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The assessment and management of third party risk around a major airport

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Abstract

Schiphol, the main airport of the Netherlands, is growing rapidly. The aircraft movements, also growing in number, place a considerable environmental burden on the surrounding population, notably, noise and odour nuisance and risks. In the process of deciding on how to extend the capacity of the airport to accommodate the anticipated twofold growth in the number of movements with respect to 1990, environmental problems form a major concern. The concern about risks for the surrounding population was enhanced after the crash on 4 October 1992, in which a Boeing 747 cargo carrier bored into a block of flats in a suburb of Amsterdam near Schiphol. In this accident, the four crew members were killed, together with 39 inhabitants of the flats/apartment building. These risks were studied as part of the Environmental Impact Assessment (EIA). To make these studies useful for decision making necessitated a major improvement in the available techniques for risk quantification. The results of the quantitative analyses, using several different methods, have all indicated that the activities of Schiphol pose a considerable risk compared to other major industrial activities in the Netherlands. This paper describes the development of the methodology from 1990 in the light of the policy context in which it took place. Use of the methods in the decision-making process is illustrated by describing the current status of this process. © 2000 Elsevier Science B.V. All rights reserved.

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1. Introduction

The international airport of the Netherlands, Schiphol, is situated some 10 km southwest of Amsterdam, the capital of the Netherlands. The airport was founded in

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1916, with the first regular service, by KLM — Royal Dutch Airlines, taking place in 1920. On the occasion of the Olympic Games in Amsterdam in 1928, the airfield was equipped with tarmac runways — the first in Europe to have them. In the Second World War, the airport was completely destroyed. Rebuilding started after the war.

Since 1960, the number of movements at the airport has grown by an average rate of about 5.3% per year. This led to a large extension plan, which was executed during the sixties, giving the airport its present four-runway layout. Although growth slowed down considerably in the early eighties due to the second oil crisis, it picked up towards 1990 and accelerated. This increasing growth led to considerable problems, both with respect to the capacity of the airport and to the environment. These problems were enhanced by the rapid growth of the population of the Netherlands and the associated growth of the cities around Schiphol and Amsterdam, in particular. This is special because Amsterdam is located northeast of Schiphol, which is also the most common wind direction. In fact, the names of the runways now refer to the places where the most nuisance is caused (Fig. 1). In the present situation, the airport already poses a substantial noise problem; this led to 135,000 complaints in 1996.

At the end of the eighties, it was expected that the number of movements would double from 202,000 in 1990 to 420,000 in 2015.

The capacity on the ground and in the air is limited and further growth is only possible through a substantial expansion of the road and rail network, and the airway system. At least one more runway will also be needed, maybe not so much for capacity, but to decrease the noise nuisance.

The decision-making process is distinguished by two periods: (1) a preparatory phase in which potential solutions were investigated and a route to the future was set out (documented in the planning document, PASO [1], and (2) an approval phase, in which the Environmental Impact Assessments (EIA) were made.

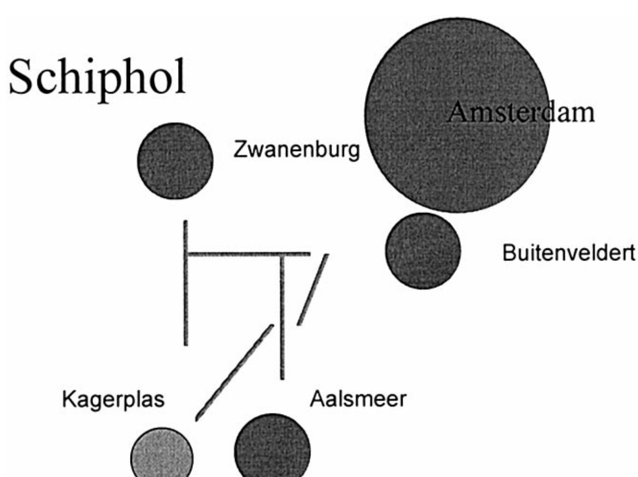

Fig. 1. Schematic view of Schiphol.

In the PASO document, two joint aims were defined for the future development of Schiphol airport:

- Schiphol should develop into a mainport; and
- The quality of the environment around the airport should improve.

One of the preferred ways of doing this implied the construction of a fifth runway.

To support the process that would lead to a decision on whether to expand the airport and how, studies were made on such aspects as the environmental consequences of several alternatives. One of these was ‘third party risk’. In the EIA, the risk for the surrounding population, also called third party risk for the alternatives selected in PASO, was considered.

These risks were considered in the light of the general policy for third party risks existing in the Netherlands.

2. The general policy

In a densely populated and highly industrialised country as the Netherlands, it is virtually impossible to reduce industrial-imposed third party risks to zero. Therefore, authorities and industry had to face the task of how to control these risks effectively. A significant fact in this respect is the considerable political pressure exerted by public opinion about these hazards.

The Dutch authorities have adopted a policy for risk management in environmental matters based on quantified techniques. This policy is described in the annex ‘Premises for Risk Management’ [2]—the National Environmental Policy document presented to the Dutch parliament in 1989. This document describes a regulatory framework based on quantification of risk and quantified risk criteria.

In Dutch environmental policy, two quantities used to measure risk have been defined.

Individual risk — the chance that a person staying at a fixed location permanently is killed as a result of an accident in the hazard source. It is expressed in units per year.

Societal risk — the chance that in a single accident in the hazard source, a certain number of victims is exceeded. It is expressed as the relationship between the number of people killed and the chance per year that this number is exceeded. (When this relationship is represented in a graph, in which the logarithm of the number (N) is plotted against the chance or frequency (F), it is referred to as the F–N curve.)

For each of these criteria, limits have been set. The limits for individual risk are limit values under the law and thus cannot be exceeded. The limits for societal risk are set as guidelines.

The current values of these limits for industrial facilities have been described in a letter of 1993 from the Minister of Housing, Spatial Planning and the Environment. For individual risk, the limit is set to 10^{-6} a^{-1} for new situations and 10^{-5} a^{-1} for existing situations. The limits for societal risk are set at $F = 10^{-3}$ N^{-2}.

The limits for the transport of dangerous goods were set in a document of 1996 by the Ministers of Housing, Spatial Planning and the Environment, and Transport, Public Works and Water Management [3]. For individual risk, the limit is again 10^{-6} a^{-1}. For societal risk, the limit is set as a limit per kilometer of the route, i.e., $F = 10^{-2}$ N^{-2}.

In these policy documents, airports and air traffic were not specially addressed. Nevertheless, a risk management policy for air transport had to be developed in the light of these existing limits (see Section 5).

3. Risk studies

The studies on the third party risk around Schiphol airport can be divided in two groups: (1) studies in the PASO period and (2) studies done for the policy statement of the government.

The studies done in the PASO period, performed by Technica [4–7], indicated not only that the risk would increase considerably, but also that this risk exceeded prior intuitive expectations to the extent that a serious political problem could be expected in the light of the official governmental policy on third party risk [2]. Almost all studies associated with PASO, e.g., noise and air pollution, were published together with the

Table 1

Airport	Primary method	Author	Year
Burbank Hollywood, USA	Solomon	Solomon	1974
Sydney, Australia	ACARRE	Anon	1990
Amsterdam Schiphol, Netherlands	Technica	Smith	1990
Rotterdam, Netherlands	NLR	Loog	1991
Kuala Lumpur, Malaysia	Technica/4-Elements	Irvine	1992
Amsterdam Schiphol, Netherlands	NLR	Piers	1993
Amsterdam Schiphol, Netherlands	EAC-RAND	Hillestad	1993
Netherlands Army Heliport	NLR	Giesberts	1994
Groningen Eelde, Netherlands	NLR	van Hesse	1994
Manchester, UK	Technica	Purdy	1994
Manchester, UK	Joint Action Group	Eddowes	1994
Amsterdam Schiphol, Netherlands	NLR	van Hesse	1995
Helsinki Vantaa, Finland	IVO International/NLR	Aho	1995
Helsinki Vantaa, Finland	NLR	Loog	1995
London Heathrow, UK	NLR	Piers	1996
Groningen Eelde, Netherlands	NLR	van Hesse	1996
Amsterdam Schiphol, Netherlands	NLR	van Hesse	1996
New Rotterdam Airport	NLR	van Hesse	1997
London Heathrow, UK	NATS	Evans	1997
London Gatwick, UK	NATS	Evans	1997
Manchester Airport, UK	NATS	Evans	1997
Birmingham Airport, UK	NATS	Evans	1997
Leeds Bradford Airport, UK	NATS	Evans	1997
Second Syney Airport, Australia	Technica/4-Elements	Anon	1997
Maastricht Aachen Airport	NLR	Pikaar	1998
Future Airport Island North Sea	NLR	Pikaar	1998
Future Airport Flevoland	NLR	Pikaar	1998
Future Airport Maasvlakte	NLR	Pikaar	1998
Kastrup Stockholm, Denmark	NLR	van Deenen	1999

PASO document. However, the publication of the risk studies has been suspended to create time for the government to formulate a policy statement.

As part of the preparation for such a statement, NLR was asked to review the Technica methodology and develop appropriate additional and improved methods. In the course of these studies, which in all took more than 10 years, the methodology was completely revisited. In this period, a total of 17 airports were analysed, out of which 12 used the methods developed in these projects in the various states of their development. Table 1 gives a survey of the analyses done, together with the method used.

Before the government could formulate a policy on air traffic regarding third party risks, a Boeing 747-200 lost two engines just after take-off on 4 October 1992. In an attempt to return to the airport for an emergency landing on the Buitenveldert runway, control was lost and the aeroplane crashed into a multi-story apartment/flat building. Some 50 flats were destroyed and 39 people killed on the ground. The four persons aboard the aircraft also lost their lives.

This accident raised the awareness of public and policy makers, forcing the question about what to do with these kinds of risks out into the public debate.

4. Risk analysis methodology

The method used to calculate third party risk around airports consists of three main elements. First, the probability of an aircraft having an accident in the vicinity of the airport must be determined. This probability depends on the probability of an accident per aircraft movement (landing or take-off) and the number of movements carried out per year. The probability of an accident per movement, the accident rate, is determined from historical data.

The local probability of an accident is not equal for all locations around the airport. The probability of an accident in the proximity of the runways is higher than at larger distances from the runways. Also, the local probability of an accident is larger in the proximity of routes followed by arriving and departing air traffic routes. This dependence is represented in an accident location probability model, which is the second main element of the third party risk assessment methodology. The accident location probability model is based on historical data for accident locations.

Effects of accidents may have lethal consequences at considerable distances from the impact location. The dimensions of the accident area and the lethality of the accident effects, as a function of the aircraft parameters, impact parameters, and possibly terrain, are defined in the consequence model, the third main element of the third party risk assessment methodology.

Individual and societal risk can be calculated through the combination of the three main elements described above and input data describing the specific airport, its surroundings and its air traffic.

4.1. Accident probability

The determination of accident rates for specific applications is a relatively straightforward activity, carried out regularly by many organisations throughout the world. For this reason, specific accident rate models for third party risk calculations are not reviewed here. This section describes instead the general characteristics of determining accident rates for third party risk calculation purposes.

Because aviation is a safe mode of transportation, resulting in a very small number of accidents at a particular airport, the accident rate cannot be determined reliably using only the data from the airport under investigation. To achieve an adequate statistical basis, data from other airports must be used as well. Since large differences exist between accident rates for different world regions, different categories of aircraft, different types of operation, etc., the accident rate calculated from a large data set can therefore not simply be applied to a particular airport. The accident rate must be calculated from a selection of the data considered representative for the airport under investigation in order to arrive at results specific to the airport. Because the results of the risk analysis must be reasonably reliable, applying many selection criteria to make the calculated accident rate airport specific must be carefully balanced with the need to have enough data remaining from a statistical point of view. The collection of a large database for accident and aircraft movements is thus an important prerequisite. The NLR database, for example, was compiled from 13 sources. The resulting database contains some 25,000 relevant accidents.

After data selection, the accident rates can be calculated through a statistical fitting process of annual data to number of years, which subsequently allows the estimation of future accident rates. For the Schiphol analysis, the following were the selection criteria used.

Period	1976–1989
MTOW [2]	> 5700 kg
Distance to the airport from origin or destination	< 26 km
Number of movements on the airport	$< 150{,}000$
Crashes outside the airfield	
Civil aviation only	
No helicopters	
Area	Western Europe, North America, New Zealand

Using these criteria, 76 relevant accidents remained for determining the accident ratio. The resulting accident ratio was 0.4×10^{-6} per movement for take-off and 0.21×10^{-6} for landing.

4.2. The accident location probability model

The accident location probability model defines the local probability of an accident provided an accident occurs; in other words, if an accident occurs, this model describes the probability that the accident aircraft will end up at a particular location. The way accident locations are distributed throughout the area before and after the runway,

[2] MTOW: Maximum Take-Off Weight.

considered not to be time-dependent, allows the distribution of accident locations in the past to be used to predict the distribution of accident locations in the future.

The accident location model is difficult to develop due to a general lack of accurate accident location data (80% of available accident reports do not contain an adequate description of the accident location). This model determines the distribution of the risk around the airport and hence the shape of the individual risk contours, and the risk levels, in populated areas; this translates into societal risk.

A few different approaches to accident location modelling for airports have been developed over the years; these can be separated into the three categories described below.

4.2.1. Nondependent accident location probability models (Category I)

Category I models [8–10] effectively divide the area around a schematic runway into angular segments and range brackets, and count the number of historical accident locations in each of the resulting cells. For a given accident, the probability of an impact in a cell is found by dividing the number of historical accident locations in that cell by the total number of historical accident locations. An advantage of Category I models is their simplicity. This way of modelling is convenient because accident reports often use a notation of the angular distance between the accident location and the extended runway centre line, and the distance of the accident location to the runway threshold. In principle, this method could lead to useful results; however, in practical applications (see Solomon [9]), the numbers are used as such, without fitting them to a continuous distribution of accident location probabilities over the area. In this way, erroneous results may be obtained.

4.2.2. Runway referenced accident location probability models (Category II)

Category II models [11–16] use historical accident location data to derive mathematical functions describing the impact probability for a particular location as (1) a function of the distance between that location and the extended runway centre line and (2) the distance of that location to the extended runway threshold. The consistent use of continuous distribution functions leads to more accurate and stable results than those of method I.

4.2.3. Traffic-route referenced accident location probability models (Category III)

Category III models [4–6,17–19,23] use historical accident location data to derive mathematical functions describing the impact probability for a particular location as a function of the (longitudinal) distance to that location from the runway threshold along the intended route and the perpendicular (lateral) distance from the route to that location (curvilinear coordinates). Therefore, these models allow the representation of traffic routing in the risk calculation. Category I and II models lack this property. The rationale for Category III models is that the location of an accident relative to the runway is strongly influenced by the intended route of the aircraft. The desire to build route-dependent models further reduces the already scanty useful data since, in many cases, the intended route is not mentioned in the accident report.

The more relevant data points are used in the derivation of the model parameters, the more accurate the model can be expected to be. Earlier models [Technica] and models developed to get a feel for the risks rather than accurate risk contours [RAND] involve very small data sets (e.g. 20 accident locations). Others are based on large data sets and a more elaborate modelling effort.

NLR has developed a set of eight separate curvilinear accident location models for take-off accidents, landing undershoot accidents and landing overrun accidents for heavy traffic (large aircraft) and light traffic (small aircraft).

The following criteria used to select accidents from the data set, of which the locations are used in the development of accident location models, are different from those used for the calculation of the accident ratio.

Civil fixed-wing aeroplanes	
Heavy traffic	MTOW $>$ 5700 kg
Light traffic	1500 $<$ MTOW $<$ 5700
Accident location within 26 km of origin or destination from the airport.	

The number of data points differs for the various (sub-)models between 30 and 130.

4.3. The accident consequence model

The consequences of an accident in terms of the size of the accident area and the lethality of the effects inside the accident area are defined in the consequence model. The only consequences considered in third party risk analysis for airports are fatal injuries to people on the ground as a direct result of an aircraft accident. Many aircraft-, impact-, and environment-related factors determine the accident consequences. Ideally, consequence models should correctly reflect the influence of each parameter, which will not affect the accident consequences.

Consequence models for risk analysis for airports can also be separated into three categories, as described below.

4.3.1. Subjective estimation accident consequence models (Category I)

Category I consequence models [9,19] are subjective estimates of the sizes of consequence areas and lethality inside those areas. Category I models originate from studies which attempt to represent many causal relations in the consequence model, while adequate accident data to support the statistical derivation of these causal relations are not available and hence must be estimated by the analyst.

4.3.2. Deterministic accident consequence models (Category II)

Category II models [4–6,20,21] are estimates of the size of consequence areas based on analytical modelling of the lethal effects, sometimes with reference to small sets of accident reports. An advantage of this approach is that it is fairly easy to model the difference in effects between large and small aircraft and between take-off accidents and landing accidents, since these differences can be expressed in terms of the amount of fuel onboard the aircraft. However, the analytical models tend to overestimate accident consequences. Analytical models require extensive input of parameters for which there is no adequate data from aircraft accidents. This necessitates many conservative assumptions. Examples are the percentage of accidents in which a fireball will develop, (fireballs are not often observed in aircraft accidents and are not specifically addressed in accident reports) and the implicit assumptions in the pool fire scenario. Pool fire models model a pool fire as a particular amount of fuel released on a flat concrete surface. In reality, the effects of absorption of fuel by the soil, the leakage of fuel into sewage systems and the fact that actual terrain does not resemble a flat plate, but is uneven (resulting in smaller pools with deeper areas) reduce the effects of fuel fires outside airports quite considerably. [3]

4.3.3. Probabilistic accident consequence models (Category III)

Category III models [12,22,23] are statistical models of the size of consequence areas and lethalities as a function of the maximum take-off weight of the aircraft, solely based on accident data derived from many accident reports. Hence, these models do not involve assumptions or subjective estimates other than those implicitly present in the accident reports themselves. Category III models are derived from: (1) the fact that the influence of the aircraft parameters (weight, size, fuel load, etc.) is well represented in a single parameter, i.e., the aircraft weight, and (2) the notion that since the impact parameters for a particular future accident cannot be predicted, knowledge on the influence of impact parameters is of limited utility in third party risk analysis. The available accident data and hence a model based on these data are considered to be representative of the combined influence of impact parameters as they occur in reality.

In the model developed for Schiphol airport, the size of the crash area was estimated from 40 accident reports and found to be correlated with the MTOW and the type of terrain. For the heavy aeroplanes, which are relevant for Schiphol, the sizes of the crash areas were found to be 150, 200 and 250 m^2/ton MTOW for wooded, built-up and open terrain, respectively.

5. Risk results and context

The methodology developed and the results of the studies were published as part of the series of reports constituting the EIA [23,24]. Calculations were made for Schiphol as it was in 1990 and an extensive series of potential alternative developments for the future. Fig. 2 gives the individual risk contours for the proposed extension of Schiphol with a fifth runway and a traffic volume of 430,000 movements per year. Fig. 3 gives the societal risk F–N curve. Although the methodology used in these studies differed from Technica's, the NLR reports largely confirmed the results of the earlier studies.

The risk results for Schiphol can be judged in the context of the aims set out in the PASO document and in the context of the risks quantified in the process of executing the policy for industrial sites.

[3] For this reason, the good correlation found by Technica between the size of the pool-fire predicted by their model and the size of that of an actual accident, must be considered with care; the reference accident occurred on the runway, which almost ideally matches a flat concrete surface.

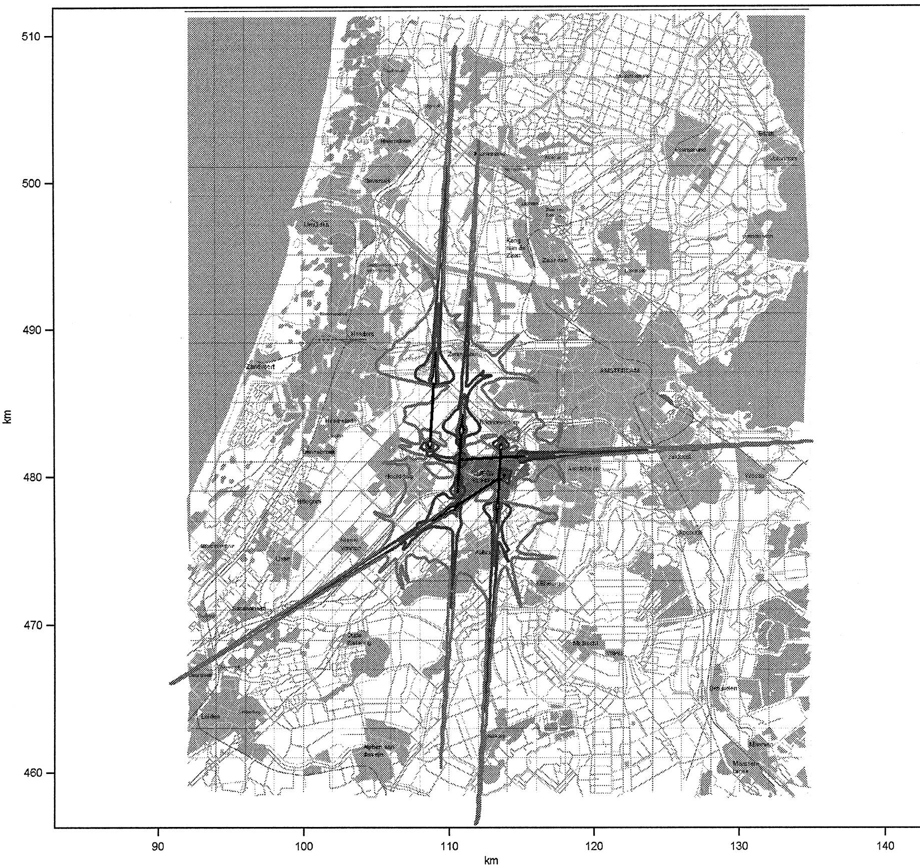

Fig. 2. Individual risks for Schiphol 2015.

The expected development of the individual risk [25–27] can be seen in Table 1, where the numbers of people exposed to risks of a certain level are given for 1990 (the reference year), 2003, the year in which the construction of the fifth runway should be completed and 2015, the time horizon of the plan. The numbers there can be seen to rise significantly; it can also be seen that considerable numbers of people are exposed to risks above a level considered acceptable for chemical installations in the Netherlands (see Section 2).

The societal risk also grows. The risks can be compared with the accumulated societal risk of the so-called major hazard installations. These are the installations of which the hazards are under mandatory control on account of a directive of the European Union [28]. This comparison [29] and the comparison with the risks of transport of dangerous goods through the Netherlands by rail and road (Fig. 4) show that in terms of disaster potential, the risk of Schiphol, which accounts for almost all air traffic risk, can be called substantial.

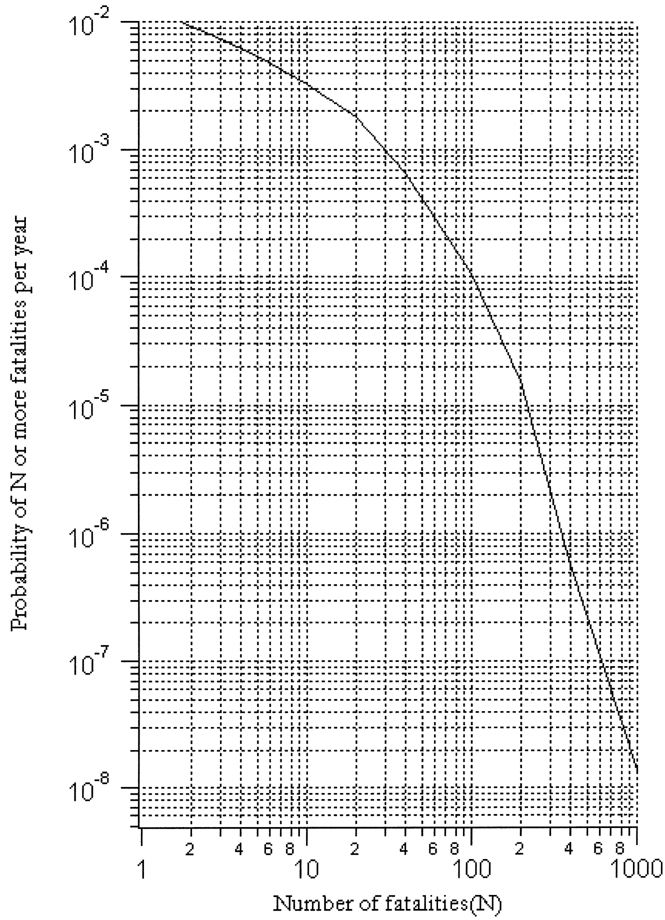

Fig. 3. Societal risks for Schiphol 2015.

Were Schiphol to be considered in the same way as industrial sites in the Netherlands, either a substantial demolishing of houses or a substantial reduction of the Schiphol's activities would be the result.

Schiphol could also be considered as a system of air transportation routes. However, even when the societal risks for the route are calculated per kilometer, limits set for transport as described in Section 2 cannot be met.

In view of the major economic importance of Schiphol, the government has decided to accept these societal risks. It was also decided to accept the increase in the numbers of people exposed to individual risks greater than 10^{-5}. A policy has been adopted to control the further growth of the risks and to reduce the numbers of people exposed to individual risks higher than 10^{-5}. In addition, the sum total of the individual risk at the location of each dwelling within the 10^{-5} and 10^{-6} contour may not increase. This summed risk is equal to the expected number of deaths per year assuming an occupation of only one person per house.

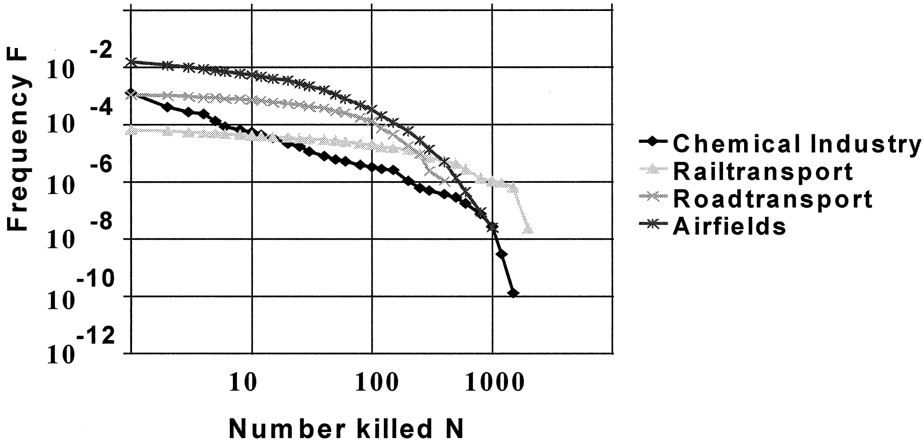

Fig. 4. Societal risks in the Netherlands.

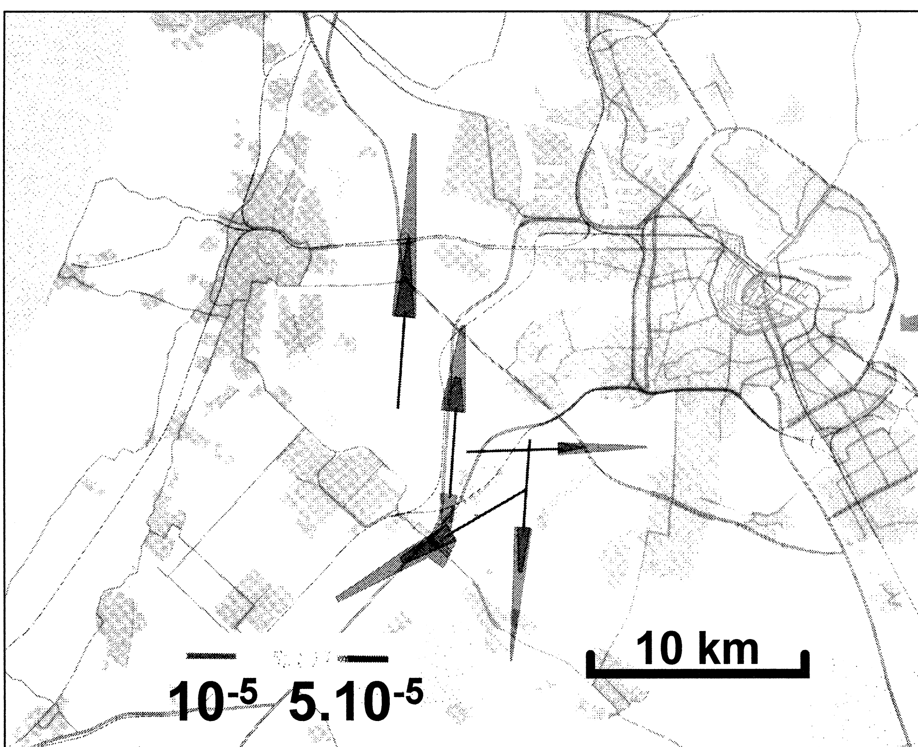

Fig. 5. Zoning system around runway ends. In the inner zone, all houses will be removed; while in the outer zone, no new housing developments will be allowed.

In the risk control policy, a zoning system was designed on the basis of the results of the risk calculations. There are two zones: an outer and an inner one. The outer zone is based on the 10^{-5} individual risk contour. In this zone, no additional building is allowed. In the inner zone, based on the 5×10^{-5} individual risk contour, houses will be removed (Fig. 5). Additional removal of houses inside the outer contour will be considered, depending on the further development of the risk, which will be monitored, for instance, using yearly *Environmental Balances* issued by RIVM [30].

6. Uncertainties

There are several uncertainties with respect to calculation of the risk, the development of Schiphol airport and the future of the risk policy.

The rate of growth of Schiphol has proven to be much higher than was expected in 1990, mainly due to the commercial success of KLM and its partners. As a result, the number of movements in 1998 will be 380,000; Schiphol is expected to reach the 430,000 movements' mark as early as 2002. If the growth of the airport continues at this rate, the number of movements in 2015 will be four to five times the number in 1990

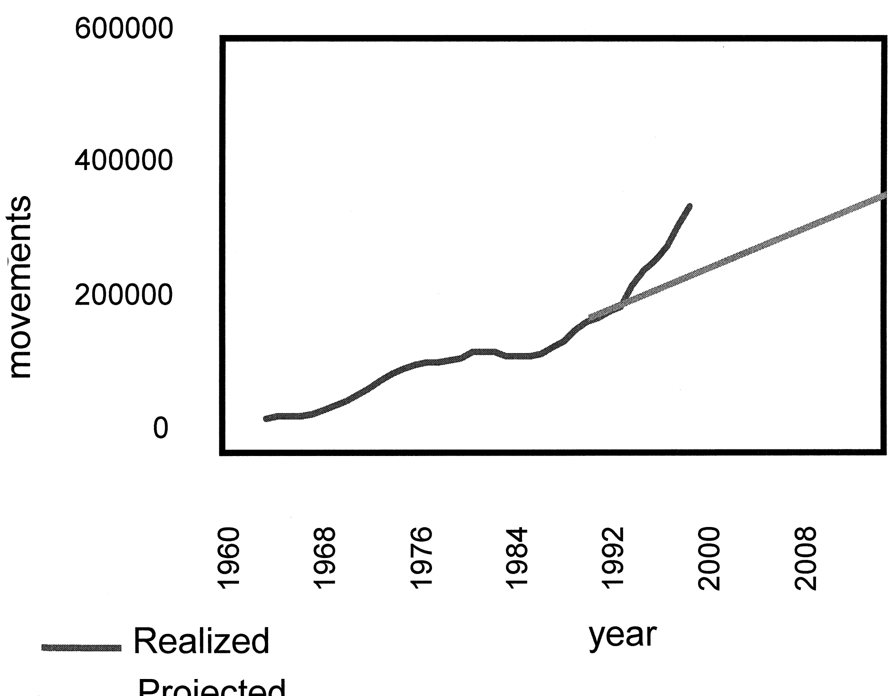

Fig. 6. The growth of the number of movements at Schiphol as they are realised and the projection that was used in the decision-making process.

Table 2
Number of people exposed to risk

Risk level	5×10^{-5}	1×10^{-5}	1×10^{-6}	1×10^{-7}
Year				
1990	24	230	7400	98,000
2003	0	970	7300	137,000
2015	0	1170	8500	158,000

rather than twice that number. It is obvious that the problems regarding third party risks will be seriously aggravated.

On the other hand, there are a number of developments in terms of the risk estimate, leading to lower estimates of the risks.

In Fig. 6, the correlation of the size of the crash area with the MTOW, as used in the present model, is plotted together with data obtained after the Schiphol studies were finished. From the figure, it can be seen that a further evaluation of the data assembled is expected, since the studies made for the EIA will lead to a smaller crash area than used in the calculations until now.

There is a considerable bandwidth in the estimates of the crash frequency, as indicated in Table 2.

From recent publications, there seems to be a considerable reduction in accident rates among different generations of aeroplanes. An extension of the model that would make distinction between these generations possible in combination with the continuous renewal of the fleet will probably lead to lower accident probabilities per movement around Schiphol (Fig. 7; Table 3).

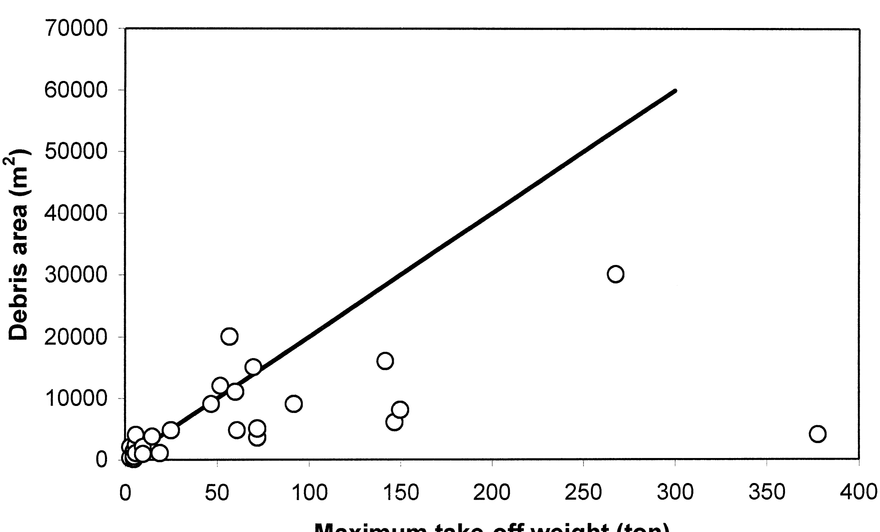

Fig. 7. Current estimate of the crash area for heavy traffic and built-up terrain compared with recent data.

Table 3
Accident ratios as quoted in different reports

Report	Landing	Take-off	Total
Technica [3]	0.22	0.57	0.79
Technica [4]	0.21	0.37	0.58
NLR [9]	0.65	0.43	1.08
RAND	0.32	0.95	1.28

However, how these developments will balance the effects of the growing traffic volumes is as yet unclear and subject of further ongoing analysis.

7. Conclusion

The third party risks around a major airfield are significant. As airports attract housing developments, a serious land-use planning problem is posed. The quantification of these risks is feasible and helps the decision-making process.

For Schiphol, a statement in principle has been made regarding the development of these risks in the future. However, measures in line with previous policies or statements of principle made by the authorities with respect to the development of the quality of the environment have only been indicated in general, but not defined.

Since 1990, the rate of growth of the number of movements at Schiphol has been more than double the anticipated rate. The current estimate is that in or around the year 2015, the traffic volume at the airport will be more than four times rather than twice the 1990 volume (Fig. 7). This again raises the question of whether the volume can be accommodated on the present location of the airport in view of the considerable risk or whether alternative locations will have to be found.

Although the techniques to calculate these risks have been improved in the period since 1990, it is believed that further major improvements are needed to keep the models up to par with the political challenges posed by the expected growth.

7.1. Disclaimer

Any opinions expressed in this paper are those of the authors and do not necessarily reflect the position of RIVM or the NLR.

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