes by transport infrastructure and business development. It has to be recognized that an airport and its related activities also positively affect health, be it indirectly, through providing jobs and generating economic welfare.

The representation of Figure 2, depicting the social, economic and environmental components of societal systems, allows for the identification of the main causal relations between the airport operations system and health. The airport and its connectivity lead to mobility on the ground and to extra economic activity that depends on good connections. Through effects of scale, the presence of such activities leads to clusters of airport-related businesses, and to extra mobility. The aircraft movements cause safety risks and direct health effects through noise. More indirectly, they also cause health effects through reduced air quality. The whole airport system produces jobs, but also occupies valuable space in the urbanised airport region. The issue of health and quality of life of the population is related to many of these other issues, as it depends on employment, safety, health services, and residential and landscape quality.

Several negative health impacts pass through the environmental domain: airport systems lead to higher emissions and concentrations and these in turn have health effects. The positive health impacts are due to the attainment of a higher socio-economic status, because of airport-related income and employment effects and run directly from the economic to the social domain. See Figure 2.

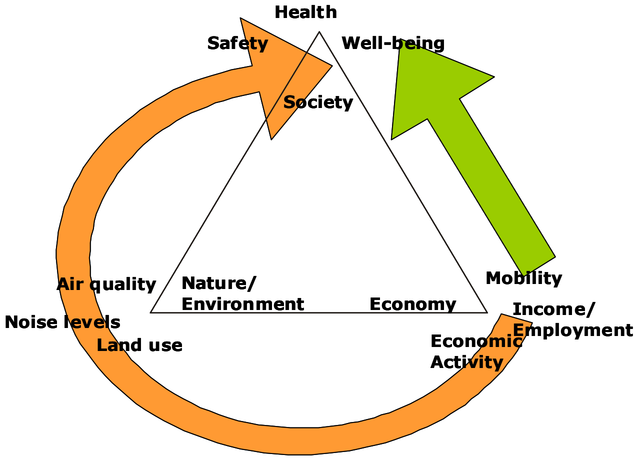


*Figure 2 Different facets of large airport systems.*

Unfortunately, the representations in Figure 1 and Figure 2 are difficult to elaborate in a concrete way. Many of the relationships between the various interacting factors and health are not well known, in any case not in any quantitative sense. A main reason, as mentioned above, is that these relationships often do not lend themselves very well for study, as is depicted in Figure 3 (that was originally derived for the effects of air pollution).

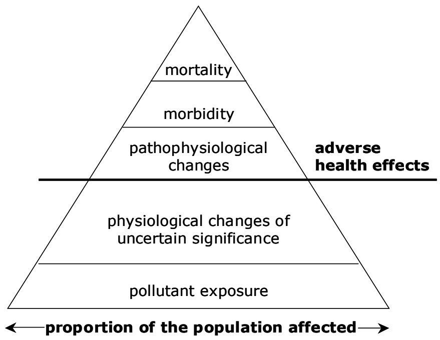


*Figure 3 Classification of the effects of air pollution. The effects below the horizontal are very difficult to study. However, they may contribute to the burden of disease and affect many of the exposed..*

Currently, our understanding of the relationship between environmental factors and health is mainly qualitative. Sometimes quantitative knowledge is available for the health effects of individual environmental factors. In a few situations data on interactions are available; as in the case of fear of accidents and noise annoyance.[10] Following the Health Council Committee on 'Public Health Impact of Large Airports', we focus on noise exposure, air pollution, accident risk, and land use.[5] The main health issues associated with these environmental factors will be discussed in more detail in the next three chapters. An overview of the findings of the Health Council Committee is presented in Annex B.

It should be noted, that activities within the airport operations system do also affect occupational health. From a literature review, however, it appears that, given the health and safety regulations in European countries, the occupational accident and disease rates are not expected to be at or near the unfavourable end of a safety and health ranking of major industry branches.[5] Moreover, occupational health clearly differs from public health, which is the focus of the present study. Therefore, occupational health impacts are not considered in any detail.

# 3 Noise

## 3.1 General

The evidence for the influence of noise on human health is only partly based on research into the health effects of exposure to aircraft and airport related noise sources.[11] The Health Council committee referred to above concluded in 1999 that the insights obtained from the study of other sources are also relevant for airport-related noise. Airport personnel, airplane crews and workers in specific businesses run a risk of hearing loss, but in general noise induced hearing loss is not a relevant effect for the population living around airports.

In the scientific literature a range of mechanisms is discussed through which noise may affect health. Except from hearing loss, all effects are based on the perception of noise. The discussion about the influence of noise on health centres on the processing of noise by people. Exposure to noise can influence in a direct or indirect way the vegetative, hormonal, cognitive and emotional control mechanisms of people. Prolonged exposure to noise can lead to chronic disorder that in the long term could cause or contribute to cardiovascular problems and possibly other diseases in the affected population. It is important to notice that the expectations of health impacts that are described here are based on the assumption of prolonged exposure, i.e. exposure for many months or years. Such circumstances are relevant for large airport systems.[5]

The Health Council of the Netherlands concluded in 1999 that there is sufficient evidence for a causal relationship between the exposure to noise and hypertension, ischemic heart diseases, severe annoyance, sleep disorders and reduced learning performance (see Table 2).[5]

*Table 2 Overview of reported health related responses to environmental noise exposure for which 'sufficient scientific evidence' is available.*

| Response | Severity[1] | Number affected[2] | Observation threshold |
|---|---|---|---|
| hypertension | ** | ** | eq. outdoors sound level (06-22 h) of 70 dB(A) |
| ischemic heart disease | *** | * | eq. outdoors sound level (06-22 h) of 70 dB(A) |
| annoyance | * | *** | outdoors day-night level of 42 dB(A)[3] |
| sleep disturbance | ** | *** | depending on effect, indoors SEL of 35-50 dB(A)[4] |
| performance at school | ** | ** | eq. outdoors sound level (school hours) of 70 dB(A) |

1 * = slight, ** = moderate, *** = severe
2 * = susceptible individuals, ** = specific subgroups, *** = substantial part of exposed population
3 threshold for 'high annoyance'; the day-night level is the equivalent sound level over 24 hours, with the sound levels during the night (period of 23-07 h) increased by 10 dB(A).
4 SEL is the equivalent sound level during the noise event normalised to a period of one second

Some of the potential effects of noise exposure warrant some further discussion here.

## 3.2 Annoyance

The most prominent effect of environmental noise in general and aircraft noise in particular is annoyance. Apart from the noise levels various other factors determine the prevalence of noise-related annoyance in the exposed population. A critical point is the way in which annoyance is measured, although standardisation is underway. Notwithstanding these critical issues, chronic exposure to aircraft noise appears to lead to more or more serious annoyance in the exposed population than exposure to road and railway noise at similar equivalent sound levels.[12]

## 3.3 Heart disease

The impact of environmental noise on hypertension and heart disease is still debated within the scientific community. Part of this debate has to do with the noise levels at which such impacts are expected to occur.[11,13]

In the early 1970s, Eiff and colleagues did not find any forms of heart disease to be systematically connected with aircraft noise at the old Munich airport.[14] In the late 1970s, Knipschild performed a series of community studies in the vicinity of Amsterdam Airport Schiphol.[15,16] Controlling for age, smoking habits, gender, height and weight of the residents, he found ‘cardiovascular impairments’ to be up to 50% higher in the noise areas. These results may be questioned because of the high rate of non-respondents (58%), but are supported by the Knipschild and Oudshoorn drug study (see below).[16] Within the framework of an environmental impact assessment for the Amsterdam Airport Schiphol, Staatsen, Franssen and Lebret investigated hospital admission rates for acute myocardial infarction and hypertension.[17] They did not find a clear effect of aircraft noise, but this may be due to the coarse units of aggregation, which did not allow for an exact specification of noise exposure. Very recently in a meta-analysis indications for a relationship between aircraft noise and hypertension were found, although the authors point to the many confounders and limitations in exposure characterization.[13] The Health Council of the Netherlands concluded in 1994 and again in 1999 that hypertension and ischemic heart disease were to be expected above noise levels of 70 dB(A).[5,11,18].

An effect on heart disease might show up in mortality figures. Scientific evidence for increased mortality by airport-related noise is inconclusive. Meecham and Shaw analysed data of the 1970-1980 period, and found that people near Los Angeles International Airport (LAX) suffer a 5% increase in mortality rates due to increases in a number of fatal diseases.[19] However, in a re-analysis of the data controlling for demographic factors, no effect of aircraft noise on mortality rates was observed.[20] Morrell and colleagues reviewed a similar study at the Sydney International Airport which compared residents under the flight path with control subjects and found a significantly higher number of deaths above the expected rates for Sydney in the noise areas. The authors criticize this study because they did not control for demographic confounders.[21]

## 3.4 Psychological effects and performance

In the first study relating aircraft noise to psychological problems, Knipschild found higher contact rates to doctors around Schiphol Airport.[22] But the results could have been due to differences in the socio-economic status of the residents. In a community survey of 6 000 residents of four noise-exposure zones at Heathrow Airport, a positive association between level of aircraft noise and depression and irritability was observed.[23] However, psychotropic drug intake was found to be negatively associated with aircraft noise levels. In a postal six-year follow-up survey of 77 women from the original survey, Stansfeld found a high correlation between noise sensitivity and noise annoyance, and a moderate statistical association between noise sensitivity and psychiatric symptoms, but there was no significant relation between aircraft noise and psychiatric symptoms in the noise sensitive group.[24] In a study into cognitive performance and health, 340 school children in high aircraft noise areas were compared with children attending matched control schools exposed to lower levels of aircraft noise. Mental health and cognitive tests were group administered to the children in the schools, but chronic aircraft noise was not significantly associated with mental health problems.[25] However, both this study and others (for a recent overview see [11]) provide some evidence for effects on cognitive performance of children, a subject that warrants further investigation.[26,27]

## 3.5 Birth weight

Ando and Hattori were the first authors to examine the statistical relation between aircraft noise and the weight of newborns.[28] They first compared babies born in Itami (near Osaka International Airport) with babies from neighbouring cities, both before the introduction of jet planes (1961-1963) and afterwards (1965-1967). When relating the rate of low-weights to estimated noise levels, the authors found a positive association between both quantities and concluded that the “growth of the human embryo was inhibited by aircraft noise”. Knipschild and Meijer partially confirmed this result and reported a statistical significant association between low birth weight and aircraft noise exposure from Amsterdam Airport Schiphol in female babies, after controlling for parental income.[15] In a report on the effects of noise from US military air bases—which differ from civil airports in many ways—an increased rate of low birth weight infants due to aircraft noise in two of three affected cities was reported, even after controlling for many socio-economic variables.[29] In addition, the rate of pre-term births increases significantly with increasing noise levels. Rehm and Jansen observed a tendency for higher pre-term birth rates with higher noise exposure at the Düsseldorf Airport (from 5.9 % to 6.7 %). Although this increase is statistically not significant, the authors evaluate it as a remarkable effect.[30] Taken together, there is limited evidence that low birth weight may be associated with high aircraft noise,[18] and this hypothesis should be tested in further studies.

### 3.6 Modifying factors: Socio-economic status

It is often held that low-income groups are suspected of having disproportionately high levels of exposure to environmental stressors such as chemicals, biological agents, allergens, toxicants, light, noise, odours, and particulate matter. This suspicion of environmental injustice is very difficult to define operationally, and the outcomes of the statistical analyses may be contradictory, depending on the operationalisation of the indicator.[31,32] For instance, the ratio of family income to area will be rather low in the vicinity of airports and increase with increasing distance from the airport, but the average family income may decrease with increasing distance, because there are mostly low-rise own-property houses in the vicinity of airports, and high-rise houses with rented flats farther away. Of course, the size of the affected population, and thus population density, is of great significance to the public health impacts of airports.

# 4 Air pollution and odour

## 4.1 Overview

Sources of air pollution in the airport operations system (Section 10.2) comprise:

- The airport site itself
- Airport related activities outside of the airport site
- Other activities around the airport
- Activities remote from the airport, which affect the regional background (to which the airport system itself is a contributor as well).

The primary source of air pollution is the combustion of fossil fuel by ground transport vehicles, aircraft, and energy plants and for heating. There is also pollution from evaporation of fuel, solvents and the emission of various chemicals used in airport operations or operations in the vicinity of the airport. The main source at most locations will be vehicles. Some of the particles in the air will also have been created by resuspension of crustal materials (e.g. road dust) by human activities or by wind.

The dominant substances emitted by these sources are nitrogen oxides ($NO_2$ and NO, also denoted together as $NO_x$), carbon dioxide ($CO_2$), carbon monoxide (CO), volatile organic compounds (VOC), sulphur dioxide ($SO_2$) and particulate matter (PM). Ozone is a secondary air pollutant. Carbon dioxide is an important greenhouse gas, but poses no direct threat to human health in concentrations observed in the atmosphere. VOC is a mixture of a large number of hydrocarbons (HC) mostly released through evaporation of fuel and a variety of solvents. Also polycyclic aromatic hydrocarbons (PAH) are part of the emissions from activities of an airport operations system.

For overview of the effect of the most common air pollutants on health the reader is referred to recent reviews (e.g. [33,34,35]). Some additional comments follow below.

*Nitrogen dioxide* Nitrogen dioxide is a product of fuel combustion at high temperatures. It is also formed in the atmosphere through the oxidation of NO by ozone and other compounds. It affects more specifically asthmatics.

*Sulphur dioxide* The main source of sulphur dioxide ($SO_2$) is the combustion of sulphur containing fuels, among which kerosene.[33] Very high concentrations of $SO_2$ are seldom encountered these days. However, $SO_2$ may cause more damage than earlier assumed, especially in mixtures of pollutants, like $SO_2$ and particulate matter.[5]

*Ozone* Ozone is a secondary pollutant formed after the interaction of nitrogen oxides with sunlight in the presence of volatile organic compounds. Ozone is not formed immediately; the reaction can take hours to days.[33] Asthmatics appear not to be more susceptible to ozone than healthy persons. Ozone levels in urban areas may be lower than elsewhere because the compound is scavenged by nitric oxides emitted by road vehicles.

*Carbon monoxide* Carbon monoxide (CO) is a product of incomplete fuel combustion. Its ambient concentration closely follows CO-emissions; therefore it is highest near the source, such as cars or aircraft.[33] High concentrations of CO can cause serious damage to the heart and brains. In the open air, concentrations of CO are not that high but recent studies have shown that CO is playing a more important role than previous assumed.[5]

*Particulate matter* Particulate matter (PM) or suspended particulate matter (SPM) is a complex physicochemical mixture, which varies from place to place and time to time according to the local and regional context. PM originating from combustion gases tends to be of submicrometer size and largely consists of carbonaceous material. Secondary particles, which form the regional background, are mainly ammonium sulphate and nitrate, formed by the oxidization of sulphur and nitrogen oxides to their respective acids and subsequent neutralization by ammonium. Particles of crustal origin tend to be larger and mainly consist of insoluble materials such as silicates. Only particles below 10 micrometer (μm) in diameter (PM10) are small enough to penetrate the lower respiratory tract, and the smaller the particle, the larger the proportion of particles reaching the distal airways and the alveoli. Larger particles will impinge on the mucus membranes of the conjunctiva and upper respiratory tract where they can cause inflammation. In the epidemiological data there is no indication that a no-effect-threshold exists for the effects of PM-exposure.[36]

The toxicity of the particle mixture is especially problematic, given its varied physicochemical composition. The physical size of the particle is also likely to be important. Current thinking is that the toxicity resides in the fine (smaller than 2.5μm, PM2.5) fraction, and some researchers suggest that the ultrafine fraction (smaller than 0.1μm), may be even more important. It has also been postulated that particle numbers (highest in the ultrafine fraction) or particle surface area are more important. The current position is one of uncertainty and the recommended routine measure remains PM10.[36,37,38]

*Polycyclic aromatic hydrocarbons* Also originating from combustion of organic materials are polycyclic aromatic hydrocarbons (PAH). PAH indicates a group of more than 250 compounds, which can be divided into light and heavy PAH's. Some of the heavy PAH's, like benzo[a]pyrene, have proven carcinogenic potential. Benzene, also belonging to the group of PAH is associated with leukaemia in humans.[33]

## 4.2 Health effects

Major air pollutants associated with an airport operations system are similar to those in most other urbanised regions in industrialized countries. We can therefore rely on the existing body of evidence relating to the health effects of these pollutants or pollutant mixtures to make inferences about the possible effects on health of air pollution in the vicinity of large airports, including the major aircraft combustion products.

At the air pollution levels currently encountered, it is unlikely that ambient air pollution initiates directly acute or chronic disease, although that cannot be excluded. It is more likely that it will add to other causes already present as part of a multifactorial aetiology. Thus four main mechanisms are likely:

- Small transient effects reflecting defence reactions of the body to exposure
- Exacerbation of a pre-existing condition
- Contribution to other causes of chronic disease
- Increased risk of certain cancers.

The Health Council of the Netherlands concluded in 1999 that there is sufficient evidence for a variety of health effects from respectively acute and chronic exposure to air pollutants that are listed in Table 3.[5] Most of the evidence has been gathered in epidemiological studies and is supported by laboratory studies.

*Table 3 Overview of reported health effects related to acute exposure (episode) or chronic exposure to air pollutants for which 'sufficient scientific evidence' is available.*

| Response | Severity[1] | Number affected[2] |
|---|---|---|
| premature death (response after an episode in susceptible groups) | *** | * |
| aggravation of respiratory and cardiovascular disorders after an episode (resulting in hospital admissions) | *** | * |
| affected lung function after an episode | * | ? |
| premature death (decrease in life expectancy) due to chronic exposure | *** | * |
| reduced lung function due to chronic exposure | ** | ** |
| increase in chronic respiratory conditions (bronchitis) due to chronic exposure | ** | ** |
| odour annoyance from chronic exposure | * | *** |

1 * = slight, ** = moderate, *** = severe

2 * = susceptible individuals, ** = specific subgroups, *** = substantial part of exposed population

## 4.3 Odour

Table 3 also refers to odour annoyance due to chronic exposure to air pollutants. This effect is reported to occur among the population in the vicinity of large airports and ascribed by the subjects to aircraft activities. The volatile organic compounds (VOC) in unburned and burned aviation fuel appear to be responsible for the odour annoyance in the vicinity of the airport. In a Dutch survey in the year 1999 it was estimated that 36 000 people living near Amsterdam Airport Schiphol airport are annoyed by odour from air transport.[17,39] Not only close to the airport but also further away from the airport, annoyance due to odour was reported. The human sense of smell is quite well developed, but chemical assessment of odour is difficult.

Environmental odours in general have been shown to be associated with psychological and somatic symptoms.[40,41] In surveys on odour annoyance around industrial complexes, people reported gastric troubles, retching, nausea, and vomiting.[42] The question is to what extent these outcomes could be extrapolated to airports. No studies have been done in this field around airports. At present, the evidence for a causal relation between odour annoyance due to airports and somatic complaints is inadequate.[5]

## 4.4 Non-major air pollutants

In discussions about the health impact of airports, more specifically the contributions of aircraft operations, the possibility of cancer induced by exposure to fuel additives or incomplete combustion is often mentioned. An example provides a study at O'Hare International Airport that found a large variety of volatile organic compounds and observed increased concentrations of 78 out of 219 compounds detected in aircraft exhaust at downwind locations (Table 4).[43] However, epidemiological studies around airport do not provide evidence for increased cancer incidence.[44] Besides observed levels of VOC and PAH concentrations and PM mutagenic activity were similar to city levels.[45] The Health Council of the Netherlands concluded that there are no convincing indications that air pollution in the vicinity of an airport causes extra health risks as compared to other urban areas.[5]

*Table 4 Volatile organic compounds found at increased levels downwind of O'Hare International Airport*

| Compounds | | |
|---|---|---|
| Propane+Propene | Chloromethane | Isobutane+Acetaldehyde |
| Butene+IsoButene | Butane | Acetonitrile |
| Acrolein | Isopentane | Acetone |
| IsoPropanol | Pentane | Methylene Chloride |
| C5H10 Alkane | Carbon Disulfide | 2-Methylpropane |
| Trichlorotrifluoroethane | Methacrolein | 2,3-Dimethylbutane |
| 2-Methylpentane | Butanol | 2-Butanone |
| 3-Methylpentane | 2-Methyl-Furan | 2-Methyl-1-Propanol |
| Methylcyclopentane | 2,4-Dimethylpentane | n-Butanol |
| Benzene | Carbon Tetrachloride | 2-Methylhexane |
| 2,3-Dimethylpentane | Pentanal | 3-Methylhexane |
| Trichloroethane | Iso-Octane | n-Heptane |

| | | |
|---|---|---|
| 4-Methyl-2-Pentanone, | Methylcyclohexane | C8H18 Compounds |
| Toluene | 2-Hexanone | Hexanal |
| 2,4-Dimethyl-3-Pentanone | n-Octane | Unidentified Compounds |
| Ethylbenzene | m- & p-Xylene | Cyclohexanone |
| Heptanol | Styrene | o-Xylene |
| Butoxyethanol | n-Nonane | alpha-Pinene |
| Benzaldehyde+2-Ethylhexane | 3-Ethyltoluene | 4-Ethyltoluene |
| 1,3,5-Trimethylbenzene | Octanol | 1,2,4-Trimethylbenzene |
| n-Decane | C8H14O Aldehyde | Acetophenone |
| C10H14 Aromatic | C11H24 Alkane | Octamethylcyclotetrasiloxane |
| Nonanal | n-Undecane | C9H16O Aldehyde |
| Naphthalene | n-Dodecane | n-Tridecane |

A crucial factor in the case of air pollution is the combination of the effects of individual substances. First the concentrations of the different air pollutants are not all independent and secondly, in view of health effects, interaction may also play a role. This combinatory effect and the identified need for information about concentrations during episodes of increased pollution makes the information requirements different than those for noise.

For carcinogenic substances the cancer risk can be assessed by a procedure recommended by the US EPA.[46] For non-carcinogenic substances a possible measure related to their harmfulness is the hazard index, developed by US EPA.[47] In fact its value is the quotient of the intake dose (as a measure of exposure) and reference dose (RfD) used as the criterion of maximum tolerable intake.

The effects of the subgroup of irritating substances are primarily related to the exposure concentration and not to the cumulative intake (dose). It appears that the average daily concentration adjusted by the lung ventilation and duration of exposure could be a good measure of their harmfulness.

# 5 Other health effects

Noise and air pollution are not the only ways by which airports affect human health. An important additional route is through a reduction, or a perceived reduction of external safety. Also, quality of living may be affected in a positive or negative way by the changes in land use. Some of these health effects, that are often disregarded, are briefly discussed in this chapter.

## 5.1 Accident risk

'External safety' or 'third party safety' refers to the risk of accidents at or in the neighbourhood of the airport for people and property not directly involved in the risky activity. Examples of accidents are aircraft crashes during take-off and landing, accidents at the gate during refuelling, accidents at the airport like fire in the arrival and departure terminals, and terrorist actions. Accident risk can be described from various perspectives. For example, individual risk relates to the additional probability of death or injury due to an accident, while societal risk refers to the probability of at least a certain number of people dying at the same time because of an accident.

Two out of three airplane crashes occur during departure and arrival. Estimation of the risk belonging to these kinds of accidents includes three main steps, to determine:

- the probability of the occurrence of the accident
- the geographical distribution of the accidents
- the consequences of the accident.

The consequences include the number of deaths and injuries, long-term health effects, economic losses of airports and the air companies concerned, and the social consequences of the accident (e.g. investigations, health care provision, court cases). Outside of the perimeter of large airports, the individual risk is generally less then one out of ten thousand people per year. At the airports themselves the individual risk may be higher.[5]

In terms of absolute numbers airplane crashes do not significantly influence mortality in the surrounding area of large airports. However, the perception of aircraft accidents can induce fear and influence the effects of other environmental factors, like noise annoyance.

The National Institute of Public Health and the Environment in the Netherlands (RIVM) and TNO Prevention and Health studied the risk perception of people living near Schiphol airport.[10,48] The results suggest that the level of airplane noise and the frequency of airplanes passing overhead are correlated with a whole range of emotional reactions. An increase in both level and frequency of noise goes hand in hand with increased fear for crashes, increased concern about the safety of living near an airport or even under the approach route. Fears and concerns decrease with increasing distance to the airport. However, the relationship between noise burden and risk perception is indirect, and thus, it is not possible to conclude that reduction of the noise burden will lessen safety concerns.

## 5.2 Land use and other quality of life aspects

The growth of airports and related infrastructure and economic activity leads to a change in land use and thus to a change in the physical (and sometimes social) surroundings of people's residences. How people perceive these changes is not well known. According to Marsman, quality of life can best be increased by improving the environmental characteristics of the area that are usually conceived as dissatisfiers. The maintenance and improvement of the positive aspects of the area come in second place.[49]

RIVM has also studied the housing conditions near Schiphol airport and the satisfaction that people derive from them. The housing conditions consist of two components: the quality of the house and the quality of the neighbourhood. The most unpleasant aspect of the neighbourhood is annoyance from the airport. Other unpleasant aspects are the amount of traffic in the neighbourhood, noise, and adverse environmental conditions. People's living conditions appear to be negatively correlated with the level of noise and positively correlated with the distance to the airport.[48] The net influence of the proximity of airports on living conditions is partly expressed in the amount that people are willing to pay for housing. Studies on the influence of noise on house prices found that an increase in the amount of noise of one dB(A) is likely to reduce house prices by 0.5 – 1.0 %.[50,51]

## 5.3 Dispersion of infectious diseases through air traffic

Air traffic increases the risk of transmitting infectious diseases, such as malaria and typhus, from one country to another. The people who run the highest risk are the travellers and their families; while the risks of directly contracting the disease for people living in the airport region are negligible. Such citizens might be infected through vectors that are imported by aircraft (so-called secondary cases) but epidemics are unlikely. Occasional outbreaks of airport malaria are reported, that occur when infected mosquitoes hitch a ride with aircraft and infect people in and around airports elsewhere. Some countries require treatment (disinfection) of aircraft with insecticides. If resistance against the compounds used increases, the efficacy of such treatment may decrease in the future. Such a situation may increase malaria prevalence around the world and increase the risk of infected vectors entering aircraft. The number of documented cases at this moment is small, but given the growth of air transport, airport authorities and airline companies should be vigilant.[5].

External safety and the dispersion of infectious diseases pose real but statistically minute threats to populations in airport regions. Nevertheless, people's perception of such threats can give rise to considerable concern and loss of quality of life. This may also be the case for the changes in land use and landscape that are associated with airport development.

A major airport is considered to be a driving force for the local and national economy, although the importance of such effects have been subject to controversies.[52] The prosperity of a population will affect health positively, but especially on a local scale this effect is at present impossible to predict.

# Part 2

## Monitoring airport developments: proposal for an indicator set

# 6 The challenge of monitoring airport development

Despite all uncertainties, the scientific literature offers a fairly good overview of the categories and seriousness of the impacts that large airport systems have on human health. Nevertheless, many questions remain unanswered. Currently, the aviation industry finds itself in a state of expansion. Particularly high is the development pace of the hubs in the global network of airports. All hubs together form the backbone of the global airline system. The function of the hub airports as transport nodes implies that these airports are characterised by large numbers of aircraft movements and a high proportion of transfer passengers.

The airports in Europe that are the subject of the present study are hub airports with the high growth rates mentioned. In many cases, large investments in infrastructure are needed to accommodate these growth rates. In the political debates surrounding these investments, public health considerations play an important role. These concerns are the ultimate reason for the present study. It aims at making a contribution to the development of a scientifically sound methodology for the monitoring of health impacts related to airport operations and airport development.

The relationship between human health and the activities in an airport operations system is complex. Economic forces determine the viability of the airport operations and the resources available to reduce human health risks. Profitable airport operations enable satisfying transportation needs and generate work and contribute to prosperity of the population in the airport vicinity of the population at large.

The economic gains of the aviation industry and the possibilities of reaching distant destinations may be beneficial for the quality of life of travellers, but at the same time, the health and quality of life of people living and working at or in the vicinity of the major airports are also negatively affected. As outlined in Chapter 2, large airports are at the core of a great range of activities, that individually or in combination have major impacts both at local and at wider levels. The airport operations entail noise and chemical emissions, an industrial environment replaces the natural environment and waste is being generated. All these impacts directly or indirectly influence human health and quality of life. The complexity of the airport operations system, also given the differing goals of the participants in the system (see Chapter 2), is such that public health will not automatically be safeguarded. Economic, institutional and regulatory factors are driving forces in the system, also with respect to public health. Apart from directly influencing public health and the health care system, these forces shape the physical environment, and determine the level of safety and security.

A wide variety of people and organisations have a stake in airports, either as part of their operation and management, or because they are affected in some way by these activities. These stakeholders need a wide variety of information, for example to help develop policies on airports and air transport, to guide the management and monitor the operation of airports, or to assess their economic, environmental and social effects.

In the study reported here, we have focused on the health impacts of airports that change according to the development of airport systems. The development of airports should be interpreted in a broad sense, so not just in terms of passengers and flights, but also in terms of qualitative changes. For example, large changes in airport facilities can be expected when an airport changes from a 'point to point' airport with few transfer passengers to a 'hub' with many transfer passengers.

Monitoring the development of airports and their health effects aims at providing stakeholders with timely and valuable information that they can use to keep an eye on the developments and to base their decisions on. Simple as it may sound, devising a monitoring system is not easy, because difficulties arise on many different levels.

Firstly, there should be agreement about what to monitor. Virtually endless lists of health effects can be compiled, but using them all as indicators would be of little practical use for policy makers, so a selection must be made. Furthermore, the concept of the airport operations system (Section 10.2) must be made operational. There must be some agreement about the relevant system, i.e. the population, infrastructure and economic activity, to consider and thus, some decision must be reached about the precise geographical area that the airport system comprises.

Secondly, the information itself is diverse, and may not be easy to obtain. Details of airport performance, for example, may be subject to commercial confidentiality; indirect and intangible impacts on the environment or communities may be difficult to observe or measure. Also, considerable time lags tend to exist between exposure to some stressor and the resulting health effect.

Thirdly, the information needs to be communicated to, interpretable by, and of relevance to a wide diversity of users. Though these may share a common interest in airports, they may share very little in terms of their expertise, responsibilities, specific concerns or 'language'. Providing information in a way that does not, implicitly, empower certain stakeholders or support certain interests, yet deny others, is therefore problematic.

Despite all these difficulties, there is a large public interest in monitoring the health effects of airport development. The way forward that is chosen in this study is to identify indicators for monitoring and to develop a framework for indicator selection. In Chapter 7 the concept of indicators is discussed, while in Chapter 8 a framework is put forward for the selection of indicators. This framework is applied to airport systems in Chapter 10.

# 7 Indicators: potential and pitfalls

## 7.1 Overview

Although the concept and use of indicators has a long history (in ecology, for example, the idea of 'indicator species' goes back at least seventy years), no generally agreed definition has yet emerged. The Organisation for Economic Co-operation and Development (OECD) defines an indicator as[53]

> A parameter (i.e. a property that is measured or observed), or a value derived from parameters, which points to, provides information about, describes the state of a phenomenon/ environment/ area, with a significance extending beyond that directly associated with a parameter value.

According to Rotmans and colleagues, indicators describe complex phenomena in a (quasi-) quantitative manner by simplifying them in such a way that communication is possible with specific user groups. The interpretation of the indicators by the user groups is principally 'normative': the indicator values are compared with a target or reference value.[54]

Considering specifically environmental health indicators, Corvalán and colleagues use the definition:[55]

> an expression of the link between environment and health, targeted at an issue of specific policy or management concern and presented in a form which facilitates interpretation for effective decision-making.

For various reasons, none of these definitions are wholly satisfactory—in part, perhaps, because there are few synonyms available which succinctly define it, and in part because different concepts of indicators have developed in different disciplines. Confusion inherent in these definitions is whether the indicator refers to the measured or imputed values, or to the variables to which these values relate, or to the linkage that they represent. A further confusion is often between the indicator and the issue or situation it is intended to represent.

In order to avoid some of these confusions, the following definition is proposed here:

> an indicator comprises a characteristic or condition which can be described or measured in a way which provides information about some other characteristic or condition which is, itself, not amenable to direct observation or measurement.

Stated simply, therefore, indicators are things that indicate something of interest to the user. A first step that needs to be taken is therefore to reach agreement on what the indicators should report about. This discussion should involve all relevant stakeholders to ensure that they 'own' the resulting indicators. The design of the 'story' involves the description of the stakeholders view on the problem and how they think it should be solved.

## 7.2 A typology of indicators

The European Environmental Agency uses a typology of questions that helps in choosing indicators so that they are most relevant to the user.[56] This typology is depicted in Table 5.

*Table 5 A typology of questions and indicators*

| | Type of question | Type of indicator |
|---|---|---|
| 1 | How are the pressures on health and the quality of health developing? | Descriptive indicator |
| 2 | Is that relevant? | Performance indicator |
| 3 | Have we become more efficient in our economic processes? | Efficiency indicator |
| 4 | What has been the effect of policies? | Policy-effectiveness indicator |
| 5 | Are we on the whole better off? | Welfare indicator |

A first category of indicators answers the question: *How are the pressures on health and the quality of health developing?* These are called *descriptive indicators*, and are usually presented as a line diagram showing the development of a variable over time.

A second category of indicators answers the follow-up question: *and is that relevant?* These are *performance indicators*. Generally these indicators use the same variables as descriptive indicators but are connected with target values. The indicators linked to targets of international conventions or national action plans are examples of performance indicators.

The third category comprises *efficiency indicators*. These answer the question: *have we become more efficient in our economic processes?* Efficiency indicators can be represented as separate lines for the development of an (economic) activity and for environmental pressures.

To answer the question: *what has been the effect of policy?*, a fourth category of indicators has been developed: *policy-effectiveness indicators*. Policy effectiveness indicators show the results of the analysis why an indicator is developing in a certain direction. This kind of indicator makes clear what has been the influence of structural changes in the economy or in production processes, and of decision-making.

Finally a fifth category of *welfare indicators* is connected with the question: *and are we on the whole better off?*, which asks for a balance between economic, social and environmental progress.

Thinking in terms of questions to be answered, and trying to identify the proper questions for solving problems helps in identifying the most suitable indicators. Systematising these questions helps in getting a balance in indicator sets.

In this study we have focused on the first two types of indicators: descriptive and performance indicators. We do not aim for developing overall welfare indicators, nor indicators for policy evaluation. Neither is our primary focus directed to monitoring the relative health effects of airport activities. Rather, our aim is to develop a set of indicators to monitor the state of health, if so desired relative to some policy target.

## 7.3 Precepts and principles

The indicator definition proposed above leads on to a number of important precepts, which help to explain more clearly the role of indicators, and forms a basis for identifying criteria for indicator selection and design.

A number of criteria must be met for an indicator to be useful. Three clusters of criteria that are mentioned in the scientific literature are discussed below.

### *7.3.1 Indicators must be interpretable*

The first principle derives very explicitly from the definition. Indicators must be interpretable—or, to express this in a more pithy way, indicators must indicate! More specifically, they must indicate something about a characteristic or condition that is otherwise not directly measurable. This implies that some form of association exists between the indicator and the characteristic or condition of interest. (Unfortunately, there is no ideal term for this 'characteristic or condition of interest', but we can usefully refer to it as the 'target condition'). Moreover, this association must be known sufficiently well for the indicator to be 'read' correctly. It must therefore be evidenced either by research, or evident from logic and first principles. Variations or changes in the indicator must also reflect changes or variations in the target. The association must therefore be consistent across the range of conditions that the indicator describes.

Devising indicators that satisfy this first principle is far from easy, because the world is complex and highly interdependent. Simple, one-to-one relationships therefore rarely exist, and most relationships we observe are confounded to some extent by other, often unseen interactions and effects. In the area of environmental health, this is perhaps most crucially illustrated by the confounding effects of socio-economic factors. Many—possibly nearly all—associations between environment and health are subject to socio-economic confounding, for the simple reason that exposures to environmental hazards (e.g. pollution), and to hazards from lifestyle (e.g. diet, drugs) are to some extent determined by factors such as age, gender, affluence and education (cf. Figure 1). Commonly, for example, more deprived people tend to live in more polluted areas; they also tend to have less access to the means to avoid or mitigate these exposures. At the same time, deprived people may also be more vulnerable to illness, because of other risk factors, such as smoking, poor diet or exposures to indoor pollution (e.g. from cooking fuels). Unravelling the effects of environmental exposures from the direct and indirect risks of deprivation is therefore difficult. Yet if these confounding effects are not considered, the indicator can easily be misinterpreted. What may seem like an indication of health effects of air pollution, for example, might in reality be partly or wholly the effect of deprivation.

Many associations are also non-linear, so that changes in the indicator do not always indicate proportional changes in the target condition. Thresholds may exist, for instance, so that step changes occur in the target condition for small increments of change in the indicator. Effects of noise on health may be of this form, as are many ecological impacts (e.g. of air pollution on plant growth), both of which have negligible effects below certain thresholds.

Associations between indicators and the target conditions they refer to can take several forms. Four main types of association can usefully be recognised:

- Causal—indicator and target are linked because one causes the other. For example, traffic accidents are a good indicator of injuries from road traffic because the former cause the latter.
- Contingent—indicator and target are linked because one is a necessary precondition for the other. For example, road length is a good indicator of road traffic volumes, because roads are a precondition for road traffic.
- Statistical—indicator and target are linked by a statistical association. In this case, one does not cause or act as a precondition for the other, but the two tend to vary in broad harmony, often because both are related to some other, common factor, or because they are part of a complex web of association or co-existence. For example, levels of air pollution may be a good indicator of traffic noise (and vice versa), because they share a common source and have broadly similar patterns of dispersion in the environment.
- Component—indicator and target are linked because one represents a subcomponent of the other. For example, petrol consumption is a good indicator of overall fuel consumption in the transport sector, because petrol makes up a large proportion of fuel usage by mobile sources.

A way to solve questions of interpretability is trying to compare the indicator with standard or reference values that are presumed to be representative of ‘good health’. The problem with such an approach is that the discussion is shifted to the validity and meaning of the standard or reference value. Also, different stakeholders might prefer different standards depending on their societal outlook and short and long term interests. In the present study we will not follow this path where we might encounter more problems that solutions..

### *7.3.2 Indicators must be measurable*

The second precept to emerge from the definition above is that indicators must be describable or measurable. Clearly any indicator is only of value if it can be used; and it can only be used if it can be computed easily—certainly more easily than measuring the target condition itself. Again, this is a principle that many proposed indicators fail to satisfy, primarily because the data needed to construct them are not available, or the methods or models for applying the indicator are not well established. One common example of this is health indicators relating to morbidity. While these indicators can be seen as especially valuable, because they provide a more sensitive and earlier measure of health effects than do indicators of mortality, the reality is that routine data on morbidity are rarely collected, especially in more remote or less developed areas. As a result, relatively few successful morbidity indicators have been developed.

One implication of this precept is that a distinction needs to be drawn between the indicator itself and the detailed variable (or parameter or descriptor) used to measure it. In the context of airports, for instance, a basic indicator is likely to be the volume of air traffic. This indicator, however, can be defined and measured in a wide variety of ways: as the total number of aircraft movements, as the number of landings, as the total number of take-offs, or as the total capacity of the aircraft. (Each of these, it may be noted, begs further questions about how these terms should be defined. For example, what comprises a movement—does it include test runs and taxiing? Equally, how should capacity be measured? In many ways, defining indicators is a progressive chase after definitions of this type.) In order to avoid confusion, to ensure that indicators are used consistently, and to make sure that they are interpreted appropriately, it is clearly essential to have details on how each indicator is defined and computed.

As this discussion illustrates, lack of data cannot be solved by the use of indicators. What indicators can do is to use the available data to provide an insight into other issues or conditions, for which data cannot be obtained. On the other hand, nor does lack of data necessarily mean that the indicator should not be identified, for in many cases this can provoke those concerned to collect the data that the indicator needs. Indicators thus act as drivers for data collection as much as consumers of the data that exist.

Simple availability of data is also not enough. If the previous principle is to be satisfied—i.e. if consistent and interpretable associations are to be maintained between the indicator and the target condition—then the data must also be accurate enough to enable changes in the target condition to be detected. In other words, the indicator must be sensitive to real variations in the target condition, and must not be blurred by errors, uncertainties, inconsistencies or gaps in the data used to apply it.

For the same reason, the scales of measurement are important. In principle, indicators need not be quantitative. However, if they are to be sensitive to change in the target condition, and are to be able to show subtle variations in this condition, then indicators need to be based on at least ordinal scales; nominal or binary scales are rarely sufficient.

### *7.3.3 Indicators must be useful*

A third principle that is implicit in the definition given above is that indicators must be of use to the user. Again, this principle may appear self-evident, for the very purpose of indicators is to convey information that would otherwise not be available. Nevertheless, it carries with it several important implications. The first is that indicators relate to issues: they address questions or concerns of the user. Unless that issue is known and is explicit, then the indicator will have little significance or use. Defining the issue that needs to be addressed is therefore the first essential step in selecting indicators. This, however, poses its own problems, for issues are themselves multi-dimensional, and the definition of any issue is likely to vary depending on the perspective of the user. In relation to airports, for example, issues might be defined in terms of their source, the agent by which they affect the environment, the environmental medium through which this impact operates, or their effect. Each of these may then be traced either backwards (towards to source) or forwards (towards the effects and consequences). Because of the many-to-many relationships involved, each will thus follow a different network of links, and result in a different definition of the issue of concern. Progressing forward from the issue of aircraft movements, for example, may lead to concerns about air pollution (of various sorts) noise, and their effects on human health (including cardio-respiratory health, cancers and hypertension), quality of life (e.g. sleep deprivation, anxiety, loss of tranquillity), and the environment (e.g. to wildlife and the landscape). Extending back from the issue of respiratory health leads to concerns about air pollution (of various types) and its sources not only in aircraft movements but also in road traffic and other activities associated with the airport. Any issue thus tends to comprise a tree-like structure of links, branching out from the specific start-point of concern. Indicators thus tend to be user specific. The reason for this is not only that different users have different needs, and may interpret and apply indicators in different ways, but also that different questions require different indicators, presented in different ways.

The use-specificity of indicators is an uncomfortable circumstance for a number of reasons. One consequence is that it is extremely difficult to develop a small set of general-purpose indicators that meet all needs. Some can certainly be designed: indicators of poverty or deprivation, of population density and growth, or of land use, for example, all have widespread relevance. Many of these are, however, relatively blunt measures: they give insight into the context of any problem, but they rarely provide a sensitive indicator of specific issues of concern. Thus, if the focus of concern is the effect of airport development on surrounding habitats, indicators are needed not just on general land use characteristics (e.g. the area of urban land), but on particular aspects of land use and land cover—for example, on the area of important habitats within 2 km of the airport, or the biodiversity of the habitats in the area around the airport, or the number of species threatened by airport expansion.

Ideally, indicators developed at the local level should feed into regional-scale indicators, and thence into those developed at national and international level, thereby providing a seamless cascade of information between the different levels—and a means of ready communication and consensus. In practice, this is difficult to achieve, since local users are likely to be concerned about different problems, and want them expressed in different ways. Furthermore, different users may read different messages from an indicator, and some potential users may simply gain nothing from a particular indicator, because it does not convey anything of obvious relevance. This is not to say that both vertical and horizontal linkage of indicators is not possible. Rather, the issue is that these means of translation need to be developed if indicators are to have meaning for all those concerned.

A further consequence of the use-specificity of indicators is multiplicity. Large numbers of indicators tend to arise, not only in response to new questions and new users, but also because any individual question may have many different facets and require a host of different indicators. One way of reducing this problem is to use composite or compound indicators. Rather than develop a separate indicator for each air pollutant, for example, it may be possible to derive a general index of air pollution that captures information on them all. Though this has the undoubted benefit of economy, it also poses challenges. One way or another, it requires that different pollutants can be combined into a single metric that still makes sense. In some cases—to address specific questions—this may be possible by giving weights to each of the components. Developing these weights, however, can be exceptionally difficult. For example, the risks of cancer from different air pollutants, even acting individually, are still only poorly known; their effects in combination are highly uncertain. Thus it may not be clear either which pollutants should be included in such an index, nor how to combine them; yet both of these decisions will directly and fundamentally determine the message which the indicator conveys.

By the same token, interpreting compound indicators can be extremely difficult, since any pattern or trend that they show cannot easily be traced back to its source. Moreover, different compound indicators may still be needed to address different questions—so even the benefit of economy is not always assured. However, aggregated environmental exposure indicators might facilitate the comparison of various airport health impacts.[57]

### *7.3.4 Criteria*

From the previous discussion it is evident that the selection and design of good indicators is not a simple task. Therefore, it is useful to identify a set of clear criteria for indicator selection and design. The precepts set out above provide a basis for defining these criteria: they emphasise the need for interpretability, measurability and utility. Many other studies, however, have attempted to define criteria for good indicators, especially in the areas of environment and environmental health.[53,55,58,59,60,61,62] The many lists of criteria that have been developed share a number of common issues, but they also differ considerably, partly because they are devised at different conceptual levels, for different types of indicators and for different audiences. Nevertheless, in general terms, the precepts outlined above, together with results from previous studies, do suggest a number of core criteria for good indicator selection and design (see Table 6). It needs to be noted that they are not all necessarily achievable in every case and that they apply not just to individual indicators, but also to the indicator set as a whole.

*Table 6 Criteria for effective indicator sets.*

| Precept | Criterion |
|---|---|
| Interpretability | *Scientifically credible*—i.e. based on known or strongly suspected relationships between what is being measured (the indicators) and what they are intended to represent (the target conditions)<br>*Sensitive*—i.e. responsive to changes in the target conditions (and thus specific to those target conditions and reasonably unconfounded)<br>*Consistent*—i.e. providing a coherent message (different indicators are not contradictory)<br>*Transparent*—i.e. computed using a clear and explicit methodology (which can thus be repeated if necessary)<br>*Understandable*—i.e. expressed in a way which can be easily and consistently understood by the user |
| Measurability | *Available*—i.e. based on data that are already available or obtainable within an acceptable delay and cost<br>*Timely*—i.e. available soon after the event or period to which it relates<br>*Spatially accurate*—i.e. at a sufficiently high resolution to show geographic variations in the target condition<br>*Robust*—i.e. unaffected by minor variations in the data source or method of computation |
| Utility | *Relevant and pertinent*—i.e. related to an issue of current or future concern to the user<br>*Exclusive*—i.e. without unnecessary duplication<br>*Comprehensive*—i.e. covering the whole area, time period and issue of concern<br>*Cost-effective*—i.e. providing information which merits the costs of implementation |

This table excludes some criteria that have been proposed by previous studies. One of these is the existence of a threshold or reference value against which the indicator can be compared.[53] The argument in favour of this criterion is that it can help to recognise progress or to interpret the meaning of indicator values. The argument against is that few issues of interest can be adequately expressed by indicators that meet this criterion, and in any case the thresholds and target values may themselves vary in response to changing policies or differences in attitude, expectations and knowledge. In many cases, thresholds are rather arbitrary from a scientific point of view, but in some other cases thresholds with a scientific significance do seem to be available.

# 8 Indicators: frameworks for selection

No single indicator, however well designed and constructed, is likely to tell all there is to know, or all that needs to be known, about any issue. Instead, as has been seen above, several different indicators need to be developed to address specific questions, and to meet the needs of different users. Many policy-relevant issues are complex and multifaceted, and thus they need to be unpacked in order to identify unambiguously the various facets, and to specify those for which of them indicators are needed.

Given the virtually unlimited number of potential indicators, coherent methodologies of indicator selection are indispensable to make this selection a structured process. A number of such frameworks have been proposed. The three influential ones that we discuss below each use a different typology to categorise indicators, based on the driving forces-pressure-state-impact-response chain of cause-effect relationship, on capital forms and on stocks & flows respectively. Finally, a less structured tool called mindmap is discussed.

## 8.1 The PSR framework and its derivatives

One of the first frameworks was the so-called Pressure-State-Response (PSR) model devised by the US Environmental Protection Agency (US EPA) and initially applied by OECD as a basis for state-of-the-environment reporting.[53] This framework is founded on the principle that effects on the environment arise largely as a result of human activities, and that policy and other actions are taken as a response to these effects. Thus, the *Pressure* component identifies the processes and factors that impact on the environment; the *State* component identifies the effects for the environment; and the *Response* component identifies the actions taken to mitigate or otherwise intervene in these effects. Figure 4 presents a way of applying the framework to an airport operations system.

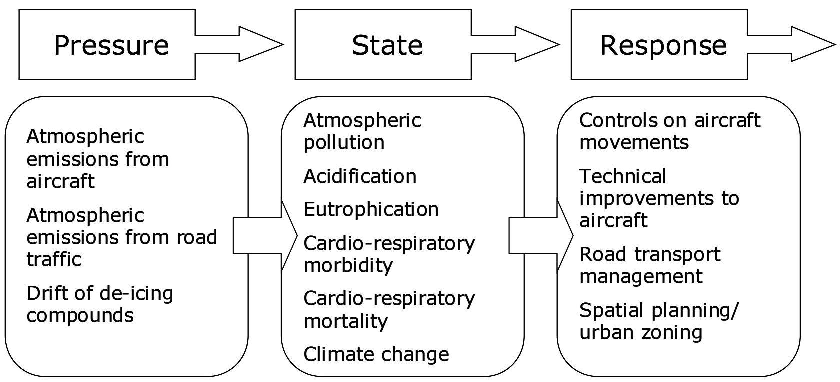


*Figure 4 The Pressure-State-Response framework: air pollution from airports.*

The PSR framework has been widely adopted both for state-of-environment reporting and for indicator development.[63,64,65] It does, however, have a number of important shortcomings. One of these is that, in its original form, it failed to recognise the complexity of factors causing pressures on the environment. These included not only immediate human actions (e.g. releases of pollutants into the environment) but also many more indirect and remote factors, such as the level of industrial activity, or traffic flows). In the same way, the framework can be criticised because the *State* component does not effectively distinguish the immediate effects on the environment from the longer-term effects, or from the wider non-environmental effects (e.g. on health). More fundamentally, the highly linear structure of the framework fails to make explicit the very interactive and reiterative nature of the processes involved. For example, the pressures acting to affect the state of the environment are themselves influenced by that state, through feedback processes.

Because of the dissatisfaction with the PSR framework, especially when applied outside the specific environmental field (e.g. to issues of sustainability or environmental health), various adaptations to the initial model have been made. The OECD subdivided the Pressure component to include both direct and indirect pressures.[53] The US EPA also extended the framework to include a component defining the more remote, upstream influences—the Driving Forces.[66] In adopting a framework for environmental policy and state of environment reporting, the European Union (EU) incorporated a component for Impacts, in order to take account of some of the downstream and longer-term effects, thus creating the DPSIR (Driving Force-Pressure-State-Impact-Response) framework (Figure 5).[56]

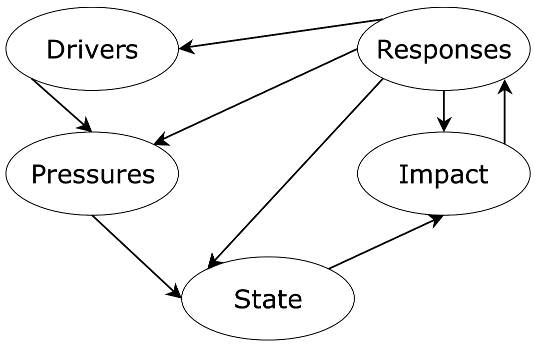


*Figure 5 DPSIR framework.*[56]

Concurrently, in translating this into the area of environmental health, the World Health Organization (WHO) made further adaptations and included links to define both Exposures and Health Effects.[55,67] The resulting DPSEEA (Driving Force-Pressure-State-Exposure-Effect-Action) framework also recognises that actions take place at different points in this chain (Figure 6). This framework has now been widely adopted in WHO as a basis for developing and reporting environmental health indicators.[68,69] A similar model, albeit using rather different terminology, has been adopted by the US Centers for Disease Control (CDC). Environment Canada and Health Canada have also applied the DPSEEA model as a basis from which to develop environmental health indicators.[70].

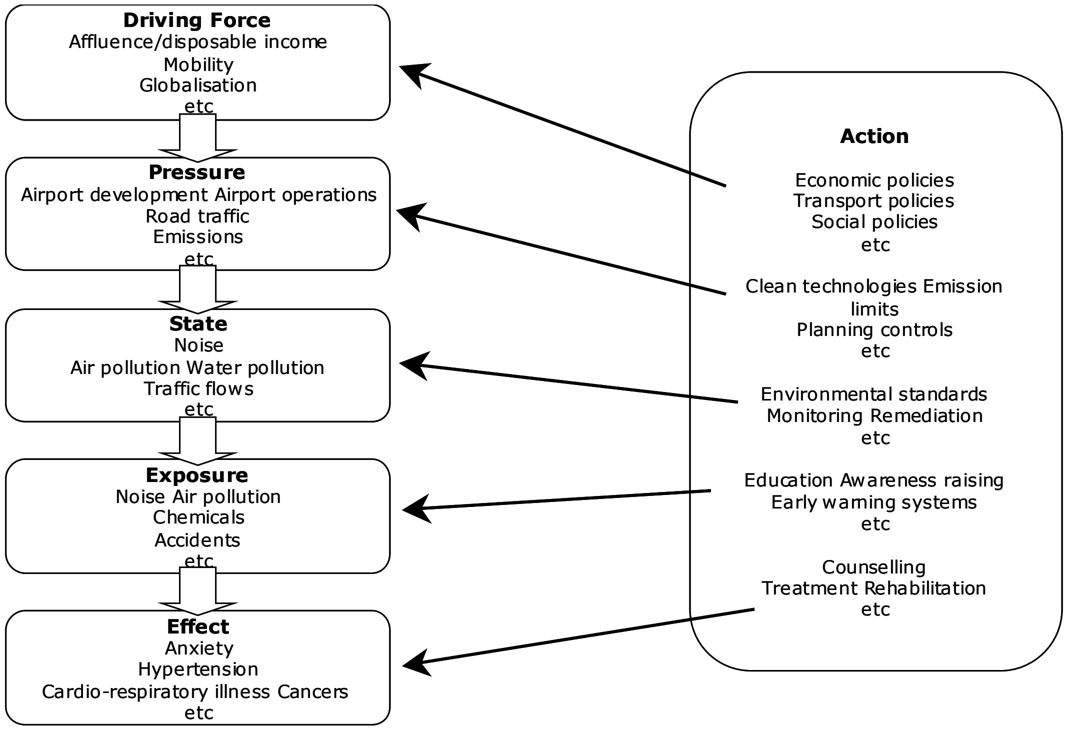


*Figure 6 The DPSEEA framework.*

Whilst the DPSIR and DPSEEA frameworks have helped to resolve many of the inherent limitations of the PSR model, a number of problems nevertheless remain. A drawback of the DPSIR-framework is the level of ambiguity associated with classifying phenomena and their indicators. Depending on the focus of attention or perspective taken, a phenomenon can take on different roles in the causal chain. For example, the clearing of forestland for agriculture may be identified as a pressure when studying biodiversity, and as a response when studying rural poverty.

Some of the more fundamental ones are related to the fact that the frameworks were developed to accommodate causal chains in the physical sphere. Causal chains in the social and economic domains tend to be even more complex and unpredictable. In principle, the frameworks can be further dimensioned to accommodate different scales and different settings. For example, the models can be extended to include more compartments, such as source activities and social effects. Forcing these into the essentially linear sequence implied by the DPSIR and DPSEEA chains, however, is difficult. So long as they represent generic and relatively rigid structures they are likely to be somewhat artificial and can lead to a contrived set of indicators, especially when applied to specific issues. No single organising framework will be appropriate in all circumstances. Instead, a specific model needs to be formulated for each issue.

## 8.2 Capital forms

Various international organisations use an indicator framework that consists of four capital forms: social, economic, environmental or ecological, and institutional.[71,72,73] This approach that sprang from the concern about the dominant position of economic capital in decision-making, emphasises the equal importance of all four capital forms, independently of the availability of quantitative data. Nevertheless, the institutional capital form has not yet been sufficiently fleshed out in the international literature on indicators.[54,74]

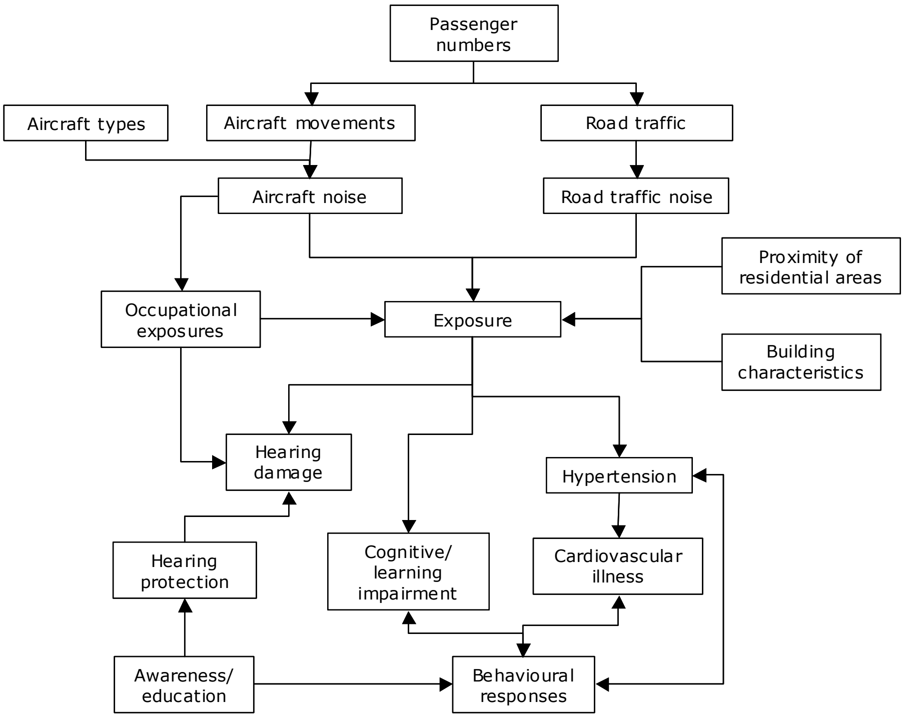


*Figure 7 Systems approach to analyse the relationships between noise and health for an airport operations system.*

Thinking in terms of capital forms is closely related to the systems approach that aims at describing an issue in terms of relevant entities and their relationships. Within the systems model different structures can be adopted according to the system concept and perspective adopted.[75] In developing indicators, however, one of the most useful approaches is to consider the airport operations system (the airport and its zone of influence) as a form of process-response system—i.e. one in which the activities associated with the airport lead to a range of effects and responses in the environment and society (see Figure 7). These operate through a variety of pathways (e.g. via energy, material and information flows), and impact on different parts of the system (e.g. different environmental media, human health, quality of life). Indicators may thus be developed to describe key links or flows, and key nodes or states, within this system.

## 8.3 Stocks and flows

Building upon the systems approach, authors such as Rotmans[76] stress the importance of including both flow and stock indicators, in response to the dominance of flow indicators in most studies. Stock indicators represent the state of a system at a particular moment in time, while flows refer to the rate of change and are thus measured over a period of time. Usually, stock levels change only slowly, so that they can often be assumed to remain constant in the short term. However, in the long run, stocks can change drastically, both in a quantitative and in a qualitative sense. In turn, this can have an important effect on the performance of the system and on the volume of the flows. For example, the technical state of a house may be considered as given in the short term, and for a house in excellent conditions it may appear a useless indicator for monitoring the living conditions of its inhabitants. Rather, attention would be focused on flows such as the electricity bill or the amount of rent that is paid. However, in the longer term, the condition of the house may deteriorate significantly and become one of the major determinants of the living conditions.

For issues that have a long-term scope, a thorough understanding of developments of both stocks and flows is necessary, because each contains unique information: flow indicators highlight short-term changes, while stock indicators do so for long-term changes.

## 8.4 Mindmap

The mindmap is constructed by defining, as its focus, the issue of interest. Links are then traced outwards to factors that are part of, associated with or derive from this issue. Both the strength and the weakness of the mindmap is its relatively unstructured form; this allows it to be freely adapted to any situation. It may, for example, take as its starting point some aspect of airport operation and bifurcate outwards to different impacts on the environment, health and society; or to local, then regional and then wider effects. Or it may focus on one specific outcome, and follow these outwards to its various causes and sources. In either case, indicators can be devised to represent the key elements identified in the mind map. On the other hand, this very lack of predetermined form also means that the mindmap can be used more or less effectively; without care, it may miss crucial links and issues, and can become repetitive and confusing.

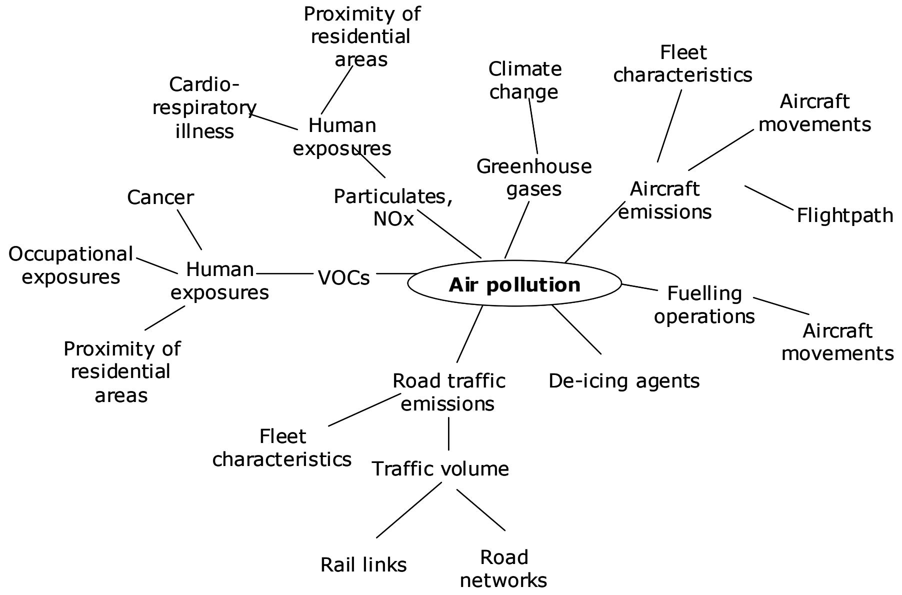


*Figure 8 Mindmap for air pollution in an airport operations system.*

## 8.5 Conclusion

In this chapter, several frameworks were discussed to structure the process of indicator selection. The PSR and related approaches provide a useful way for structuring the analysis in terms of cause and effects. However, their linear character makes them less suitable for issues such as the health impacts of large airport systems, because these are dominated by confounding and accumulation effects. Therefore, we propose to use the less linear, but still structured systems framework to compose our indicator set. In the next chapter, the systems framework is applied to the main categories of airport-related health effects.

# 9 Systems representations of the major health issues

As indicated in Chapter 8, systems models are convenient for systematically analysing causal relationships between airport system activities and health effects, as well as the interactions and feedbacks that may exist between the various health themes. An advantage of the systems approach is that we can build upon the research performed along the lines of the PSR and related frameworks. The chains of cause and effect that are central to these latter approaches can be accommodated in the systems framework in a straightforward way, while avoiding discussions about what exactly constitutes a pressure or a response.

In this chapter, systems models are developed for the four major health issues that were identified in Part I of this report. Both the dynamics of the airport systems and their main health impacts are assumed to be similar for most of the large European airports. Therefore, the systems models that are developed in the following sections are assumed to be generic. The systems models are used in Chapter 10 to guide the process of indicator selection.

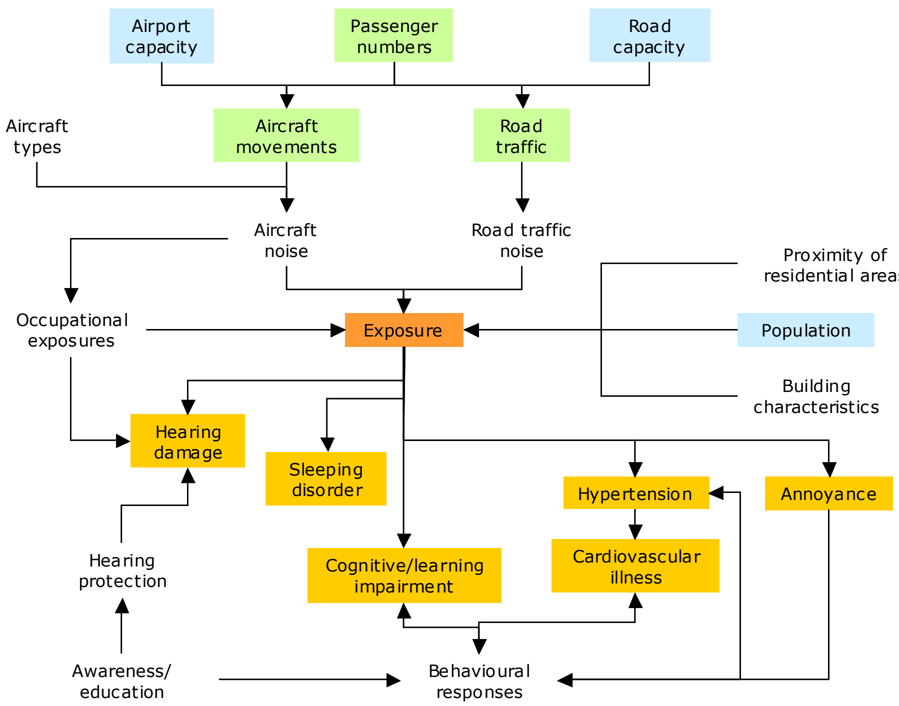


*Figure 9 A systems model for airport indicators: noise.*

## 9.1 Noise

In Chapter 3 a number of health effects caused by noise were identified that are well founded on scientific evidence. These included hypertension, ischemic heart diseases, severe annoyance, sleep disorder and reduced learning performance. Figure 9 is a systems representation of how these noise-related impacts are embedded in the broader airport system.

The figure emphasises the earlier comment that health impacts are the result of both exposure to stressors and behavioural responses. From a societal perspective exposure again has two components, being the stressor and the size and conditions of the affected population. In the case of large airport systems, the main sources of noise are air traffic and road traffic. How much noise the vehicles emit is in turn partly determined by the state of technology.

On the other end of the causal chain, the behavioural responses are influenced by awareness and education. Although this statement is relatively undisputed, there is little data about the precise chain of cause and effects underlying it (cf. [77]).

Considerably more knowledge is available on the stressor side. A central concept in this respect is exposure. The actual exposure to noise is the upshot of both slow and fast developments, i.e. of both stocks and flows. The human population in the airport region tends to be ‘slow moving’, just like the available infrastructure for air and road traffic. These variables do not tell much about the system’s development on a year-to-year basis, because the system’s variability may be larger than the change in stocks. However, they are crucial in assessing the airport system’s long-term developments.

In contrast, actual aircraft and car movements are typical flows, that are useful for monitoring short-term developments, but do not convey much information about structural changes. They are normally much more vulnerable to large fluctuations than stock variables. For example, the developments following ‘September 11th’ led to very substantial changes in air traffic in the short term, but the long-term changes may well be much smaller.

Although they are separate notions, stock and flow variables are highly interconnected. For example, the amount of traffic in a year is partly determined by the available fleets of vehicles and aircraft and the available infrastructure. In the same vein, the amount and quality of airport infrastructure is, in the long run, determined by short-term expenditures on maintenance and investments. Information on flows can indicate acute problems that need to be addressed, while information on stocks can provide information about long-term concerns that are important when making strategic decisions.

## 9.2 Air pollution and odour

In Chapter 4 we identified the main health effects related to air pollution for which sufficient scientific evidence is available. These effects can be clustered into four main groups. Acutely or chronically reduced lung functions form a cluster of impacts that are caused by air pollutants. These substances also cause acute or chronic bronchitis, sometimes leading to premature death or hospitalisation. There is also sufficient evidence to support the idea that air pollution may lead to acute asthma. Annoyance by smell is the last cluster of impacts that we distinguish. If this annoyance is chronic, it can cause somatic or psychosomatic disorders, although the evidence. There is insufficient evidence for an increased incidence of cancer in large airport systems, when compared to other urban areas.

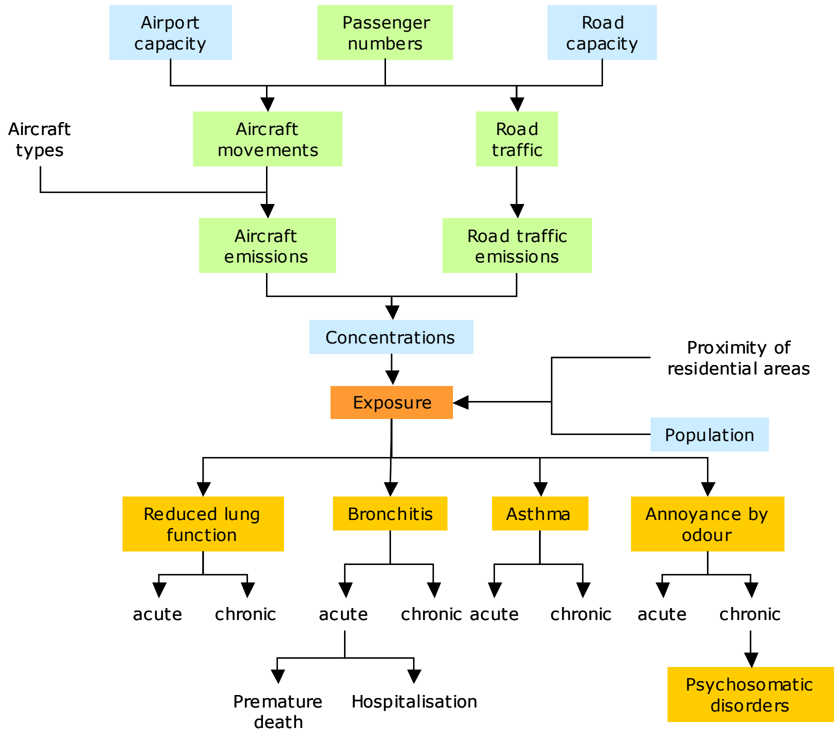


*Figure 10 A systems model for airport indicators: air pollution.*

Figure 10 is a graphical representation of the health impacts that are of interest and their relations with the emissions of air pollutants. As in the case of noise, health effects not only depend on the environmental stressor but also on the processing these stressors by the affected individuals. However, there are few clues whether these processing mechanisms are subject to change over time when a whole population is considered. In this report we therefore start from the assumption that the distribution of sensitivity to air pollution remains constant over time for a population as a whole.

The distinction that is made in the literature between acute and chronic effects poses additional requirements to the selection of indicators. The average emissions or concentrations of chemical substances may be of most interest for the chronic effects, but for the acute problems peak emissions are the relevant factor.

## 9.3 External safety

From the overview in Chapter 5, we know that the health problems associated with external safety are largely related to risk perception by the people living around large airports. The probability of an aircraft accident is very small and the risk of anybody on the ground getting hurt by a crash is remote. To many people, overflying aircraft provoke feelings of anxiety. If such feelings occur on a sustained basis, they can give rise to health problems of a psychosomatic nature. Aircraft noise can trigger feelings of fear and can thus contribute to these health problems.

Figure 11 depicts a systems representation of the health problems related to external safety, including both the statistical health risk and the perceived risk. The calculated risk is mainly determined by the number of aircraft movements, the pertinent flight paths, and the number of people living in the area around the airport in general and under the flight paths in particular. The risk of an accident is still decreasing for new generations of aircraft, although the rate of this improvement is relatively slow. If no major technological breakthrough is achieved, the statistical risk can be assumed to be a function of the number of aircraft movements.

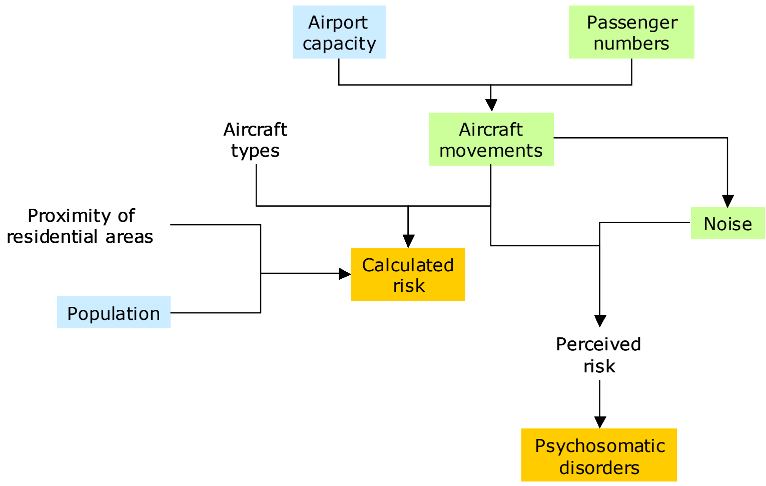


*Figure 11 A systems model for airport indicators: external safety*

The perception of external safety issues is not easily monitored. The most obvious way of monitoring perceptions is directly eliciting them from the affected population. Disadvantages of such an approach are that it is relatively costly and that continuous monitoring is not possible. Another possibility is to take advantage of the known relationship between annoyance by noise and feelings of anxiety. It may be possible to make inferences about the incidence of such feelings from the indicators designed for noise.

## 9.4 Living conditions

The influence of living conditions on public health has so far not been explored systematically. Nevertheless, if this influence would turn out to be significant, it could be an important aspect of the health impacts of large airport operations systems. Infrastructure (roads, railways, etc.) and industrial development in airport operations systems occupy a lot of space and tend to change the landscape in a radical way. This changing landscape may in turn have an effect on the well being of people living in the affected area. Figure 12 offers a preliminary systems representation of this idea.

Because little is known about the relationship between changes in the physical environment and people's well being, at present the only way of monitoring living conditions is by directly asking those affected.

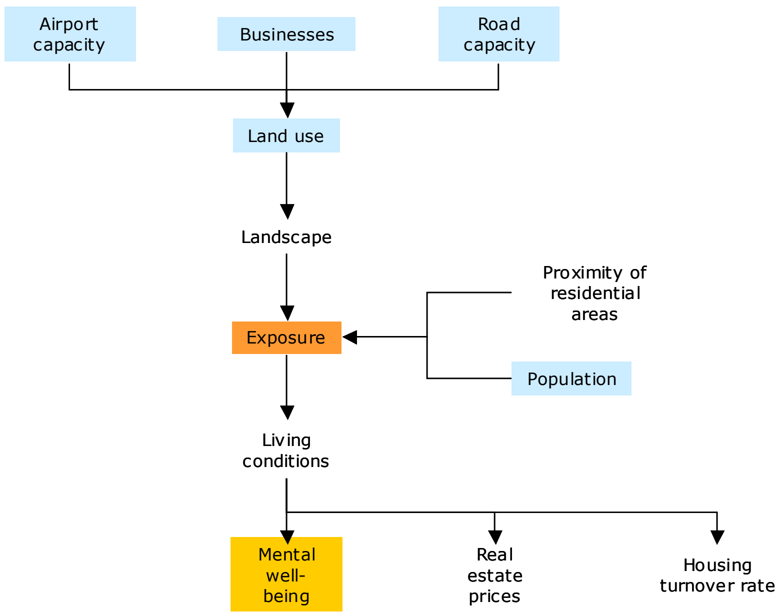


*Figure 12 A systems model for airport indicators: living conditions.*

An alternative approach would be to base inferences on the actual behaviour of people. The state of the physical environment is one of the elements on which people base their choice for a place of residence. Information about the housing market could thus indirectly convey some information about the judgment that people make about the quality of their physical environment. One way of going about this is to estimate the contribution of the environment to the housing prices in the area around the airport. This hedonic pricing method requires a great deal of data, however, and there is a substantial risk of missing important price determinants. Also suffering from this latter problem, but less data-intensive is taking the turnover rate of houses as an indicator. A high turnover rate might then indicate some dissatisfaction with the current living conditions.

# 10 Selecting indicators for airport systems

## 10.1 Overview

Table 7 presents an overview of the set of selected indicators. Below this choice is further explained.

*Table 7 Proposed indicator set.*

| Name | Definition | Comment |
|---|---|---|
| *Health indicators* | | |
| Complaints | Number of spontaneous complaints per year about noise and odour related to airport activities | No geographical restriction of complaints |
| Annoyance | Number of people highly annoyed by air traffic noise stratified to age (15-25, 25-60, 60+) | Based on periodic surveys, extrapolated to the airport operations system area |
| Cardiovascular disease | Prevalence of cardiovascular disease in the 45-65 age group | Based on periodic surveys and hospital data, extrapolated to the airport operations system area |
| Respiratory disease | Prevalence of respiratory disease in the 4-12 age group | Based on periodic surveys and hospital data, extrapolated to the airport operations system area |
| Sleep disturbance | Number of people highly sleep annoyed by air traffic noise stratified to age (15-25, 25-60, 60+) | Based on periodic surveys, extrapolated to the airport operations system area |
| *Emission/exposure indicators* | | |
| Aircraft noise | Fraction of population exposed to aircraft noise with Lden of <55, 55-60, >60 dB(A) | Based on measurements and model computations, extrapolated to the airport operations system area |
| Nighttime aircraft noise | Fraction of population exposed to aircraft noise with LAeq,23-7h of <40, 40-50, >50 dB(A) | Based on measurements and model computations, extrapolated to the airport operations system area |
| Particulates | Annual emissions of PM10 from air traffic, road traffic and other sources | Based on measurements and model computations, extrapolated to the airport operations system area |
| | Mean annual concentration of PM10 | Based on measurements; select points upwind and downwind near the airport and at the perimeter of the airport operations system not near a road traffic corridor or industrial area |
| Hydrocarbons | Annual emissions of gaseous hydrocarbons from air traffic, road traffic and other sources | Based on measurements and model computations, extrapolated to the airport operations system area |

| Name | Definition | Comment |
|---|---|---|
| | Mean annual concentration of gaseous hydrocarbons | Based on measurements; select points upwind and downwind near the airport and at the perimeter of the airport operations system not near a traffic corridor or industrial area |
| Nitrogen oxides | Annual emissions of nitrogen oxides (NOx) from air traffic, road traffic and other sources | Based on measurements and model computations, extrapolated to the airport operations system area |
| | Mean annual concentration of nitrogen oxide (NO2) | Based on measurements; select points upwind and downwind near the airport and at the perimeter of the airport operations system not near a traffic corridor or industrial area |
| *Throughput indicators* | | |
| Number of aircraft | Arriving and departing aircraft per year (scheduled flights, chartered flights and 'general aviation') | |
| Number of aircraft at night | Arriving and departing aircraft per year during 23-07 h (scheduled flights, chartered flights and 'general aviation') | |
| Passengers | Number of arriving and departing passengers per year | Transfer passengers are counted once |
| | Number of transfer passengers per year | |
| Freight and mail | Freight and mail loaded and unloaded per year (tons) | |
| Public transport | Fraction of passengers going to and from the airport using public transport | |
| Geography | Area of the airport | |

## 10.2 Airport operations system

Up to now the notion of 'airports operations system' has been loosely described as the zone of influence of the airport and airport related operations. However, when defining indicators it becomes essential also to define the system in a geographical sense. On the outset it should be clear that any such definition has some arbitrariness. Take for example a railway line with a stop at the airport terminal. Not all passengers get on or off at the airport terminal, but the capacity of the railway and the frequency of the trains will most certainly be determined to an important extent by the airport operations. At which distance from the airport is the 'influence of the airport' becoming unimportant?

We could not find criteria applicable in all cases to define the airport operations system. A decision has to be made in each specific case based on consensus between the primary users of the indicator set. As the indicators are targeted at the health of the population living in the surroundings of the airport one may use as a criterion the perception of the people of airport activities. As a more objective criterion the noise levels may be used, e.g. $L_{den}$ =55 dB(A). One may argue that air pollution and business developments will not follow the noise contours and therefore opt for a more airport independent approach by drawing a circle with, e.g., a 20 km radius around the airport. In view of interpretability and transparency of the indicator data both these suggestion might be modified to take account of boundaries between municipalities and city quarters. In the Heathrow case study both suggestions have been combined (see Section 11.4).

We propose that the primary users of the set of indicators use these considerations to define the airports operations system in a specific case and stick to that definition until experience with monitoring data necessitates changes. It should be stressed that the area of the system should not be made too big as far as indicator definition is concerned: not all residential areas where people may be affected by the airport and related operations, need to be included as that may lessen the sensitivity of various indicators. The indicator data should only be used (at least ideally) to 'indicate' changes in health impacts due to developments within the system. Such changes may lead to an in depth risk assessment and then all people 'at risk' have to be taken into account.

## 10.3 Process and indicator types

To arrive at the indicator set, we used the systems models from Chapter 9 as input for a discussion among an international group of scientists and stakeholder representatives. This discussion took place during a three-day workshop held in Baarn, the Netherlands, from 21-23 March 2002. The participant list is presented in Annex C.

As a first step we selected the issues thought to be most relevant to airport operations systems and for which indicators should be developed. Aircraft noise was identified as the issue most specifically related to airports, while road traffic noise, air pollution, safety and living conditions were deemed to be related to urbanised areas in general, but were nevertheless considered important. As a next step, using the systems models as guidelines a set of key indicators was obtained that was subsequently confronted with the criteria laid out in Chapter 7.

In the current project, two main questions play a central role: 1) how does the public health situation in the airport system develop and 2) how are these developments related to the activities in the airport operations system? This second question must be addressed if prognoses are to be made about the health impacts of development in the airport operations system.

Directly relating airport activities to health impacts is currently a bridge too far, as has been discussed above. To make progress in this direction further research into the relevant causal relationships is needed. As a workable compromise for the short term, we focus attention on the downstream segments of the causal chains for health monitoring (i.e. question 1) but propose to start monitoring upstream indicators to develop a track record for future efforts to establish a closer link between activities and health effects.

Based on these considerations and for convenience sake, three categories of indicators are distinguished:

- health indicators that directly reflect the public health status
- concentrations/emissions indicators that reflect the exposure of the population
- throughput indicators that reflect the development of the activities in the airport system.

For the second category, a clear distinction can be made between the issues of noise and air pollution, while for the other two categories, there is a significant amount of overlap. For example, the number of air movements has an impact on both noise and on air pollution (also from road traffic!), and annoyance can be caused by both noise and air pollution.

## 10.4 Health indicators

*Complaints*, *annoyance*, *cardiovascular disease, respiratory disease*, and *sleep disturbance* were selected as the health effects for which indicators should be developed. For other types of health effects or disease, e.g. carcinogenicity, the scientific basis was deemed to be insufficient to derive indicators that would satisfy the criteria.

### Complaints

Complaints could be considered as an indicator for dissatisfaction with the (residential) environment and has a relationship to annoyance and, self-reported health.

*Definition*

Number of spontaneous complaints per year about noise and odour related to airport activities.

*Notes*

The implementation of a complaint indicator is relatively straightforward: it requires a structure to register complaints. The basic idea is that people contact a special agency by phone, fax, e-mail or Internet when they are disturbed by noise or odour that they relate to airport operations. So, the indicator can be defined as the number of calls or the number individual callers to the special telephone number (depending on the implementation augmented by the number of e-mails, etc.). For the indicator we propose to simply use the total number of calls (complaints). This choice is not without problems as is illustrated by the following data from Amsterdam Airport Schiphol.[78] In 2000 the complaints office received 177 thousand complaints from somewhat over 15 thousand complainants. However, about 6 thousands complainants had more than 1 (21 on average) complaints per phone call or letter, i.e. 75% of the total number of complaints. Without further study, it is not clear which quantity is most relevant as an indicator. For that reason we choose the most simple one. In more in depth analyses the complaints may be split up into the number of individual complainants, time of the day, etc.

*Criteria*

The scientific credibility of complaint registration is disputed as its interpretation may produce biased results. For one thing, the complainants must be aware of the possibility and ways of complaining and this awareness should be relatively constant in the course of time. Furthermore, complaints seem to be more related to changes in noise or odour levels or to deviations from the expected noise or odour levels than they are to the actual noise or odour levels. Thus, some believe that complaints are a better indicator for awareness and short term changes than for long term noise or odour levels and related health effects.[79]

As complaints appear to react strongly to short term changes, the indicator complies with the sensitivity criterion. The same holds for consistency, because exposure indicators (number of flights, noise levels) will change in the same direction as the complaints indicator. As the methodology for registering complaints is rather straightforward, the criterion is also transparent and understandable. The measurability issues are of less importance for the complaints indicator, because it is 'complainant-driven': the measurement part boils down to accounting techniques. However, stability of the indicator requires a well-defined structure for addressing complaints and the maintenance of knowledge among the population about this structure. The major disputes regard interpretability: to which extent is an increased number of complaints an indicator for long term health effects?

*Complaints: summary (- difficult, 0 fair, + good)*

| Definition | Criterion | Score |
|---|---|---|
| Number of spontaneous complaints per year about noise and odour related to airport activities | Interpretability | - |
| | Measurability | 0 |
| | Utility | + |

### Annoyance

The goal of using an annoyance indicator is to get information about the number of people that are annoyed by aircraft noise generated in the airport operations system and of the extent of the annoyance.

*Definition*

Number of people highly annoyed by air traffic noise stratified to age (15-25, 25-60, 60+).

*Notes*

Information about annoyance is gathered through periodic surveys. Because of the costs of large scale surveys, annual telephone surveys might be performed with limited sample size stratified to noise level, supported by more in depth studies every five years using postal questionnaires to a larger sample and personal interviews. Questions (directed specifically at aircraft noise) and analysis should follow ISO-guidelines (in preparation).[80] The data in the form of the fraction of the population highly annoyed are to be stratified to age and extrapolated to the full residential population in the airport operations system.

*Criteria*

The indicator proposed is the sum of individual scores on annoyance scales. If one takes as a definition of noise annoyance “a feeling of resentment, displeasure, discomfort, dissatisfaction which occurs when noise interferes with someone’s thoughts, feelings or actual activities”[18] the question arises whether the individual answers can indeed be summed. At the present time its is impossible to solve this problem, but it implies some scientific problems with the interpretation of the indicator (one might call this measurability problem, but we prefer to list it under the interpretability criterion) .

Questions about considering annoyance to be a health effect (or a quality of life measure) in its own right, should not arise, unless the fraction of people highly annoyed due to aircraft noise is also dependent on non-airport related societal developments. Although this will to a certain extent be the case, given the importance of non-acoustical factors[77,81], this effect is expected to be less for specific annoyance due to aircraft noise than for general noise annoyance.

The indicator is extremely useful as aircraft noise annoyance is high on the political agenda in any discussion on airport development.

*Annoyance: summary (- difficult, 0 fair, + good)*

| Definition | Criterion | Score |
|---|---|---|
| Number of people highly annoyed by air traffic noise stratified to age (15-25, 25-60, 60+) | Interpretability | -/0 |
| | Measurability | 0 |
| | Utility | + |

## Cardiovascular disease

The goal of including a cardiovascular disease indicator is to monitor the prevalence of this type of disease in the airport operations system given its possible relationship with noise exposure and air pollution. It should be stressed that noise and air pollution are among a variety of factors causing and contributing to cardiovascular disease incidence.

*Definition*

Prevalence of cardiovascular diseases in the 45-65 age group.

*Notes*

This indicator should preferably be measured by surveys (using the approach proposed by annoyance) and using hospital data. In case both techniques are used the results should be reported separately. Survey questions can be taken from validated questionnaires; it does require some further study to select a concise set of questions to be used in the proposed annual telephone survey. Hospital registration data can be restricted to ICD9-codes 401 (essential hypertension), 410-414 (ischaemic heart disease), 427 (arrhythmias) and 430-438 (cerebrovascular diseases).[a]

*Criteria*

Here also, problems with respect to scientific credibility arise. Survey results reflect people's perception on their personal health status, which makes interpersonal comparison difficult. Nevertheless, self-reported health indicators are one of the few possibilities for a bottom-up assessment of the distribution and severity of health issues such as cardiovascular problems.

If surveys are performed periodically, trends in the public health situation may become apparent, indicating sensitivity. However, interpreting such trends will remain difficult, due to problems of scaling individual results to the community level and because of the many other factors influencing cardiovascular health status.

Further drawbacks of survey-based indicators are in the field of measurability. Those related to the survey data have been discussed under annoyance.

[a] ICD9: International Classification of Disease, 9th revision, originally published by the World Health Organization (WHO).

Hospital data may not be available with patients' addresses (for privacy reasons). The detail of the address code will also determine the specification of the airport operations system (if 4 digit codes are available one might choose the system to consist of a full number of 4 digit-areas).

The indicator scores high on transparency and comprehensibility but scientific credibility and sensitivity to changes pose reasons for concern. One reason for this are the non-airport related factors affecting disease incidence and prevalence. The other is the variety of conditions caused by environmental factors making people more vulnerable for manifest cardiovascular diseases. From a public health point of view the indicator should also be sensitive to the prevalence of those conditions but that relationship is quite uncertain and only qualitatively known.

To increase sensitivity and decrease costs, we propose to focus attention on subgroups. For cardiovascular disease the proposed 'marker group' is the age group of 45 to 65, that is considered to be most vulnerable for this type of disease.

*Cardiovascular and respiratory disease: summary (- difficult, 0 fair, + good)*

| Definition | Criterion | Score |
|---|---|---|
| | Interpretability | - |
| Prevalence of cardiovascular diseases in the 45-65 age group | Measurability | + |
| | Utility | + |

## Respiratory disease

The goal of adding a respiratory disease indicator is to monitor the prevalence of this type of disease in the airport operations system given its possible relationship with air pollution.

*Definition*

Prevalence of respiratory disease in the 4-12 age group.

*Notes*

This indicator should preferably be measured by surveys (using the approach proposed by annoyance) and using hospital data. In case both techniques are used the results should be reported separately. Survey questions can be taken from validated questionnaires; it does require some further study to select a concise set of questions to be used in the proposed annual telephone survey. Hospital registration data can be restricted to ICD9-codes 490-496 (obstructive lung diseases).

*Criteria*

In general the criteria discussion resembles that of the cardiovascular disease indicator. However, the relationship between air pollution and respiratory disease was better studied and exposure-response relationships have been published. Therefore interpretability is rated higher than in the cardiovascular case.

To increase sensitivity and decrease costs, we propose to focus attention on subgroups. Children are thought to be most vulnerable for respiratory disease, so that the age cohort 4-12 is selected as the 'marker group'. If changes are detected in the incidence of respiratory diseases among children, then a change in the situation of the overall population can be suspected.

*Respiratory disease: summary (- difficult, 0 fair, + good)*

| Definition | Criterion | Score |
|---|---|---|
| Prevalence of respiratory disease in the 4-12 age group | Interpretability | 0 |
| | Measurability | + |
| | Utility | + |

## Sleep disturbance

The main reason for including an indicator on sleep disturbance is to collect information about the number of people that are disturbed in their sleep because of airport-related activities at night, and about the severity of this disturbance. Sleep disturbance plays a prominent role in discussions on airport development.

*Definition*

Number of people highly sleep annoyed by air traffic noise stratified to age (15-25, 25-60, 60+).

*Notes*

Information about sleep disturbance is again gathered using the survey approach described under the annoyance indicator. Questions (directed specifically at aircraft noise) and analysis should follow ISO-guidelines (in preparation)[80]. The data in the form of the fraction of the population highly sleep annoyed is to be stratified to age and extrapolated to the full residential population in the airport operations system.

*Criteria*

It is well known that self reported sleep disturbance might differ appreciably from sleep disturbance measured by more objective methods. However, various studies have been performed recently or are under way that might give a better insight in the interpretation of the self-reported data and their correlation with actimetry or ECG data.[82,83]

Given the perceived importance of sleep for health and the fact that sleep disturbance is a main item on the agenda in discussions of airport development, the utility of this indicator is high.

*Sleep disturbance: summary (- difficult, 0 fair, + good)*

| Definition | Criterion | Score |
|---|---|---|
| Number of people highly sleep annoyed by air traffic noise stratified to age (15-25, 25-60, 60+) | Interpretability | 0 |
| | Measurability | 0 |
| | Utility | + |

As a conclusion of this section on health indicators, we stress the importance of surveys for data gathering. Valuable information about annoyance, sleep disturbance, and respiratory and cardiovascular disease can be obtained with this method. Moreover, against little extra cost, additional information can be collected on depression and overall health status.

## 10.5 Emission/exposure indicators

We propose to include indicators for emissions of and exposure to *noise* and *air quality*. With respect to air quality only a few of the main air pollutants are selected, both for practical and theoretical reasons. Many minor compounds in terms of concentrations are not measured routinely and are not expected to be included in routine measuring programmes in the foreseeable future. Furthermore, from the literature one might conclude that these indicators would be rather insensitive, at least in the setting of monitoring programmes.[5]

### Aircraft noise

Aircraft noise is commonly seen as the cause of health effects that is most uniquely related to airports. The goal of including indicators about noise is to monitor the distribution and levels of noise in the airport operations system. Subsequently, this information can be used to make inferences about actual health impacts.

*Definition*

Fraction of population exposed to aircraft noise with $L_{den}$ of <55, 55-60, >60 dB(A).

*Notes*

The noise indicator is defined as the distribution of the population in zones within the airport operations system bounded by aircraft noise contours ($L_{den}$). In the past these data were generally generated from computations based in air traffic data and aircraft noise characteristics only. However, it has become more common to combine calculation with measurement data, an approach that we strongly recommend.

*Criteria*

Many different methodologies exist for calculating and expressing noise levels, so that transparency and comprehensibility are issues of concern. In an effort to standardise methodologies, the European Union now promotes the usage of noise contours based on the day-evening-night equivalent sound level ($L_{den}$).[84] Such a standard will significantly increase the scores on transparency, because the calculation algorithm would be uniform. Exposure-annoyance relationships based on $L_{den}$ have been published. However, interpretation remains difficult as many other factors apart from the noise level determine the degree of annoyance, as discussed above. Furthermore the relationship between the sound level and cardiovascular disease is less well known.

Few problems are expected where measurability is concerned. Data on noise levels are gathered on a regular basis and are generally available in a timely and spatially accurate manner. Nevertheless, differing methodologies remain a problem in the short term, because many countries have been using different methodologies for measuring noise levels and different units to express these levels.

Comprehensiveness was a major issue of concern for us. $L_{den}$ was considered an acceptable indicator for daytime noise levels, but it was deemed insufficient to fully cover issues related to night time noise (cf. [84,85]). Therefore a separate indicator for nighttime noise is included in the proposed indicator set (see below).

Among all health issues, the aircraft noise-related ones are the most specific to airport systems. These effects also tend to play an important role in the public debate about airports. Monitoring noise levels is thus clearly relevant for policy makers and for other stakeholders. $L_{den}$ and $L_{night}$ (see below) can thus be considered a comprehensive pair of indicators. As aircraft noise levels are commonly monitored anyway, the $L_{den}$ and $L_{night}$ contour indicators can be implemented in a cost-effective way from the point of view of the current project.

The issue of exclusivity is of more concern, because many of the health effects that the exposure indicators aim to 'indicate', are also elicited by other factors.

*Aircraft noise: summary (- difficult, 0 fair, + good)*

| Definition | Criterion | Score |
|---|---|---|
| Fraction of population exposed to aircraft noise with Lden of <55, 55-60, >60 dB(A) | Interpretability | 0 |
| | Measurability | + |
| | Utility | + |

## Nighttime aircraft noise

Nighttime aircraft noise effects are a separate and important issue in debates on airport development. A nighttime noise exposure indicator is instrumental in getting insight in the development of exposure and related effects.

*Definition*

Fraction of population exposed to aircraft noise with $L_{Aeq,23\text{-}7h}$ of <40, 40-50, >50 dB(A)

*Notes*

Following the EU development[84] we propose to use the $L_{night}$ quantity being defined as the equivalent sound level between 23 and 07 hours, averaged over a year. As, at least intuitively, sleep disturbance is related to peak levels of noise events such as an aircraft overflight, one might prefer to use the maximum equivalent sound level ($L_{max}$). However, because a relationship exist between $L_{max}$-values and $L_{night}$[85] we propose to use $L_{night}$ in any case, supplemented by $L_{max}$ if this indicator would be preferred by the parties involved.

*Criteria*

The confrontation of this indicator with the criteria follows closely the one on full day aircraft noise. The indicator is probably somewhat more exclusive as the health effects—sleep annoyance and next day performance are relatively exclusively caused by nighttime aircraft noise as far as environmental factors are concerned.

*Nighttime aircraft noise: summary (- difficult, 0 fair, + good)*

| Definition | Criterion | Score |
|---|---|---|
| Fraction of population exposed to aircraft noise with LAeq,23-7h of <40, 40-50, >50 dB(A) | Interpretability | + |
| | Measurability | + |
| | Utility | + |

## Air quality: particulates

Much of the discussion below is also applicable for gaseous hydrogen carbons and nitrogen oxides. The text will make it clear where the discussion specifically relates to particulates

The goal of taking up indicators about particulate matter in outdoor air is to monitor the distribution and levels of air pollution in the airport system. Subsequently, this information might be used to make inferences about both actual health impacts and primary sources.

*Definition*

Two PM10-indicators are defined:
- Annual emissions of PM10 from air traffic, road traffic and other sources
- Mean annual concentration of PM10 at representative locations.

*Notes*

There are two types of indicators for air pollution. The first consists of the emissions of air pollutants by various activities within the airport system. The second one focuses on immissions: the concentration of air pollutants in the airport operations system at a given point in time, regardless of the source.

With respect to the emission indicators, we propose to distinguish emissions from road traffic, air traffic and other sources. Concentrations are (at least) to be measured upwind and downwind near the airport and at a representative point at the airport operations system perimeter not close to a road traffic corridor or an industrial area

*Criteria*

The health effects of particulates in the atmosphere are well established, even though the critical chemical compounds and mechanisms are not well known. It has been hypothesized that particles with a diameter less or even much less than a few micrometer are responsible for the effects. However, because of the scientific uncertainties about the toxicological processes taking place and given the available data, we propose to use PM10, i.e. the fraction of particulates with aerodynamic diameters of 10 µm and less.

As far as interpretability in terms of health effects is concerned, PM10-concentrations score well. However, it is more difficult to connect the health effects to specific sources. Therefore we want to complement the concentration indicator by a source related emission indicator using the concentrations measured and source characteristics as input for model calculations.[86] Using these indicators in tandem also increases the sensitivity. A single concentration indicator might lead to inconsistent interpretations given the dominating influence of road traffic as an air pollution source at many large airports and the non-localized character of air pollution.

Emission indicators have a measurability problem, as they are dependent on model calculations and source characteristics. The models used have to be validated and the relevant source characteristic should be calibrated from time to time, as these are dependent on technological developments and the nature of the fuels used. Robustness is a concern for PM10: the concentration of these particles appears to be unevenly distributed across space and time. Using annual averages and averages over data from several measurement stations might alleviate this problem. Emission indicators are more difficult to implement. The necessary data are usually not available at the level of the airport system. Emission statistics for aircraft may be available in a timely manner, but statistics for airport-related industries and for the share of road transport that can be attributed to the airport system are very likely to be unavailable. The measurability issue is thus of prime concern for the emission indicators.

Both emission and concentration indicators ultimately relate to the health impacts of air pollution, which is an issue of current and very likely also of future concern. The emission indicators may not be very relevant in the short term, because of their unclear link to health impacts, but their relevance is expected to increase in the future, when they offer the handles for policy makers and other actors to take action. If the measurability issues can be solved, emission and concentration indicators together give a reasonably comprehensive picture of air pollution and its effects in the airport operations system. Apart from this, emission indicators are also reasonably exclusive. However, the low cost-effectiveness of this type of indicators is a drawback: new, transparent methodologies will have to be designed and implemented, while most of the benefits arise in the longer term. For the concentration indicators it is the other way around. They score high on cost-effectiveness, because they are based on existing methodologies and measurements, while there may be some overlap with direct health indicators.

*Air quality—particulates: summary(- difficult, 0 fair, + good)*

| Definition | Criterion | Score |
|---|---|---|
| ▪ Annual emissions of PM10 from air traffic, road traffic and other sources | Interpretability | 0 |
| | Measurability | 0 |
| ▪ Mean annual concentration of PM10 | Utility | + |

### Air quality: hydrocarbons

The goal of taking up indicators about gaseous hydrocarbons (HC) in outdoor air is to monitor the distribution and levels of air pollution in the airport system. Subsequently, this information might be used to make inferences about both actual health impacts and primary sources. It should be stressed that in fact ‘emissions of gaseous HC’ and ‘concentrations of gaseous HC’ are in fact a sort of aggregated indicators. 'HC' represents a complex mixture of various compounds with quite different toxicities. However, at least for the time being, we propose to use this indicator for practical reasons (measurability).

*Definition*

Two hydrocarbon (HC)-indicators are defined:
- Annual emissions of HC from air traffic, road traffic and other sources
- Mean annual concentration of HC at representative locations.

*Notes*

The indicators are directed at the gaseous hydrocarbons emitted.

*Criteria*

The criteria discussion parallels the one under particulates. Relationship between hydrocarbon exposure in the general environment and health effects is less well established than with particulates. Also, the indicators may be more difficult to interpret given de different HC mixtures studied in the literature.

*Air quality—HC: summary (- difficult, 0 fair, + good)*

| Definition | Criterion | Score |
|---|---|---|
| ▪ Annual emissions of gaseous HC from air traffic, road traffic and other sources | Interpretability | - |
| | Measurability | 0 |
| ▪ Mean annual concentration of gaseous HC | Utility | + |

## Air quality: nitrogen oxides

The goal of including indicators about nitrogen oxides in outdoor air is to monitor the distribution and levels of air pollution in the airport operations system. Subsequently, this information might be used to make inferences about both actual health impacts and primary sources.

*Definition*

Two $NO_x$-indicators are defined:
- Annual emissions of nitrogen oxides ($NO_x$) from air traffic, road traffic and other sources
- Mean annual concentration of nitrogen oxide ($NO_2$) at representative points

*Notes*

Emissions are denoted by ‘$NO_x$’ as full oxidation has not taken place at the emission points. In ambient air oxidation to $NO_2$ will take place, so nitrogen oxide concentrations measured are essentially $NO_2$-concentrations.

*Criteria*

The criteria discussion parallels the one under particulates.

*Air quality—nitrogen oxides: summary (- difficult, 0 fair, + good)*

| Definition | Criterion | Score |
|---|---|---|
| ▪ Annual emissions of NOx from air traffic, road traffic and other sources | Interpretability | 0 |
| | Measurability | 0 |
| ▪ Mean annual concentration of NO2 | Utility | + |

## 10.6 Throughput indicators

Based on the literature review and the discussions during the Baarn workshop, we selected seven basic indicators: *total aircraft movements*, *aircraft movements at night*, *number of passengers*, *number of transfer passengers*, *amount of freight and mail*, *the fraction of passengers that use public transport* and *the area of the airport***.** These indicators can be directly linked to the activities in the airport system and can thus be used to monitor and improve the system's performance. Therefore, throughput indicators are also referred to as performance indicators.

All throughput indicators are discussed together.

As the diagrams in Chapter 9 demonstrate the chain between throughput data and health effects encompasses many links. A direct relationship can hardly be established. The primary goal of these indicators is to characterise airport development and use this characterisation to interpret the health and exposure indicators. In this way they are important from a managerial point of view, although for determining the health impacts of airport development in depth analyses are required. Basing a judgement on the values of these indicators only will generally not suffice.

*Definition*

The following seven indicators are proposed:
- Arriving and departing aircraft per year (scheduled flights, chartered flights and ‘general aviation’)
- Arriving and departing aircraft per year during 23-07 h (scheduled flights, chartered flights and ‘general aviation’)

- Number of arriving and departing passengers per year
- Number of transfer passengers per year
- Freight and mail loaded and unloaded per year (tons)
- Fraction of passengers going to and from the airport using public transport
- Area of the airport.

*Notes*

The throughput indicators can be defined as the yearly production in physical terms of core products by the most prominent activity in the airport operations system: the airport.

*Criteria*

The scientific credibility of the throughput indicators is high, because there are known relationships between these indicators and what they are intended to represent, i.e. airport system development. They are also quite sensitive: the development of an airport system leads to changing numbers of aircraft movements and passengers. Consistency may give rise to some concern if developments are relatively slow. In that case, developments in intensity may dominate developments in scale, e.g. the number of passengers could rise while the number of aircraft movements could be reduced. These two indicators would then offer conflicting evidence. However, the indicators are likely to be consistent in the case of a clear trend. The level of transparency of indicators depends quite heavily on their actual implementation. In this case, however, transparency is not expected to be problematic. Given the straightforwardness of the throughput indicators, they are also readily understandable.

The throughput indicators can stand the test of the measurability criteria. Most of the necessary information is directly available from the airport operator in a timely and spatially accurate manner. Comparison of the information between different airports could still be a problem, however, because methodologies differ between large airports. Within each of the airport systems measurement methodologies are usually standardised, so that robustness is not a major concern.

This picture would be quite different if indicators on road traffic and ground activities would be included. Methodologies for gathering data in these fields are much less developed and all kinds of methodological questions arise. One of these questions is directly related to the definitions and boundaries of the airport operations system: what proportion of road traffic should be attributed to the airport system? Moreover, the necessary statistics are not gathered regularly, so that availability, timeliness, spatial accuracy and robustness become major issues.

According to the list of indicator criteria, relevance indicates whether an indicator relates to an issue of current or future concern to the user. Currently, the throughput indicators are not yet of a direct concern to the user who is interested in health effects. However, as more knowledge will become available about the linkages between airport activities and health, the importance of this class of indicators will increase.

*Throughput: summary (- difficult, 0 fair, + good)*

| Definition | Criterion | Score |
|---|---|---|
| ▪ Arriving and departing aircraft per year (scheduled flights, chartered flights and 'general aviation') | Interpretability | + |
| ▪ Arriving and departing aircraft per year during 23-07 h (scheduled flights, chartered flights and 'general aviation') | Measurability | + |
| ▪ Number of arriving and departing passengers per year | Utility | 0 |
| ▪ Number of transfer passengers per year | | |
| ▪ Freight and mail loaded and unloaded per year (tons) | | |
| ▪ Fraction of passengers going to and from the airport using public transport | | |
| ▪ Area of the airport | | |

# Part 3

## Monitoring airport developments: case studies

# 11 Pilot studies

## 11.1 Design

The selection criteria for indicators (Table 6) also encompass considerations relate to the exact definition of the airports operations system area, the availability of indicator data and the feasibility of obtaining such data. In order to study these practical aspects of potential indicator sets the present project included a pilot phase consisting of three case studies. The ‘cases’ selected were: Malpensa Airport near Milano (Italy); London Heathrow (UK); and Amsterdam Airport Schiphol (The Netherlands).

Before the work on the cases started we compiled a list of 71 indicators that is reproduced in Annex D (Table 10). Among the 71 indicators 16 were labelled as ‘first choice’. These represented our preference at the time of beginning of the pilot phase. Given the restraints in time and resources these had to be studied with first priority. It should be pointed out that the ‘first choice’ differs from the recommended indicator set (Chapter 10). Table 8 indicates whether one of the selected indicators was among the ‘first choice’ and whether data were available at one of the three ‘case airports’.

*Table 8 Overview of the indicators studied. The first three sets of rows (Health indicators, Emission/exposure indicators, Throughput indicators) pertain to the indicators of the recommended set (Table 7). The final set of rows lists indicators from the ‘first choice’ list that were not included in the final set. A ‘X’ in the columns Malpensa, Heathrow or Schiphol indicates that data for the given indicator appear to be available.; ‘(X)’ indicates that data may be become available in the foreseeable future.; ‘=’ indicates that data are not available now and probably will not become available in the foreseeable future; ’—‘ indicates that the indicator was not studied.* [a]

| **Name** | **Definition** | **Belongs to** | | | |
|---|---|---|---|---|---|
| | | **First Choice** | **Mal-pensa** | **Schip-hol** | **Heath-row** |
| *Health indicators* | | | | | |
| Complaints | Number of spontaneous complaints per year about noise and odour related to airport activities | X | (X) | X | (X) |
| Annoyance | Number of people highly annoyed by air traffic noise stratified to age (15-25, 25-60, 60+) | X | (X) | X | (X) |
| Cardiovascular disease | Prevalence of cardiovascular diseases in the 45-65 age group | X | (X) | X | X |
| Respiratory disease | Prevalence of respiratory disease in the 4-12 age group | X | (X) | X | X |

[a] Data on several indicators marked ‘not studied’ for Heathrow will be or will most probably be available.

| Name | Definition | Belongs to | | | |
|---|---|---|---|---|---|
| | | First Choice | Mal-pensa | Schip-hol | Heath-row |
| Sleep disturbance | Number of people highly sleep annoyed by air traffic noise stratified to age (15-25, 25-60, 60+) | | — | — | — |
| *Emission/exposure indicators* | | | | | |
| Aircraft noise | Fraction of population exposed to aircraft noise with Lden of <55, 55-60, >60 dB(A) | X | X | X | X |
| Night time air-craft noise | Fraction of population exposed to aircraft noise with LAeq,23-7h of <40, 40-50, >50 dB(A) | X | = | X | = |
| Particulates | Annual emissions of PM10 from air traffic, road traffic and other sources | | (X) | X | — |
| | Mean annual concentration of PM10 | | X | X | — |
| Hydrocarbons | Annual emissions of gaseous hydro-carbons from air traffic, road traffic and other sources | | (X) | X | — |
| | Mean annual concentration of gase-ous hydrocarbons | | = | = | — |
| Nitrogen oxides | Annual emissions of nitrogen oxides (NOx) from air traffic, road traffic and other sources | | (X) | X | — |
| | Mean annual concentration of nitro-gen oxide (NO2) | | X | X | — |
| *Throughput indicators* | | | | | |
| Number of air-craft | Arriving and departing aircraft per year (scheduled flights, chartered flights and ‘general aviation’) | X | X | X | X |
| Number of air-craft at night | Arriving and departing aircraft per year during 23-07 h (scheduled flights, chartered flights and ‘general aviation’) | | X | X | — |
| Passengers | Number of arriving and departing passengers per year | X | X | X | X |
| | Number of transfer passengers per year | | X | X | — |
| Freight and mail | Freight and mail loaded and unloaded per year (tons) | | X | X | — |
| Public transport | Fraction of passengers going to and from the airport using public trans-port | | X | X[a] | — |
| Geography | Area of the airport | | X | X | — |

[a] Only data on arriving passengers available

| Name | Definition | Belongs to | | | |
|---|---|---|---|---|---|
| | | First Choice | Mal-pensa | Schip-hol | Heath-row |
| *'First choice' indicators not included in the final set (Table 7)* | | | | | |
| Income | Distribution of income in the airport operation system | X | (X) | X | X |
| Noise | Fraction of houses within noise intervals | X | (X) | X | X |
| PM10 | Fraction of the population in the airport operation system exposed to a PM10-concentration exceeding the standard | X | (X) | X[a] | X[b] |
| Road accidents | Number of persons killed by road traffic in the airport operations system | X | (X) | X | X[c] |
| Landscape | Green space open to the public | X | (X) | X | X |
| Mortality | Annual mortality rate stratified to age group | X | (X) | X | X |

The reports of the three pilot studies are published separately.[87,88,89] Below the findings are summarized.

## 11.2 Malpensa Airport

*The case study*

The case study was performed by one of the partners of our study group, Pietro Caratti di Valfrei, and his colleague Ms Valeria Papponetti at Fondazione Eni Enrico Mattei (FEEM), Milano, Italy.[87]

*The airport*

Malpensa airport is a fast developing airport near Milano, Italy. It has been designated as an international hub airport. Part of the air traffic to and from Linate Airport (also near Milano) has been transferred to Malpensa. In 2000 about 20 million passengers travelled to and from the airport in about 250 thousand airplanes.

*The airport operations system*

The authors choose to define the 'airport operations system' on the basis of noise contours. They proposed to use the LVA = 60 dB(A) contour; LVA is an

a Present standard of 40 µg/m3 is not exceeded.
b Idem
c Data are available for areas under the jurisdiction of local authorities.

Italian measure of aircraft noise.[a] Local health authorities suggested using the 55 dB(A) contour. However, that appeared to be not feasible given the lack of data on that noise level. Italian regulations identify the zone with restrictions with respect to aircraft noise as the area within the 60 dB(A) contour.

Widening the system's area in view of emissions of air pollutants was also considered but deemed not to be feasible due to lack of location specific emission and immission data.

The airport operations system used in the Malpensa study is of Y-shaped form encompassing an area of 31 $km^2$ with 6625 inhabitants.

*Results*

The authors of the Malpensa case study were able to gather information about the full set of 71 indicators.[b] An overview is given in Table 8. As can be seen from the table at present data are available for only a few of the indicators of the recommended set. This situation is expected to improve in the foreseeable future due to the increased attention for environmental health matters in the Malpensa airport development. The main data gaps are in the domain of the 'health' and the 'air pollution' indicators.

The Malpensa case study also highlighted the need for more systematic methods of data collection. By integrating these methods among data holders a cost-effective system of monitoring environmental health related to airport operations and developments might be realised.

The consultations with local municipalities and health authorities also resulted in proposals of including various other indicators in the recommended set. Examples are the use of tranquillisers, incidence and prevalence of psychiatric disorders and exposure to electromagnetic fields. Although such recommendations have to be taken seriously in the final selection of a comprehensive set of indicators at a given location, it also highlights the need of explaining the utility of an indicator set for monitoring purposes: it provides (should provide) a 'thermometer' for the environmental health impact related to the airport, but it does not alleviate the necessity of studying in depth specific questions about the impact of the airport and airport related activities on public health and the environment.

An interesting conclusion of the Malpensa case study was the proposal of integrating the environmental health indicators monitoring program in a policy directed at sustainable development.

a LVA is similar to the Lden-metric, be it with a day period of 6-23 h and no penalty for evening noise.

b The very valuable contribution of *Società Esercizi Aeroportuali* (SEA), the Malpensa airport operator is gratefully acknowledged.

## 11.3 Schiphol Airport

*The case study*

The case study was performed by Ms Tilly Fast of Fast Advies, Utrecht, The Netherlands.[88]

*The airport*

Amsterdam Airport Schiphol (AAS) is among the top five airports in Europe in terms of passenger data. It has been designated by the Netherlands' government as an international hub airport ('mainport Schiphol'). In 2000 about 39 million passengers travelled to and from the airport in about 430 thousand airplanes.

*The airport operations system*

The public debate on the further expansion of AAS, more specifically the planning procedure of a fifth runway, has been instrumental in designing an extensive research programme into the health impacts of the airport operations (the Health Impact Assessment Schiphol)[90]. In this programme the study area was defined as a circle with a 25 km radius around the airport. For that study area aircraft noise data are available (such data are computed by the National Aerospace Laboratory NLR for a 55x55 $km^2$ square with the airport at its centre). The author proposes to use a similar area for the airports operations system, noting that effects of the airport (e.g. noise complaints) are being perceived at larger distances. With respect to road traffic the author suggests to study a system definition related to airport access roads.

From the data availability in the Schiphol case it follows that the system area should also take into account other area definitions, such as hospital region (disease data), municipality (mortality data) and 4-digit postal code area (income data). In particular the disease and mortality data are not routinely available at a more detailed geographical level for privacy reasons.

*Results*

The author of the Schiphol study was able to gather information about all 71 indicators listed in Annex D.[a] As the overview in Table 8 illustrates indicator data appear to be available for all relevant indicators. In fact a monitoring programme is at present being implemented on the basis of a similar, but somewhat more extended set of indicators as proposed in Chapter 10.[91] The area to be covered by this programme is not fixed yet but will probably be a

[a] The very valuable contributions of *Schiphol Group*, the Amsterdam Airport Schiphol operator and the National Institute of Public Health and Environment (RIVM) are gratefully acknowledged.

75x75 $km^2$ square with Schiphol at its centre. That area would encompass the $L_{den}$ = 45 dB(a) contour projected for 2030.

Data on sleep disturbance were not studied. However such data will be included on the Schiphol monitoring programme using survey data.[91] For the relationship between emission sources of air pollutants and pollutant concentrations a programme is available.[86]

As the author indicates in her report costs will be an important consideration in designing a monitoring programme based on the indicator set selected. Although practically all data are being collected, some data are not being published routinely or are made public in a less appropriate format. Obtaining the data in the required format may entail considerable costs.

We wish to recall here the observation of the author that the airport operator collects many of the relevant environmental data as part of the company's sustainability policy.

## 11.4 London Heathrouw

*The case study*

The case study was performed by Dominic Tantram of Blue-Bag Ltd (at present of Terra Consult), Northampton, UK.[89]

*The airport*

London Heathrow Airport is among the top five airports in the world and Europe's number one airport in terms of processed passengers. It serves as a major international hub airport. In 2000 about 65 million passengers travelled to and from the airport in about 467 thousand airplanes.

*The airport operations system*

The author proposes an airport operations system area of a 15 km radius with the airport at its centre. This area encompasses the maximum Leq = 60 dB(A) noise contour for the period 1996-2000.[a] [92] The area is heavily urbanized; about 40% is classified as industrial or urban area. Various health and exposure data are available for this system selection on the basis of a fairly detailed geographic information system. Such systems enable the study of the distribution of certain indicators within the system or more accurate estimates of system data in case of spatially-related missing values.

[a] Leq: equivalent continuous sound level (due to aircraft noise) averaged over a 16 hour day from 0700 to 2300 hours BST and calculated during the peak summer months mid-June to mid-September.

*Results*

Access to data holders turned out to be a major problem. This is understandable to some extent, as the last quarter of 2001 and the first quarter of 2002 were hard times for airport operators. It appeared that support for the present project was not the number one priority for BAA, Heathrow's operator. It also took considerable efforts to get access to the pertinent health data. Therefore the case study was necessarily restricted to studying the 'first choice' indicators. As the recommended indicator set (Table 7) differs from the 'first choice', several finally selected indicators could not be studied in the Heathrow case (Table 8). This concerns more specifically the air pollution indicators. Several of the data required appear to be available, as is illustrated by a recent environmental report of BAA Heathrow[93], although it is not clear to which extent that data are complete (more particularly immission data) and available in the required format.

One of the most interesting findings from the Heathrow case study is the prospects for using geographical information systems (GIS) for environmental health indicators. Aggregating exposure and health data using a GIS enables routinely presenting aggregated data and occasionally making more in depth analyses with only limited extra resources. We point specifically to the presentation of the cardiovascular and respiratory disease data in the case study report.[89] Using the full power of the GIS approach requires data collection for the different variables using similar definitions of geographical units. Once such a standardisation between the varies data registries is achieved the possibility exists for more in depth analyses, usually as a response to questions that arise from certain time trends in the environmental health indicators.

Contrary to the 'first choice' set of indicators the recommended set (Table 7) does not contain a landscape indicator. The author of the Heathrow case study points to the possibility of using the data gathered in the EU sponsored Corine project[94], that might provide an opportunity for introducing a landscape indicator. This is a topic that should be explored further.

Finally, the author has added to each indicator profile critical remarks about the relevance and interpretation of the indicator. These comments have been taken into account in the selection leading to the final indicator set. However, they should also be taken into account in the further implementation of the indicators in actual practice.

# 12 Conclusions and recommendations

## 12.1 The recommended indicator set

We have presented in this report (Chapter 10) a set of indicators to be used as the basis for a programme of monitoring the environmental health impact of large airports. These indicators were selected from among a multitude of suggestions in the literature. Although it is essential that in practice the set be defined in interaction with the indicator 'users', our proposal has a scientific basis and reflects the concerns of the most important stakeholders, i.e. the national and local authorities, the airport operators and the populations living in the vicinity of the airport.

The indicators of the set were rated in terms of *interpretability*, *measurability* and *utility* (difficult, fair, good). An ideal set would have consisted of indicators scoring top marks on all three criteria. This is not the case in the set recommended by us, as is clear from the summary tables in Chapter 10. However, with the accumulation of experience with monitoring programmes based on the proposed indicators, we expect ratings to improve. Of course, experience may also dictate changes in indicator definition or deleting some indicators from the set and adding others.

We wish to reiterate here the limitations of using indicators for monitoring. As mentioned above they can be compared to a 'thermometer' indicating the way in which the airport and related activities and their environmental health impacts develop. But just as a reading of body temperature only indicates the possible need for further medical diagnosis and treatment, a 'reading' of the indicator set may point to the need of further, more in-depth study of effects of airport development and of taking measures to mitigate unwanted impacts.

This function of the indicator set might necessitate setting standards: what is considered to be a change in 'temperature' sufficiently large to warrant further examination. The scope of the present project did not include deriving such standards. In fact we think that such standards should be developed as part of a policy process (including stakeholder consultation) in which the practice of gathering indicator data and interpreting indicator trends is taken into account.

## 12.2 Comparison between European airports

Even though one might decide to modify the indicator set to satisfy the needs of the users of the indicator data at a given airport, we feel its scientific basis makes the proposed set a good basis for comparing the environmental health status between airport operations systems in Europe. However, this would require further study. Two main issues have to be resolved:

- The definition of the airport operations system
- The scaling of the indicators.

We deal with the first point (again) in the next section (12.3). The issue of scaling was discussed extensively in meetings of our study group, but not resolved. The problem is that in terms of health impact absolute numbers are of course highly relevant ('how many people are seriously annoyed by aircraft noise', etcetera), but that especially for the airport operators relative measures are relevant from an operational point of view ('how much $NO_x$ is emitted in the system for each 1000 passengers', or 'what is the prevalence cardiovascular disease with respect to a national reference value'). We propose that the issue of scaling is studied in more depth by comparing indicator data over at least a 10-year period between airports with at least a tenfold difference in passenger throughput. Furthermore, the question of an appropriate and consistent choice of reference values should be studied in this respect.

Research recommendation: study scaling of indicators both in view of a more pertinent interpretation of indicator data and in view of comparison between European airports.

## 12.3 Airport operations system

A crucial aspect of our proposal is the airport operations system, introduced in Section2.2 and further discussed in Section 10.2 and in the chapter on the case studies (11). In each case study the system area was defined differently from the other two, whereas in the Schiphol case study it was further suggested that geographical delineation of the system might be indicator dependent.

For a single airport the system definition can be based primarily on the availability of data, considerations of statistical power with respect to survey data and perception of airport activities. In all three cases studies aircraft noise contours were used as starting points, in agreement with the most promising option for system definitions discussed by our study group. It should be pointed out that a noise contour approach has a dynamic component: aircraft noise profiles will change with airport development, as these profiles are dependent, *inter alia*, on the number of flights, type of aircraft, flight paths and distribution of flights over the day. With reference to the 'stocks and flows' model (Section 8.3) one might consider only long term adjustment of the system definition (e.g. every decade), but given the fast growth potential of some airports (e.g. Malpensa) this might be an incorrect procedure. The 'rolling average' proposal in the Heathrow study is an intermediate solution for the adjustment question.

When aiming at comparing airports the question of the definition of the airport operations system gets an extra dimension. The system definition for the airports to be compared have to be identical, or at least very similar, in order to make any comparison possible. The most important issues are:

- Using a single geographical delineation for all (or at least most) indicators
- Using noise contours as a basis for system area definition
- Extending the system area beyond the noise contours.

*Geographical delineation*

In the Malpensa and the Heathrow case studies similar areas were used for the health and the various exposure indicators. In the Schiphol study it was suggested that air pollution exposure indicators might benefit from a system definition different from that for the noise indicators. This might also pertain to the health indicators associated with the various exposures. Although this suggestion might lead to an increased sensitivity and even interpretability of indicator data trends, it might be less preferable from a communication point of view. Furthermore, the issue of how to delineate the system in terms of transport infrastructure and stationary emission sources will probably be resolved quite differently at different airports and would therefore also be difficult to harmonize. So we propose to use a single geographical definition of the airports operation system for all system area dependent indicators.

*Noise contours*

In the Malpensa case study the LVA = 60 dB(A) contour was used as a starting point and in Heathrow the Leq = 60 dB(A) contour, whereas the area proposed for the new Schiphol monitoring programme will encompass the $L_{den}$ = 45 dB(A) contour[91]. For comparison purposes it would at least be preferable to use $L_{den}$, the noise metric defined in the recent European directive on environmental noise.[84] In numerical terms the $L_{den}$-value for Malpensa and Heathrow will probably only differ by a few dB from the value selected. The difference between 45 and 60 dB(A) on the other hand is considerable.[a] From the point of view of costs and of data availability it might be wise to strive for a system definition encompassing the $L_{den}$ = 55 dB(A) contour, as suggested in Section 10.2.

*Extending the system beyond noise contours*

In the Heathrow case study the system area was further defined by drawing a circle just encompassing the selected noise contour. A similar approached is advocated at Schiphol. In Malpensa the system was not extended beyond the selected noise contour because of lack of data. We propose to follow the Heathrow approach, i.e. selecting a five year rolling average (or maximum) of a $L_{den}$-contour and defining the system area as the area with a touching circle of that

[a] A formal decision about the extent of to region around Schiphol to be monitored still has to be taken by the Netherlands Government.

contour. If the $L_{den}$ = 55 dB(A) contour is used to determined the geographic extent of this system, using the 'Heathrow-approach' would also include a substantial number of people exposed to noise levels less that 55 dB(A).[a] Taking the five-year rolling average (or maximum) would dampen the changes in system definition from year to year. We recommend studying this approach, especially with respect to its applicability in addressing the airport related environmental health issues at various European airports.

Research recommendation: study a harmonized airport operations system definition in view of the relevant public health and environmental issues at various European airports.

## 12.4 Periodic surveys

We proposed to collect indicator data using periodic surveys, i.e. annual telephone surveys, followed up by more extensive questionnaires (by mail or preferably by personal interview) every five years. This proposal, that at least in its design, appears to be a cost-effective approach, has to be further examined and detailed. Questions arise with respect to sample size and sample stratification for both the annual and the five-year-survey. Also the questions to be asked have to be further defined. We advocate using as much as possible standardised questions from validated questionnaires, also in view of comparing various European airports. Several of these issues have been addressed in a recent proposal for a monitoring programme at Schiphol airport.[91] If this programme is implemented it might serve as a pilot for monitoring programmes at other European airports with respect to these issues.

Research recommendation: study the design of the surveys proposed for gathering indicator data.

## 12.5 Geographical information systems

Several of the indicators of the recommended set are location dependent, such as exposure distributions. The health indicators proposed are aggregated quantities for the whole system. For more in depth analysis of indicator trends the distribution of health indicator data within the system may be of help. Thus gathering data using a geographical information system (GIS) might be of tremendous help, as was demonstrated in the Heathrow case study. The main obstacle at present, as is clear from the two other case studies, is that the various data registries use different definitions of geographical units in data collection, or only make data available in aggregated form for privacy reasons.

We want to highlight the advantages of using a GIS as a cost-effective way of gathering data that may be used in answering questions arising from observed indicator trends. It would also provide a means of extending the indica-

[a] As is mentioned in the Schiphol case study report the number of highly annoyed people outside the 55 dB(A) contour is considerable. For Schiphol it is actual larger than the corresponding number within this contour.

tor set to socio-economic and landscape data in a consistent way (see below, Section 12.6). The objection against using a GIS as a basis for gathering information on the environmental health impact of airport operations may be the necessity of setting up and maintaining an organisation structure that, at least for the short term, appears to be expensive and without direct benefits. However, in the longer run, as noted above, we see considerable advantages. Furthermore such a system may have other uses beyond the issue of the present study and thus may have other cost bearers.

Research recommendation: study the pros and cons of using a geographic information system as the basis for indicator data gathering.

## 12.6 Socio-economic, landscape and aggregated indicators

*Aggregation*

As is demonstrated by the list in Annex D, many more indicators were evaluated in the present study, than the recommended set listed in Table 7. One possibility of keeping the number of indicators in the set limited, while on the other hand addressing the complex relationship between airport and airport related operations and environmental health impacts is using aggregated quantities.

Aggregation as meant here could be both explicit and implicit. An explicit way would be combining single quantity indicators. An example is representing air pollution by the combined mass of all pollutants. In a more sophisticated approach quantities are combined after applying weighting factors. An example is using an aggregated quantity to represent cancer risk from air pollutants that is obtained by multiplying exposure concentrations of single compounds by the slope of the dose-response curve and subsequently adding them to obtain an aggregated cancer risk quantity.[46] The problem with this approach is that the resulting indicator looses interpretability, that the weighting factors are generally rather uncertain and that the required data of the composite quantities are not available. Another problem is the compensation mechanism (a high value of one quantity is compensated by a low value of another quantity) that is implicit in many of such aggregation methods.[95] We feel that in the airport case this is not particularly helpful and have preferred, e.g. in the case of air pollution, selecting a few characteristic single quantity indicators.

An example of an implicitly aggregated indicator is ‘house value’ or house values distribution.[96,97] Such an indicator would depend on a variety of system attributes, such as: noise levels, air pollution, landscape, services in the neighbourhood, access to public and private transport infrastructure, etcetera. The compensatory mechanisms inherent in aggregated indicators may also reflect compensatory effects on health, although data in that respect are absent. After extensive discussion we opted for not including this type of indicators because of difficulties with a consistent interpretation of indicator trends. However, we suggest it to be an area for further investigation. We refer here also to the work performed in the EU sponsored ExternE project that has developed methods for monetizing various environmental and health impacts.[98] This approach might be used for correlating trends in different indicators and elucidate the significance of trends in aggregate economic indicators as house values.

Finally we want to point out that also seemingly single quantity indicators are aggregates of data. Noise levels are a case in point. $L_{den}$ aggregates noise levels at certain times of the day using time dependent weighting factors and further averages ('aggregates') the daily values over a full year. The same applies to the emission and concentrations of gaseous hydrocarbons; in fact these indicators represents 'exposure indicators' for a mixtures of compounds with varying toxicities.

Research recommendation: study the interpretation of trends in house values with a view of using this quantity as an indicator for the health and environmental impact of airport and airport related operations.

*Income distribution*

Our 'first choice' list of indicators (Table 8 and Annex D) included an income distribution indicator. The reasoning behind this indicator was that socio-economic status, which to an important extent is represented by income, appears to be correlated with health.[99,100] Even though data appear to be available (Heathrow, Schiphol), or forthcoming (Malpensa) we did not include this indicator in the final selection. Although the correlation between socio-economic status and health is established, it is unclear whether the observed correlation is a causal relationship and what is the cause and what the effect. This lack of knowledge would generate insurmountable problems in interpreting indicator trends. A possible application of income information might be the standardisation of hospital data. This would require that data linkage is possible on a routine basis, which is uncertain. We do not recommend further study into the feasibility of socio-economic attributes as indicators for environmental health in airport operations system, as this type research will not result in solutions in the short run. However, from a more long-term, general public health point of view, such research is very relevant.

*Landscape*

The way in which the structure and naturalness of the physical environment impacts on health is an issue that is increasingly getting attention.[5] Especially in the airports operations system area there are possibilities for conserving or strengthening the natural appearance of the landscape because of noise and safety zoning regulations. Such developments may possibly compensate to some extent for the negative impacts of noise exposure. However, knowledge about these effects is still at a rudimentary level.

In the 'first choice' list of indicators we included a landscape indicator that was eliminated in the final selection. However, as can be seen from Table 8 data on the amount of 'natural' landscape are available (Heathrow, Schiphol) or forthcoming (Malpensa). Furthermore in the Heathrow case study the suggestion was made to make a link with EU Corine project in which the European landscape is characterised using a grid with 500x500 $m^2$ cells.[94] We propose to further study the feasibility of including a landscape indicator in the indicator set.

Research recommendation: study the interpretation of a landscape indicator (e.g. degree of naturalness of the airports operations system) and the possibility of deriving indicator data from the EU Corine project database.

## 12.7 Implementation

The present study can be considered as a first step in implementing a comprehensive set of environmental health indicators for airport operations systems. As indicated above several aspects have to be further analysed and defined before the set can be applied in practice. We already mentioned that with respect to Schiphol a large part of that work has been performed.[91] The Schiphol exercise also covered an aspect that is outside the scope of the present study: organisational structure. As it is found, at least in the three case studies reported here, that the majority of data reside with the airport operator and the national statistics bureau it seems appropriate to enlist the full cooperation of these two entities. One might envisage a small office either attached to the airport or the statistics bureau with oversight of the relevant users of the indicator set (i.e. the airport operator, the local and national authorities and the local citizens).

We deem it essential that such a cooperative structure, but with a dedicated office, is implemented in order to guarantee continuity in the data flows. Once an indicator set is implemented it would not help policy debates if indicator data were not becoming available at the expected point in time, because of changing priorities at, e.g., the airport operator's organisation or of budgetary cuts at, e.g., the statistics bureau.

Apart from publicizing regular reports (e.g. every year and at least every five years), the Internet may be used to provide access to indicator data as soon as they are available. With help of interactive software the interested user could visualize indicator trends, correlate trends in different indicators and use the throughput indicators for various scaling exercises. This would be a cost-effective way of making data available for all interested parties, would enhance the transparency of the reporting system and may in the long run eliminate the necessity of written reports at all.

Research recommendation: study options for the organisational infrastructure of indicator data gathering and processing.

Research recommendation: study possibilities of reporting indicator data through an interactive Internet-site.

## 12.8 Evaluation

Apart from the further research recommended in this chapter, that might lead to adjustments of the recommend set of indicators and to improvements in the interpretation of indicator trends, each programme aimed at monitoring indicators in airport operations system should have resources set aside for evaluation, roughly at five years intervals. The system diagrams (Figure 9, Figure 10, Figure 11, Figure 12) can be used as a primary guidance for this evaluation. The evaluation may result in improved interpretation of indicators and indicator trends, in adjustment of the various diagrams and in proposals for adjusting the indicator set.

## 12.9 Sustainable development

We conclude this report with the observation that there appears to be a willingness among airport operators to place their policies under the heading of ‘sustainable development’. Although the various parties in the public and policy debate on airport development would probably define ‘sustainability’ differently it would at least make agreement on principles possible. On a European level this ‘trend’ parallels the policies of the Commission and the Council.[6]

Indicator sets as studied and proposed here could be part of an approach towards sustainable operation of airports and airport operations systems. It might be feasible to supplement the set with other performance indicators coverings other aspects of sustainable operations apart from impacts on public health and environment.

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The research consortium that carried out the project encompassed scientists from Germany, Italy, the Netherlands, Poland, and the United Kingdom. The project was co-ordinated and administered by affiliates of the Universiteit Maastricht, the Netherlands. Names and addresses are given below.

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# B Executive summary

Of the report

## Health Council of the Netherlands: Committee on the Health Impact of Large Airports. Public health impact of large airports. The Hague: Health Council of the Netherlands. 1999; 1999/14E

### Civil aviation

Civil aviation represents a growing industry and most economists expect this growth to continue. It is developing into a truly global industry, with a few conglomerates of airlines serving a world-wide network of large 'hub' airports. In 1997 the scheduled airlines carried 1,5 billion passengers and 26 million tons of freight

The economic gains of the aviation industry and the possibility of reaching far away locations may be beneficial for health and quality of life, probably mainly so for affluent populations in the industrialised parts of the world. However, aviation affects the environment both globally and locally in a negative sense and consequently has also negative impacts on health

### Request and report

This report responds to a request of the Ministers of Health, of Transport and of the Environment of the Netherlands Government to assess the health impact of large airports.[a] The request was related to the public and political debate about the future of the Dutch aviation infrastructure and about the expansion of Amsterdam Schiphol airport in particular, although a specific assessment for the Dutch National Airport was not called for. To prepare the report the President of the Health Council appointed an international committee of experts.

Three case studies were carried out to provide the committee with background material on the way public health plays a role in airport development. The cases chosen were; a new passenger terminal at London Heathrow, Munich International Airport that opened at a new location in 1992, and the planning process for an airport in Berlin, to replace the three existing airfields in the beginning of the next century. The committee was also informed on the progress with the health impact assessment studies at Amsterdam Schiphol.

[a] These Cabinet Ministers are officially denoted by, respectively, Minister of Health, Welfare and Sport, Minister of Housing, Spatial Planning and the Environment, and Minister of Transport, Public Works and Water Management

The committee focused on the public health impact of local changes in environmental factors. 'Public health impact' has been defined by the committee as to include impacts on 'quality of life'. Effects of aviation on climate and thereby health and indirect positive and negative public health effects through economic mechanisms, transport possibilities and tourism are outside the scope of the present report.

## Airport operations system

The committee has approached the relationship between airport operations and public health in an integrative manner. It evaluated public health impacts in airport operations systems encompassing the area up to a few tens of kilometres distance from the airport. Apart from the direct aviation related operations the system also includes the activities of businesses that are attracted to the airport region, as well as the infrastructure necessary to serve to airport, other businesses and the residential locations in the area. Even when airports are originally located in remote areas, then over of the years the airport region becomes more and more urbanised and settled with freight handling industries, catering and hotel activities, high-tech industries and offices that prefer to be located close to the airport.

The impacts of all these activities within an airport operations system on public health are only partly specific for the system. Aircraft noise, kerosene odour and aircraft crash risk are specific factors. Air pollution, landscape changes by transport infrastructure, road traffic and industrial noise and occupational health risks are, however, also encountered in other urbanised and industrialised settings

## Environment and public health

The committee has considered the impact of several environmental factors on health separately:

- air pollution
- noise
- accidents
- soil and water pollution at the airport
- importation of infectious diseases
- appearance of the environment
- occupational health risks at the airport.

In the concluding chapters the committee has tried to integrate these findings and suggests approaches for improving public health protection.

Does the airport operations system affect public health? This central question is answered by the committee with; yes. Considering the relationship between environmental factors and public health, infringements on the quality of life, such as sustained odour and noise exposure, also have a potential of causing clinically observable disease in the long run. This depends on a variety of factors such as individual susceptibility, social-economic status and life style, and the simultaneous exposure to a variety of environmental factors. Some of these factors may aggravate the public health effects, but others could reduce or offset them. The relationships between environment and health are fraught with uncertainties, not in answer to the question about whether factors such as environmental noise and air pollutants do affect public health negatively, but to the questions as to what extent and which population groups are most vulnerable.

In determining the impact of environmental factors the committee uses classification schemes for:

- evidence for the causal relationship between the exposure to an environmental factor and a public health effect
- severity of the effect (slight, moderate, severe)
- number of people affected.

The classes for causal evidence are; sufficient, limited or inadequate evidence, or evidence for the lack of a causal relationship. Severe effects seriously impair day-today functioning and usually require professional medical care. A public health effect is rated as 'slight' if the impact on daily functioning is not very significant, or is reversible , or has a small effect in the long run. Moderate effects are in between these two extremes. The number of affected people can only be very roughly indicated. Classes are: susceptible individuals, specific subgroups, substantial part of the exposed population, and are only given if the causal relationship is deemed to be supported by sufficient evidence.

### Air pollution

The contributions from aircraft, other airport operations, road traffic to or from the airport or to other destinations to the public health effects of air pollution in an airport operations system are intricately mixed. This is due to the spread of air pollutants in the atmosphere by dispersion processes, whereas total pollution is also determined by sources outside the system, possibly far away. The important conclusion is that air pollutant levels around large airports are similar to those in urbanised areas and are to a large extent determined by road traffic emissions. At such concentrations public health effects are to be expected, even though the concentrations are generally below official guideline values.

The present understanding of air pollution effects is that exposure will impair respiratory functions, for most people in a reversible way. Effects become more invalidating in the case of sustained exposure. The table below lists the effects of air pollution for which there is sufficient scientific evidence for a causal relationship:

| Response | Severity[1] | Number affected[2] |
|---|---|---|
| premature death (response after an episode in susceptible groups) | *** | * |
| aggravation of respiratory and cardiovascular disorders after an episode (resulting in hospital admissions) | *** | * |
| affected lung function after an episode | * | ? |
| premature death (decrease in life expectancy) due to chronic exposure | *** | * |
| reduced lung function due to chronic exposure | ** | ** |
| increase in chronic respiratory conditions (bronchitis) due to chronic exposure | ** | ** |
| odour annoyance from chronic exposure | * | *** |

1 * = slight, ** = moderate, *** = severe

2 * = susceptible individuals, ** = specific subgroups, *** = substantial part of exposed population

Effects, related to an air pollution episode, for which there is limited evidence are respiratory symptoms and aggravation of asthma. These effects are rated by the committee as slight and severe, respectively.

Epidemiological studies of the prospective, cohort and case-control variety have linked long-term exposure to air pollution with survival, increased lung cancer mortality, reduced lung function and increases in chronic respiratory conditions, especially bronchitis. The committee rates this evidence as sufficient, even though more work need to be done to elucidate exposure-response relationships and to what extent the effects observed are due to exacerbation of existing disorders. There is to date only inadequate evidence to link long term exposure to community air pollution to the prevalence of allergy ands asthma. As yet no airport specific carcinogenic compounds have been identified.

The number of epidemiological studies on air pollution and public health near airports are scarce. Morbidity and mortality levels, related to diseases that may be air pollution related, do not appear to differ between airport regions and cities. A study at Amsterdam Schiphol has provided evidence for a decrease in the prevalence of respiratory complaints with increasing distance from the airport. To what extent air pollution levels and other factors play a role is subject of further study.

Chronic exposure to odour has been reported to induce, apart from annoyance, a variety of moderate somatic and psychosomatic effects. The evidence for a causal relationship is rated as limited.

With respect to controlling air pollution the committee notes that in most industrialised nations industrial and road traffic sources of air pollution are subject to regulatory control, contrary to aircraft emissions. An integrated approach to combat air pollution is at odds with a system in which one important source, i.e. aircraft emissions, is exempt from such control.

## Noise

Aircraft noise is one of the most noticeable environmental factors of airport operations and is specific to the system. Although there are other noise sources in the system, noise from aircraft taking off and landing, from aircraft braking and taxiing at the airport and from aircraft engine testing are dominant ones. At the airport, noise from ground traffic can be considerable and will in particular affect airport workers. In the vicinity of an airport one will usually find residential locations where air traffic noise is a dominant source of environmental noise exposure. Aircraft noise levels are determined by the position of the runways and the flight patterns. Outdoor aircraft noise exposure in residential areas around large airports may exceed 60 and occasionally 70 dB(A) (day-night or day-evening-night exposure level).

Hearing impairment is a well-documented effect of noise exposure. In an airport operations system it is of concern at operations at the airport, especially in ground handling and in engine testing. Only in very exceptional cases will environmental noise exposure induce hearing loss. The other effects for which there is sufficient evidence for a causal relationship with noise exposure are listed in the table below. Effects are only observed in exposed populations at noise levels above the observation threshold. 'Sleep disturbance' in the table denotes a conglomerate of effects, including awakening, sleep stage and sleep pattern changes, heart rate changes, and effects on mood the next day. Limited evidence exists for the effects of night-time noise exposure on performance the next day and changes in hormone levels.

| Response | Severity[1] | Number affected[2] | Observation threshold |
|---|---|---|---|
| hypertension | ** | ** | eq. outdoors sound level (06-22 h) of 70 dB(A) |
| ischemic heart disease | *** | * | eq. outdoors sound level (06-22 h) of 70 dB(A) |
| annoyance | * | *** | outdoors day-night level of 42 dB(A) 3 |
| sleep disturbance | ** | *** | depending on effect, indoors SEL of 35-50 dB(A) 4 |
| performance at school | ** | ** | eq. outdoors sound level (school hours) of 70 dB(A) |

1 * = slight, ** = moderate, *** = severe
2 * = susceptible individuals, ** = specific subgroups, *** = substantial part of exposed population
3 threshold for 'high annoyance'; the day-night level is the equivalent sound level over 24 hours, with the sound levels during the night (period of 23-07 h) increased by 10 dB(A).
4 SEL is the equivalent sound level during the noise event normalised to a period of one second

A variety of other effects has been linked to noise exposure, such as decreased general performance, biochemical effects, deterioration of the immune system, decrease in birth weight, psychiatric disorders and negative effects on psycho-social well-being. The committee considers the evidence for the causal relationship of these phenomena with noise exposure to be limited. With the exception of psychiatric disorders (severe), and effects on birth weight and psycho-social well-being (moderate), the committee rates the other effects as slight. There is evidence that congenital effects do not result from the exposure of pregnant women to environmental noise.

The understanding of the committee is that, hearing impairment excepted, the public health effects of noise depend on both the (psychological) appraisal of the noise exposure by the organism and the vegetative reactions induced. Some of the somatic and psychosomatic effects, such as hypertension and cardiovascular disease may be a direct consequence of this processing of noise exposure by the organism, others are possibly a consequence of noise-related annoyance. Annoyance is defined here as a feeling of resentment, displeasure, discomfort, dissatisfaction or offence which occurs when an environmental factor interferes with a person's thoughts, feelings or activities.

Noise exposure is only one of the determinants of annoyance. Studies have shown that aircraft noise is more annoying than road and rail traffic noise at the same day-night exposure levels. Aircraft noise-induced annoyance is influenced by the degree of anxiety associated with the possibility of aeroplane crashes. Other so-called non-acoustical factors that modify annoyance are the degree of openness on the part of the airport authorities or the government concerning the developments at the airport and the way in which the authorities enforce environmental standards. These latter factors can work both ways, i.e. they can be instrumental in reducing (more openness, strict enforcement) or increasing annoyance.

Recent studies appear to confirm older work on the negative impact of aircraft noise on the cognitive abilities of children. The committee deems this to be a subject that warrants further study to elucidate exposure-response relationships and to assess the possible long term impacts.

### Safety

Aircraft crashes come first to mind when mentioning safety in relation to airport operations. However, accidents, such as fires, may also occur (and have occurred) at fuelling operations and aircraft maintenance. Fires not related to fuelling can have severe consequences, especially those at the air, rail and bus passenger terminals. Also terrorist actions have been recognised as a serious risk associated with airports. Elsewhere in the airport operations system traffic accidents, accidents at industries, fires, etcetera can occur.

The present report focuses on aircraft crashes. The landing and takeoff stage are the most critical parts of a flight as far as crash risk is concerned. The probability of an accident further depends on the type of aircraft, its weight and its state of maintenance and the weather conditions. The management quality of the systems and organisations involved in aviation and in accident control, and the quality of the managed personnel are components determining the accident risk. This holds for flight personnel, air traffic control, airlines and rescue and other safety services alike.

In the past decades world-wide, on average, 50 crashes occurred per year, resulting in about 1500 fatalities per year, among which 35 individuals of the general population. These data show that the primary victims are the crew and passengers. The services of the large airlines are associated with considerably less fatalities per aircraft hour than, e.g., general aviation (non-commercial aviation). Aircraft crashes are rare events given the large number of flights. At present the crash frequency in the vicinity of a large airport is roughly one to two crashes per ten million movements (takeoffs and landings). This implies that a rough estimate of the average crash rate in the vicinity of larger airports is one to two per decade.

Using the evidence, severity and number affected classifications accidents do occur (sufficient evidence), the health consequences are always severe and the whole population in the airport operations system is at risk, be it that only a small number of people will be actually affected.

The individual risk levels for people living, working and travelling in the vicinity of a large airport are low (being hit by a crashing aircraft is a very extraordinary event) and will vary strongly geographically depending on the flight paths. Calculated individual risks (probability per year of dying due to an accident at a given location) exceeding 1 per 10 thousand per year are confined, within the airport territory, to places close to the runways. Locations with calculated individual risks between 1 per 100 thousand and 1 per million per ear that encompass residential zones, have been identified around large airports. In the Netherlands around industrial installations new houses would only be allowed in zones with individual risk levels not exceeding 1 per million per year.

## Soil and water pollution

Leaking underground storage tanks and pipes, fuel spillage or leakage during ground handling of aircraft, washing of aircraft and vehicles and fire-training for which flame-retardant chemicals are used, are sources of water and soil pollution at airports. If policies to prevent such pollution are in force and effective, the public health impact is minor. A pollution pathway specific for airports is related to de-icing operations to prevent, for safety reasons, the formation of ice on aircraft parts and runways. Effects on humans due to exposure to all these compounds appear to be unlikely in practice.

## Importation of infectious diseases by air traffic

World-wide air traffic increases the potential for transmission of infectious diseases from one country to another. An example is ‘airport malaria’, that occurs when mosquitoes infected with Plasmodium falciparum, originating at airports in regions where malaria transmission frequently occurs, contaminate people around airports elsewhere. The number of documented cases at present is small, but giving the growth of air transport the committee recommends airport authorities and airline companies to be vigilant.

### Occupational health risk

In general the nature of the work in the vicinity of the airport is not expected to have characteristics specific to the airport operations system. This is different for work at the airport and for the operation of aircraft, although for aviation ground personnel only the incidence of musculo-skeletal disorders appears to be higher than what might be generally expected. Accident mortality among pilots is increased, but flight crew mortality from other causes is not exceptionally different from what would be expected. Fatigue and job stress would be expected among air traffic controllers and flight crew, but research data do not point to specific problems. Although activities within the airport operations system do affect occupational health, the situation is not out of line with the situation in comparable industries.

### Comprehensive public health impact assessment

Environmental factors in an airport operations system operate in a cumulative way: people are exposed to, e.g., air pollution, noise and accident risk at the same time. People living in the vicinity of airports are not able to avoid exposure when performing everyday activities such as working, shopping, going to school, etcetera. Furthermore, the factors interact; for example anxiety related to aircraft crashes may enhance noise induced annoyance and vice-versa. Other factors will modify the cumulative impacts. The visual appearance of the environment may act both in a positive and a negative sense, depending, e.g., on how well the traffic infrastructure has been embedded in the natural landscape. The availability of facilities, such as shops, public transport, parks, schools, will influence the way people rate their living environment and will also influence the public health impacts of factors that primarily or partly act via psycho-social mechanisms, such as noise and odour. Measures that increase the perceived control of people over their living environment may be beneficial in this respect.

Published results of comprehensive assessments of the public health impact of large airports, that would have allowed a definitive and complete answer to the Ministers' request, are lacking. In fact, the health impact assessment study in progress at Amsterdam Schiphol is an exceptional example of what, in the opinion of the committee, should be normal practice. On the basis of such studies measures to safeguard public health effectively and efficiently can be implemented. The committee strongly recommends that public health impact assessment, to guide the further international development of the civil aviation system, become the norm instead of the exception.

## Way ahead

Airport and aviation development affect the lives of many people. Decisions to be taken are of a strategic nature and therefore require carefully and specifically designed procedures in which all stakeholders involved, including the people living in the vicinity of the airport in question, play a role. Although differing views on the significance of health and health effects, including impacts on quality of life, will make it difficult to reach consensus on the necessity and desirability of developments, a decision making structure in which those views can be discussed and are accounted for is preferable to autocratic decision making. The nature of the decisions to be made also require that mobility policies have to be discussed with the aim to let air transport be an integrated part of a sustainable mobility strategy.

Two approaches to reduce public health risk can be distinguished. On the one hand environmental quality standards can be set on a geographical basis (‘zoning’) and enforced by the government. In a different approach stakeholders ‘negotiate’ a comprehensive package of measures in which the negative effects of factors like noise, apart from being reduced by exposure limiting measures, are offset by improvements in the natural landscape, the quality of facilities in residential areas and an open communication between all parties concerned about developments at the airport and elsewhere in the system and about the measures taken to reduce noise exposure and air pollution. In practice a mix of both approaches will probably be used, depending on the prevailing political culture.

Aviation technology will have to innovate if the growth in air transport continues at its present rate. Already now large airports are congested and accident and near-accident frequencies might rise. Furthermore new technology is needed in order to lessen the public health impact of the expanding airport activities or in any case not aggravate it. The committee recommends that the technology development is accompanied by a technology assessment process that explicitly considers the short and long term environmental and health impacts of changes in technology.

Given the many parties involved in an airport operations system and given the interactions between different measures to reduce public health effects, the committee recommends that all developments are monitored and assessed on their public health consequences in an integrated manner. How such an integrated risk management structure reaches this goal is to be decided through the political process, but in order to be effective all parties involved should support such a structure and be willing to provide the necessary data in good time.

# C Participants in the workshop held in Baarn

*The Netherlands, March 21-23, 2002*

*Table 9 Workshop participants*

| | |
|---|---|
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# D Indicator list available for the pilot studies

*Table 10 List of indicators compiled from literature in the beginning of the present project. A 'YES' in the 'First choice' column indicates the preference of the study group in the beginning of the project. This 'first choice' deviates from the indicator selection presented in Chapter 10. The column 'Data source' list possible sources for indicator data.*

| # | Type | Domain | Name | Definition | Unit | Issue | Relevance | Data source | First choice |
|---|---|---|---|---|---|---|---|---|---|
| 0T01 | Throughput | Airport | Area | Surface area of airport premises | [ha] | ? | To be used as scaling parameter | Annual reports | - |
| 0T02 | Throughput | Air Traffic | Aircraft movements | Arriving and departing aircraft per year | [a-1] | Activities | Determines disturbance from airport in airport operations system | Annual reports | YES |
| 0T03 | Throughput | Air Traffic | Aircraft movements at night | Arriving and departing aircraft 23:00-07:00 h per year | [a-1] | Activities | Determines night time disturbance in airport operations system | Annual reports | - |
| 0T04 | Throughput | Air Traffic | Aircraft movements per hour | Arrivals and departures of aircraft at x:00-(x+1):00, averaged over a year | [h-1] | Activities | Determines peak disturbances in aircraft operations system | Annual reports | - |
| 0T05 | Throughput | Air Traffic | Passengers | Arriving and departing passengers per year; transfer passengers counted once | | Activities | Determines air traffic and ground movement of passengers | Annual reports | YES |
| 0T06 | Throughput | Air Traffic | Cargo | Freight loaded and unloaded | [t x a- | Activities | Determines to some extent | Annual | - |

| # | Type | Domain | Name | Definition | Unit | Issue | Relevance | Data source | First choice |
|---|---|---|---|---|---|---|---|---|---|
| | | | | per year | 1] | | airport related activities in airport operations system | reports | |
| 0T07 | Throughput | Air Traffic | Airmail | Mail unloaded and loaded per year | [txa$^{-1}$] | Activities | Determines to some extent airport related activities in airport operations system | Annual reports | - |
| 0T08 | Throughput | Surface traffic | Passengers travel-ling by public transport | Number of passengers arriving and departing at the airport using public transport per year | | Activities | Determines nature of the 'burden' to the airport operations system by pas-sengers travelling to and from the airport | Annual reports | - |
| 0T09 | Throughput | Surface traffic | Fraction of annual number of passen-gers travelling by public transport | Number of arriving and departing passengers using public transport x 100 dividend by total number of non-transfer passengers [%] | | Activities | Determines nature of the 'burden' to the airport operations system by pas-sengers travelling to and from the airport | Annual reports | - |
| 0T10 | Throughput | Surface traffic | Airport staff arriving by public transport | Airport staff arriving by public transport averaged over a year | | Activities | Determines mode of home-work traffic. Is less relevant as a system indicator be-cause only airport staff is taken into account | Annual reports | - |
| 0T11 | Throughput | Surface traffic | Airport staff arriving by public | Airport staff arriving by public transport averaged | | Activities | Determines mode of home-work traffic. Is less relevant | Annual reports | - |

| # | Type | Domain | Name | Definition | Unit | Issue | Relevance | Data source | First choice |
|---|---|---|---|---|---|---|---|---|---|
| | | | transport | over year x 100 / Number of airport staff averaged over a year [%] | | | as a system indicator because only airport staff is taken into account | | |
| 0T12 | Throughput | Demographic | Distribution of income in airport operation system | Number of households in highest earning quintile / number of households in lowest earning quintile | | Health and quality of life | The indicator describes the income variation in the airport system, which may be related to health | | YES |
| 0T13 | Throughput | Demographic | Population density in the airport operation system stratified by age and income | Number of people in age group A and income group I / (area of airport operations system - airport area) | [$km^{-2}$] | Health and quality of life ?? | Relative measure for degree of disturbance in airport operations system | | - |
| 0T14 | Throughput | Demographic | Urbanisation ratio in the airport operation system stratified by age and income | Number of people in urbanised areas x 100 / total number of people living in airport operations system [%] | | Driver?? | Relationship with airport operations or related operations and with health probably very complex. Proxy for migration behaviour | | - |
| 0T15 | Throughput | Demographic | Employees in airport operations system | Number of people having paid jobs in airport operations system averaged over a year | | Driver?? | Measure for industrial activities and services in the airport operations system | | - |

| # | Type | Domain | Name | Definition | Unit | Issue | Relevance | Data source | First choice |
|---|---|---|---|---|---|---|---|---|---|
| 0T16 | Throughput | Demographic | Fraction of employees at the airport | Number of people employed at the airport premises averaged over a year / Number of people having paid jobs in airport operations system averaged over a year | | Driver?? | Measure for industrial activities and services in the airport operations system | | - |
| 1E01 | Environment | Noise | Fraction of population within noise intervals 55-65, 65-75, >75 dB (in Lden) | Number of people in airport operations system between noise contours N1 and N2 x 100 / Total number of people in airport operations system [%] | | Exposure | Noise exposure indicator. Relevant for noise related health effects. Should not be limited to aircraft noise. | Annual reports | YES |
| 1E02 | Environment | Noise | Fraction of population with a given Lden-interval and night-time noise intervals of <40, 40-50, >50 dB(A) | Number of people in airport operations system in Lden-interval L and between night noise contours NN1 and NN2 x 100 / Total number of people in Lden-interval L [%] | | Exposure | Night-time noise exposure indicator. Relevant for noise related health effects. Should not be limited to aircraft noise. | | YES |
| 1E03 | Environment | Noise | Peak levels above 85 dB(A) | Number of people exposed to peak level of 85 dB(A) at | | Environmental | Noise peaks may be relevant for annoyance, although | Annual reports | - |

| # | Type | Domain | Name | Definition | Unit | Issue | Relevance | Data source | First choice |
|---|---|---|---|---|---|---|---|---|---|
| | | | | least once a day x 100 / total number of people in airport operations system | | effects | opinions differ. | | |
| 1E04 | Environment | Noise | Fraction of houses within noise intervals | Number of houses in a given Lden-interval (or Lden - Lnight interval) x 100 / Total number of houses in airport operations system [%] | | Exposure | Noise regulations are usually based in dwellings | | YES |
| 1E05 | Environment | Noise | Fraction of chapter 2 aircraft arriving and departing | Annual number of chapter 2 aircraft arriving and departing x 100 / Total number of aircraft arriving and landing [%] | | Driver | Probably less relevant for Europe. Better indicator might be fraction of small airplanes. | Annual reports | - |
| 1E06 | Environment | Noise | Population highly annoyed by air traffic noise | Number of people in airport operations system highly annoyed | | Health and quality of life | Estimating the impact of noise by annoyance data (questionnaire). | | YES |
| 1E07 | Environment | Noise | Population highly annoyed by air traffic noise stratified to age | Number of people in airport operations system in age group A highly annoyed x 100 / Total number of people highly annoyed [%] | | Health and quality of life | Estimating the impact of noise by annoyance data (questionnaire) | | YES |

| # | Type | Domain | Name | Definition | Unit | Issue | Relevance | Data source | First choice |
|---|---|---|---|---|---|---|---|---|---|
| 1E08 | Environment | Ground noise | Number of engine running tests on screened-off test sites | Number of engine running tests on screened-off test sites per year | [$a^{-1}$] | Pressure | Often related to complaints. | Annual reports | - |
| 1E09 | Environment | Ground noise | Total time of engine running tests on screened-off test sites | Total time of engine running tests on screened-off test sites per year | [$hxa^{-1}$] | Pressure | Often related to complaints. | Annual reports | - |
| 1E10 | Environment | Air | Emissions of NOx by air traffic | Emissions of NOx by arriving an departing aircraft per year | [$txa^{-1}$] | Pressure | Air traffic impact on air pollution | Annual reports | - |
| 1E11 | Environment | Air | Emissions of NOx by airport handling operations | Emissions of NOx by airport handling operations per year | [$txa^{-1}$] | Pressure | Air traffic impact on air pollution | Annual reports | - |
| 1E12 | Environment | Air | Emissions of NOx by landside road traffic | Emissions of NOx by road traffic in the airport operations system but not on the airport premises per year | [$txa^{-1}$] | Pressure | Ground traffic impact on air pollution | Annual reports | - |
| 1E13 | Environment | Air | Emissions of CO by air traffic | Emissions of CO by arriving and departing aircraft per year | [$txa^{-1}$] | Pressure | Air traffic impact on air pollution | Annual reports | - |
| 1E14 | Environment | Air | Emissions of CO by | Emissions of CO by airport | [$txa^{-1}$] | Pressure | Air traffic impact on air | Annual | - |

| # | Type | Domain | Name | Definition | Unit | Issue | Relevance | Data source | First choice |
|---|---|---|---|---|---|---|---|---|---|
| | | | airport handling operations | handling operations per year | | | pollution | reports | |
| 1E15 | Environment | Air | Emissions of CO by landside road traffic | Emissions of CO by road traffic in the airport operations system but not on the airport premises per year | [$txa^{-1}$] | Pressure | Ground traffic impact on air pollution | Annual reports | - |
| 1E16 | Environment | Air | Emissions of VOC by air traffic | Emissions of VOC by arriving and departing aircraft per year | [$txa^{-1}$] | Pressure | Air traffic impact on air pollution | Annual reports | - |
| 1E17 | Environment | Air | Emissions of VOC by airport handling operations | Emissions of VOC by airport handling operations per year | [$txa^{-1}$] | Pressure | Air traffic impact on air pollution | Annual reports | - |
| 1E18 | Environment | Air | Emissions of VOC by landside road traffic | Emissions of VOC by road traffic in the airport operations system but not on the airport premises per year | [$txa^{-1}$] | Pressure | Ground traffic impact on air pollution | Annual reports | - |
| 1E19 | Environment | Air | Emissions of PM10 by air traffic | Emissions of PM10 by arriving and departing aircraft per year | [$txa^{-1}$] | Pressure | Air traffic impact on air pollution | Annual reports | - |
| 1E20 | Environment | Air | Emissions of PM10 by air traffic airport handling | Emissions of PM10 by air traffic airport handling operations per year | [$txa^{-1}$] | Pressure | Air traffic impact on air pollution | Annual reports | - |

| # | Type | Domain | Name | Definition | Unit | Issue | Relevance | Data source | First choice |
|---|---|---|---|---|---|---|---|---|---|
| | | | operations | | | | | | |
| 1E21 | Environment | Air | Emissions of PM10 by landside road traffic | Emissions of PM10 by road traffic in the airport operations system but not on the airport premises per year | [tx$a^{-1}$] | Pressure | Ground traffic impact on air pollution | Annual reports | - |
| 1E22 | Environment | Air | Emissions of $CO_2$ by air traffic | Emissions of $CO_2$ by arriving and departing aircraft per year | [tx$a^{-1}$] | Pressure | Air traffic impact on climate change | Annual reports | - |
| 1E23 | Environment | Air | Emissions of $CO_2$ by airport handling operations | Emissions of $CO_2$ by airport handling operations per year | [tx$a^{-1}$] | Pressure | Air traffic impact on climate change | Annual reports | - |
| 1E24 | Environment | Air | Emissions of $CO_2$ by landside road traffic | Emissions of $CO_2$ by road traffic in the airport operations system but not on the airport premises per year | [tx$a^{-1}$] | Pressure | Ground traffic impact on climate change | Annual reports | - |
| 1E25 | Environment | Air | Mean NOx-concentration at airport site | NOx-concentration at airport site averaged over a year | [μg x $m^{-3}$] | Environmental effect | Measure for local air pollution at the airport | Annual reports | - |
| 1E26 | Environment | Air | Number of times NOx-standard at airport site is exceeded | Number of hours per year the hourly standard is exceed at the airport site / Total number of hours per | [$a^{-1}$] | Environmental effect | Occurrences that air quality values are exceeded. Measure for local air pollution at the airport | Annual reports | - |

| # | Type | Domain | Name | Definition | Unit | Issue | Relevance | Data source | First choice |
|---|---|---|---|---|---|---|---|---|---|
| | | | | year when validated measurements were taken | | | | | |
| 1E27 | Environment | Air | Mean SO2-concentration at the airport site | SO2-concentration at the airport site averaged over a year | [μg x $m^{-3}$] | Environ-mental effect | Measure for local air pollution at the airport | Annual reports | - |
| 1E28 | Environment | Air | Number of times SO2-standard at airport site is exceeded | Number of days per year above daily standard / Total number of days per year when validated measurements are taken | [$a^{-1}$] | Environ-mental effect | Occurrences that air quality values are exceeded. Measure for local air pollution at the airport | Annual reports | - |
| 1E29 | Environment | Air | Mean O3-concentration at the airport site | O3-concentration at the airport site averaged over a year | [μg x $m^{-3}$] | Environ-mental effect | Measure for local air pollution at the airport | Annual reports | - |
| 1E30 | Environment | Air | Number of times O3-standard at airport site is exceeded | Number of hours per year the hourly standard is exceed at the airport site / Total number of hours per year when validated measurements were taken | [$a^{-1}$] | Environ-mental effect | Occurrences that air quality values are exceeded. Measure for local air pollution at the airport | Annual reports | - |
| 1E31 | Environment | Air | Mean PM10-concentration at the airport site | PM10-concentration at the airport site averaged over a year | [μg x $m^{-3}$] | Environ-mental effect | Measure for local air pollution at the airport | Annual reports | - |

| # | Type | Domain | Name | Definition | Unit | Issue | Relevance | Data source | First choice |
|---|---|---|---|---|---|---|---|---|---|
| 1E32 | Environment | Air | Number of times PM10-standard at airport site is exceeded | Number of hours per year the hourly standard is exceed at the airport site / Total number of hours per year when validated measurements were taken | [$a^{-1}$] | Environmental effect | Occurrences that air quality values are exceeded. Measure for local air pollution at the airport | Annual reports | - |
| 1E33 | Environment | Air | Fraction of the population in the airport operation system exposed to a PM10-concentration exceeding the standard | Number of people in the airport operations system exposed to an annual mean PM10-concentration exceeding the standard x 100 / Total number of people in the system [%] | | Exposure | Exposure to PM10 is associated with an impact on health. It is not possible to estimate a threshold level. Measure for local air pollution in the airport operations system | Annual reports | YES |
| 1E34 | Environment | Air | Mean CO-concentration at the airport site | CO-concentration at the airport site averaged over a year | [$\mu g \times m^{-3}$] | Environmental effect | Measure for local air pollution at the airport | Annual reports | - |
| 1E35 | Environment | Air | Number of times CO-standard at airport site is exceeded | Number of hours per year the 8-hourly standard is exceeded at the airport site / Total number of 8-hour periods per year when | [$a^{-1}$] | Environmental effect | Occurrences that air quality values are exceeded. Measure for local air pollution at the airport | Annual reports | - |

| # | Type | Domain | Name | Definition | Unit | Issue | Relevance | Data source | First choice |
|---|---|---|---|---|---|---|---|---|---|
| | | | | validated measurements were taken | | | | | |
| 1E36 | Environment | Air | Mean HC-concentration at the airport site | HC-concentration at the airport site averaged over a year | [$\mu g \times m^{-3}$] | Environ-mental effect | Measure for local air pollu-tion at the airport | Annual reports | - |
| 1E37 | Environment | Air | Mean BTX-concentration at the airport site (BTX - benzene, toluene, xylene) | BTX-concentration at the airport site averaged over a year | [$\mu g \times m^{-3}$] | Environ-mental effect | Measure for local air pollu-tion at the airport | Annual reports | - |
| 1E38 | Environment | Safety/ inci-dents | Number of reports filed at air traffic control and local, regional and national authori-ties | Number of reports filed at air traffic control and local, regional and national authorities per year | [$a^{-1}$] | Environ-mental effect | Weak indicator for preva-lence of incidents and near-accidents. May also measure willingness to learn from mistakes | Annual reports | - |
| 1E39 | Environment | Safety/ inci-dents | Number bird strikes | Number arriving and de-parting aircraft striking birds per year | [$a^{-1}$] | Activities | Indicator for aircraft safety | Annual reports | - |
| 1E40 | Environment | Safety/ inci-dents | Number of occa-sions that fuel was dumped | Number of aircraft that had to dump fuel before being allowed to land per year | [$a^{-1}$] | Activities | Aircraft that have to land shortly after take-off need to dump fuel. Weakly related | Annual reports | - |

| # | Type | Domain | Name | Definition | Unit | Issue | Relevance | Data source | First choice |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | or hardly related to health effects. Related to perception of safety | | |
| 1E41 | Environment | Safety/ incidents | Amount of dumped fuel | Amount of fuel dumped by aircraft before being allowed to land per year | [t x a] | Activities | Aircraft that have to land shortly after take-off need to dump fuel. Weakly related or hardly related to health effects. Related to perception of safety | Annual reports | - |
| 1E42 | Environment | Safety/ incidents | Number of persons killed by road traffic in the airport operations system | Number of persons killed by road traffic in the airport operations system per year | [a] | Effect | Measures traffic safety in airport operations system. May be indicator for overall transport safety | | YES |
| 1E43 | Environment | Water | Drinking water consumption at the airport | Volume of drinking water consumed at the airport per year | [m x a ] | Pressure | Determines environmental burden in system (waste water) | Annual reports | - |
| 1E44 | Environment | Water | Waste water discharge at the airport | Volume of waste water discharge at the airport per year | [m x a ] | Environmental effect | Determines environmental burden in system | Annual reports | - |
| 1E45 | Environment | Water | BOD of waste water op airport | Average BOD of airport waste water per year | [mg x l] [g x | Environmental | Determines environmental burden in system | Annual reports | - |

| # | Type | Domain | Name | Definition | Unit | Issue | Relevance | Data source | First choice |
|---|---|---|---|---|---|---|---|---|---|
| | | | (BOD - biological oxygen demand) | | $m^{-3}$] | effect | | | |
| 1E46 | Environment | Water | Amount of de-icing chemical used | Mass of de-icing chemical used per year | [kg x $a^{-1}$] | Activities | Determines environmental burden in system | Annual reports | - |
| 1E47 | Environment | Water | Fraction of de-icing fluid recycled | Amount of de-icing fluid recycled average over a year x 100 / Amount of de-icing fluid used in a year [%] | | Activities | Determines environmental burden in system | Annual reports | - |
| 1E48 | Environment | Energy | Electricity con-sumption at airport | Electrical energy consumed at the airport per year | [MWh x $a^{-1}$] | ? | Determines environmental burden; to a large extent outside the system | Annual reports | - |
| 1E49 | Environment | Waste | Amount of house-hold waste gener-ated at the airport | Total amount of household waste generated at the airport per year | [t x $a^{-1}$] | Pressure | Determines environmental burden; often outside the system | Annual reports | - |
| 1E50 | Environment | Landscape | Green space open to the public | Area of green space in the airport operations system outside the airport premises accessible to the public / Number of people living in the airport operations system | [$m^2$] | Environ-mental ef-fect/health and quality of life | Determines visual quality of the system. Has an impact on health and quality of life | | YES |

| # | Type | Domain | Name | Definition | Unit | Issue | Relevance | Data source | First choice |
|---|---|---|---|---|---|---|---|---|---|
| 2C01 | Community | | Number of complaints about airport operations system related activities | Number of complaints about airport operations system related activities per year | [a-1] | Health and quality of life | Indicates impacts on quality of life | Annual reports | YES |
| 2C02 | Community | | Fraction of complaints about a specific item: aircraft noise, odour, soot | Number complaints in a year about item C x 100 / Total number of complaints in a year [%] | | | Indicates impacts on quality of life; targets impact from aircraft | Annual reports | YES |
| 3P01 | Public Health | | Annual mortality rate stratified to age group | Number of deaths in age group A in a year x 100 000/ Number of people in age group A in a year | | Health and quality of life | General health indicator; not very sensitive | | YES |
| 3P02 | Public Health | | Annual mortality rate stratified to age group and cause of death | Number of deaths from cause D in age group A in a year x 100 000/ Number of people in age group A in a year | | Health and quality of life | General health indicator; not very sensitive | | YES |
| 3P03 | Public Health | | Prevalence of cardiovascular and respiratory dis- | Average number of cases in age group A x 100 000 / Number of people of age | | Health and quality of | General health indicator; is relevant for effects of noise, air pollution, anxiety | | YES |

| # | Type | Domain | Name | Definition | Unit | Issue | Relevance | Data source | First choice |
|---|---|---|---|---|---|---|---|---|---|
| | | | eases in a year stratified to age group | group A | | life | | | |