THE DEVELOPMENT AND APPLICATION OF A METHOD FOR THE ASSESSMENT OF THIRD PARTY RISK DUE TO AIRCRAFT ACCIDENTS IN THE VICINITY OF AIRPORTS

ICAS-94-6.2.1

by Michel A. Piers

National Aerospace Laboratory NLR
Amsterdam, the Netherlands

Abstract

Third party risk due to aircraft accidents around airports is an increasingly important factor in airport growth- and suburban development planning. Objective and accurate risk information is required to support the decisionmaking process. The National Aerospace Laboratory NLR has developed a method for the calculation of local risk levels around airports. The models used in this method to describe the accident probability, the accident location probability and the accident consequences, are based on data derived from accident reports. Calculation results are presented as iso-risk contours on maps of the airport area. This paper describes the method and its successful application in support of decisionmaking on the growth plans of Schiphol airport of Amsterdam.

1. Introduction

Airports are hubs in the airtransportation system. Consequently, their presence causes a convergence of airtraffic over the area surrounding the airport. For the population living in the vicinity of an airport this implies involuntary exposure to the risk of aircraft accidents. Although the public is generally aware of the fact that flying is a very safe mode of transportation and hence the probability of an accident is very small, the frequent noise associated with aircraft passing overhead nevertheless acts as a strong reminder that sooner or later one may come down. While this may seem irrational, actual local risk levels around airports are higher than one might expect. Although the probability of an accident per flight is very small (typically in the order of 1 in one million), accidents tend to happen during the take-off and landing phases of flight and hence close to an airport. In addition, the small probability of an accident per movement is combined with the large number of movements (typically several hundred thousand) to arrive at the probability of an accident per year. This probability is of course much greater than the well known and very small probability of being involved in an aircraft accident as passenger. Local risk levels around large airports consequently are of the same order of magnitude as those concerned with participation in road traffic. Because an increase in airport capacity usually involves changes to runway lay-outs, route structures and traffic distributions which in turn affect the risk levels around the airport, third party risk is an important issue in decisionmaking on airport development.

Major airport development plans, such as building additional runways, invariably involve government decision making and public inquiries. Therefore, public perception of the local consequences of developments is of paramount importance. This applies in particular in the Netherlands, where the El Al Boeing 747 accident in suburban Amsterdam occurred while the dutch government was carrying out the environmental impact analysis for further development of Amsterdam Schiphol Airport. The plans of Schiphol involve more than doubling its current capacity, a.o. by adding a fifth runway.

In order to prevent a predominantly emotion-driven role of third party risk in the evaluation of airport development options, objective and accurate risk information is required to provide guidance to local and national government, the population around the airport and the airport authorities. Because no adequate method for third party risk assessment did exist world wide, the National Aerospace Laboratory NLR of the Netherlands was contracted by the netherlands government to develop a comprehensive method for the assessment of third party risk around airports and to apply this method to the Schiphol development plans.

2. Definitions of risk

In order to investigate third party risk around airports, objective measures of risk are required. Risk is generally defined as a combination of the probability of an event and the severity of that event. For third party risk analysis two dedicated measures of risk are often used: individual risk and societal risk.

Individual risk is defined as:

the probability (per year) that a person permanently residing at a particular location in the area around the airport is killed as a direct consequence of an aircraft accident.

Societal risk is defined as:

the probability (per year) that more than N people are killed as a direct consequence of a single aircraft accident.

While individual risk is location specific, it is present regardless of whether or not someone is actually residing at that location. Societal risk applies to the entire area around the airport and hence is not location specific within that area. Societal risk only exists when people are actually present in the area around the airport. In an unpopulated area, individual risk levels may vary from location to location but societal risk is zero by definition.

In order calculate risk in terms of the risk measures defined above, a methodology was developed by NLR under contract with the Ministry of Transport and Public Works of the Netherlands. This method and the models employed are described in the next paragraphs.

3. Methodology

The method used to calculate third party risk around airports consists of three main elements. First, the probability of an aircraft accident in the vicinity of the airport must be determined. This probability depends on the probability of an accident per aircraft movement and the number of movements (landings and take-offs) carried out per year. The probability of an accident per movement, the accident rate, is based on historical data on numbers of movements carried out and the number of accidents which occurred during these movements. The accident rate is not constant over time. Due to a steady improvement in the level of safety of aviation, the accident rate decreases with a diminishing rate over the years. The development of the accident rate over time is modelled by a statistical function which can subsequently be used for extrapolations to estimate future accident rates. Since large differences in safety levels exist between different types of operation and different regions of the world, a careful data domain definition is required to render airport specific results. After the accident rate has been determined and is combined with the number of movements in a particular year, the probability of an accident in that year is known. If this probability would be equally distributed around the airport, this probability could be represented by a cylinder, centered around the airport, with the height of the cylinder representing the local probability of an accident (Fig. 1).

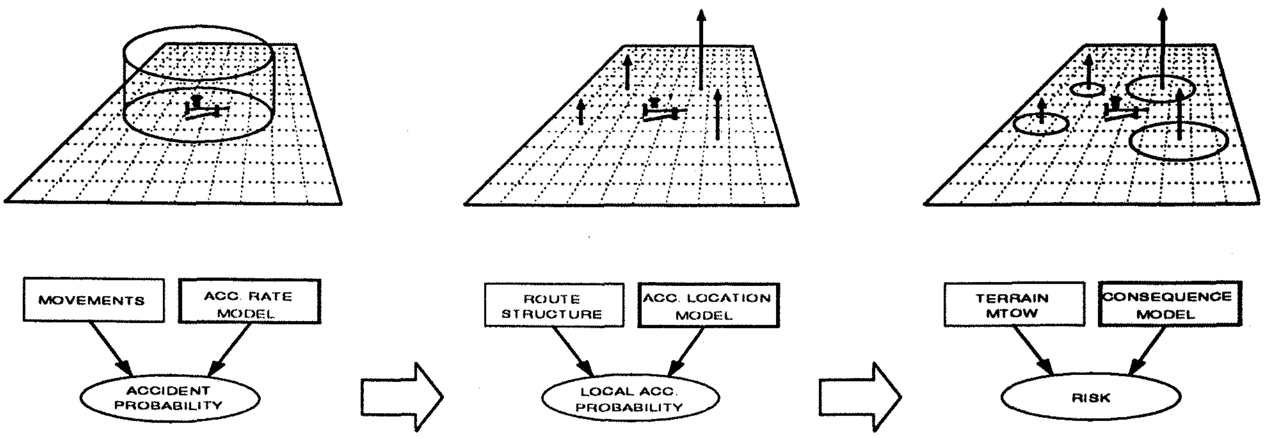

Figure 1 *Three main elements of third party risk analysis for airports.*

In reality, 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 dependent on the proximity of routes followed by arriving and departing airtraffic. The probability of an aircraft accident is larger in the proximity of a route and decreases with an increasing distance. Consequently, the local probability of an accident is strongly dependent on the position of the location relative to runways and 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 on accident locations. The distribution of accident locations relative to arrival and departure routes is modelled through statistical functions. By combining the accident location probability model with the accident probability, the local probability of an accident can be calculated for each location in the area around the airport. This probability can be presented as a local vector of which the length indicates the local accident probability (Fig. 1).

A person residing in the vicinity of an airport is not only at risk when an aircraft accident occurs at this persons exact location, but also when an accident occurs in this persons close proximity. The accident consequences may have lethal effects at considerable distances from the impact location. The dimensions of the accident area are not only a function of the aircraft and impact parameters but also of the local type of terrain and obstacles. Consequently, the size of the accident area is not equal for every location around the airport (Fig. 1). The influence of the aircraft and impact parameters and the type of terrain on the size of the accident consequence area as well as the lethality of the consequences are defined in the consequence model, the third main element of the third party risk assessment methodology.

Through the combination of the three main elements described above, individual risk and societal risk can be calculated. To calculate the individual risk level for a particular location (x,y), the sum must be determined of the local accident probability at (x,y) and the local accident probabilities of all locations in the proximity of (x,y) of which the accident area overlaps location (x,y). This sum in combination with the lethality of the accident consequences yields the individual risk at location (x,y).

Societal risk is determined by calculating the probability of more than N victims in case of an accident, for each location in the area around the airport using the consequence model and information on the local population density. This probability is multiplied by the local probability of an accident which renders the local probability per year of more than N victims. By summing this probability for all locations around the airport the probability per year of more than N victims for the entire area around the airport is found, which is societal risk.

4. Accident probability

Because aviation is a safe mode of transportation and hence the number of accidents at a particular airport is very small, an accident rate can not 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 dataset can however not simply be applied to a particular airport. The accident rate used in third party risk analysis must be tailored to the characteristics of the airport under investigation. This requires knowledge on the relation between the accident rate and causal factors in the characteristics of the airport including its environment (weather, terrain, etc.) and the characteristics of the prevailing traffic. To that end NLR has collected a large worldwide database of accidents and movements. The most important criteria of the data domain definition are :

- timeframe 1976-1990
- civil, fixed wing aircraft with maximum take-off weight > 5700 kg
- flightphases: approach, landing, takeoff, initial climb
- accidents at runways excluded

Since none of the available sources provides complete information, the information from 13 sources (ICAO ADREP, Flight Int., AISL, CAA DORA 8924, CAA CAP 479, NTSB, Kimura, CAA Digest, FAA, Flight Safety Digest, Lloyds list, FTBI, Boeing) was combined. The resulting database of some 1100 accidents is considered the most complete database of its kind available. Movement data for the same timeframe was collected mainly from ICAO. Since the ICAO data is assembled from voluntary reports submitted to ICAO by airports, it is not always complete and manual editing is required to fill in the omitted data. ICAO data for the USA was replaced by FAA data because ICAO data for the USA is generally incomplete.

The collected data was found not to support the quantitative identification of detailed cause-effect relations with regard to the accident rate. The primary obstacle to calculating the influence of particular causal factors on the accident rate, is the fact that the available movement data does usually not allow a subdivision in movements based on the same causal considerations. One might for example be well able to establish the number of accidents in which crew fatigue was a causal factor, but the number of movements during which the crew was fatigued can not be determined and consequently the influence of crew fatigue on the accident rate can not be calculated. The often limited information on causation and contributing factors in accident reports and the fact that many causal factors usually interact, hamper the identification of quantitative influences on the accident rate of individual causal factors as well.

Since the currently available data does not support the identification of detailed quantitative cause-effect relations, an airport specific accident rate can not be derived from the general worldwide accident rate through corrections based on the characteristics of the airport under investigation and its prevailing traffic.
Consequently, the accident rate must be calculated from data collected from a data domain which is considered representative for the airport under investigation. Because the results of the risk analysis must be reasonably reliable, the application of 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. For example in the Schiphol case, two selection criteria were applied to the data in addition to the domain criteria described above. First the large regional differences in safety were accounted for by only using data from western europe, north america, australia, new zealand and a selected asian countries. A second criteria was applied because significant differences in accident rates for large airports and smaller airports were identified in the data. These differences are caused by differences in the operational standard of the airports, their facilities and the prevailing traffic. This effect was accounted for by only using data from airports exceeding 150,000 annual movements. After the additional rejection of a few individual accidents due to non-representative accident conditions, the remaining accident and movement data was used to calculate yearly accident rates. The behavior of the accident rate over time was statistically modelled and the resulting statistical function was used to calculate current and future accident rates which are considered representative for airports like Schiphol.

5. The Accident Location Probability Model

The accident location probability model is a two-dimensional probability density function which defines the local probability of an accident provided the occurrence of an accident. In other words, if an accident occurs, this models describes the probability that the accident aircraft ends up at a particular location. The way accident locations are distributed in the area before and after the runway is considered not to be time-dependent and hence the distribution of accident locations in the past can be used to predict the distribution of accident locations in the future.
The location of an accident relative to the runway is strongly influenced by the intended route of the aircraft. A model which is based on historical accident locations relative to the runway (and hence disregarding the intended route) does therefore not adequately model the distribution of the accident location probability for a particular runway-route combination. Instead a model based on the curvi-linear coordinates (s,t) of accident locations must be defined (Fig. 2).

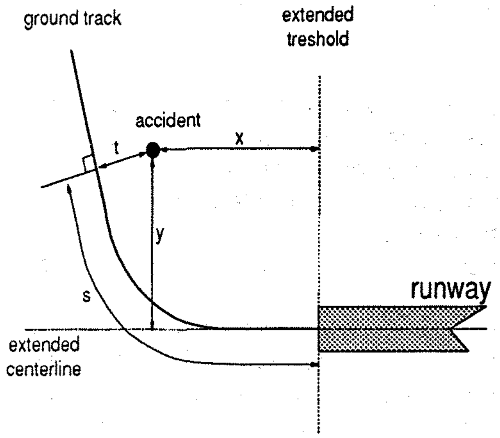

Figure 2 *The accident location relative to the route (s,t) or the runway (x,y).*

In this model, s denotes the (longitudinal) distance to the accident location from the runway threshold along the intended route and t denotes the perpendicular (lateral) distance from the route to the accident location. The curvi-linear model must be transformed into a model in cartesian coordinates (x,y) relative to the runway. The adaptation of the generic curvi-linear model to a route specific cartesian model is carried out using a Jacobian transformation based on a description of the groundprojection of the route. In order to build an adequate model, a sufficiently large set of historical accident locations must be collected. NLR reviewed some 1100 accident reports from the data domain described above. Figure 3 shows a sample of the landing accident location dataset collected for the Schiphol study.

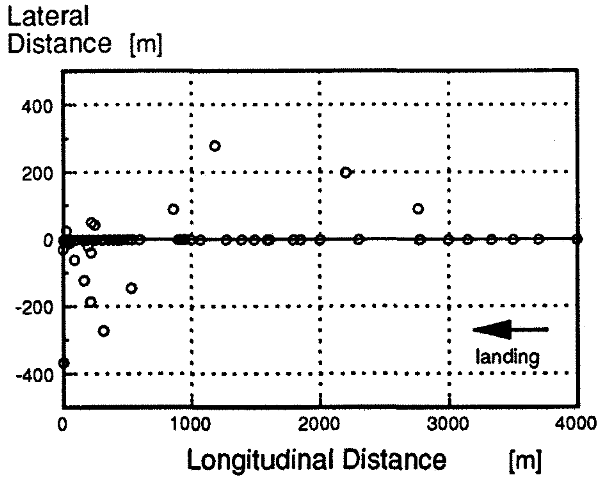

Figure 3 *Sample of the landing accident location data (relative to the route (s,t)).*

The five most important findings of this review were:

- approximately 20% of the available reports contain an adequate description of the accident location,
- in many cases the intended route is not mentioned,
- many accidents occur at or close to the intended route,
- the accident probability increases progressively with decreasing distance of the location to the runway threshold and with decreasing distance to the intended route,
- the distributions of take-off accidents, landing accidents and landing-overruns are distinctly different which means that three separate location probability models are required for take-off, landing and landing-overrun.

Modelling of the data into accident location probability models is a complex process, the meticulousness of which is vital to the quality of the results of the risk analysis. In short, the delta-function of Dirac, a Weibull probability density function and a Generalized Laplace probability density function are used. The free parameters in these three functions are determined from the available data using the "maximum likelihood estimation method. The resulting accident location probability models are tested with regard to their correspondence with the data using the Kolmogorov-Smirnov "Goodness-of-fit" test. The test results confirmed that all three models adequately represent the available data.

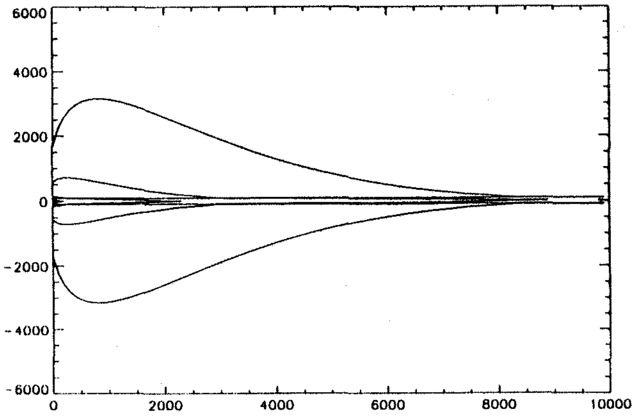

Figure 4 *The accident location probability model for a straight landingroute.*

Figure 4 shows iso-probability contours of the accident location probability model which was derived through statistical modelling of the full dataset. This model was used in the Schiphol and London Heathrow risk analyses. In the figure the contours converge to the route with increasing distance from the threshold. This might give the impression that the lateral dispersion of accident locations decreases with increasing longitudinal distance from the threshold. The contrary is the case however. In the model, the lateral distribution actually becomes wider with an increasing longitudinal distance from the threshold. The relatively large width of the contours close to the threshold is caused by dominant influence of the longitudinal distribution.

The longitudinal distribution increases sharply with decreasing distance to the threshold. Consequently, it "lifts up" the (narrower) lateral distribution to render wider contours.

6. The Accident Consequence Model

The consequences of an accident in terms of the size of the accident area and the lethality of the consequences inside the accident area are defined in the consequence model. The only consequences considered in third party risk analysis are fatal injuries to people on the ground as a direct result of an aircraft accident. Fatal injuries may be inflicted by a variety of effects such as impact by parts of the aircraft or collapsing structures, fire, explosion, toxic fumes, etc. Many causal factors determine the accident consequences which can generally be categorized into impact factors (impact velocity, impact angle, etc.), aircraft factors (weight, size, fuel capacity, etc.), and environment factors (type of terrain, wind, etc.).

For an adequate representation of the accident consequences, the influence of these causal factors must be accounted for.

Many analytical models exist which describe singular cause-effect relations. The utility of these models for third party risk analysis was found to be limited. When comparing model results with data from real accidents, many analytical models tend to overestimate accident consequences due to conservative assumptions. In addition, analytical models are not very well capable of predicting the combined effects of multiple causal factors. Finally, the level of detail in of some of the single-effect analytical models and the need to model the effects of many causal factors, renders the effort required to construct a complete analytical consequence model prohibitive in most cases.

An alternative to the use of analytical models is to extract cause-effect relations from accident data. To that end, accident reports were reviewed and a database of accident consequences and the associated causal factors regarding the aircraft, the impact and the environment was constructed. Since the utility of this kind of information for accident prevention is limited, only a small portion of accident reports provides adequate information on accident consequences. The available data does however allow the definition of an adequate consequence model based on the following observations. The aircraft factors are not independent parameters. Large aircraft are heavy, carry much fuel, have large dimensions, have higher approach speeds, etc. Therefore, the influence of these parameters can be considered to be adequately represented by a single parameter which is the maximum takeoff weight (MTOW). The relation between the MTOW and the accident consequences has subsequently been derived from accident data. With regard to the impact parameters, while there is an obvious relation between for example the impact angle and the size of the consequence area, the impact parameters for a particular future accident can not be predicted. Therefore, knowledge on impact parameters and accident consequences is of limited utility in third party risk analysis. The available accident data and hence a model based on that data, is considered to be representative of the combined influence of impact parameters as they occur in reality. Therefore, a separate description of the influence of impact parameters is not required in the consequence model. With concern to the accident environment factors, accident data shows that the local type of terrain is the dominant factor. Whether the accident area is open terrain with little obstacles or it is an area mainly occupied by buildings does determine the size of the accident area to a large extend. Since this factor is known for each location in the area around an airport its influence can be incorporated in the risk analysis.

The accident consequence model developed by NLR describes the size of the accident area as a function of the MTOW of the aircraft and the local type of terrain. Lethality, which is defined as the ratio between the number of people present in the consequence area and the number of people who are fatally injured, is the second part of the consequence model. Lethality of accident consequences has been derived from accident data. While the number of third party victims is usually reported in the accident report, the number of people present must be estimated from photos or drawings of the accident area and the associated narrative. In the risk calculations, lethality is treated as a probability of death for a person who is present in the consequence area of an aircraft accident.

7. Input data

7.1 Traffic distribution

The distribution of traffic over the area around the airport is determined by the local route structure and the traffic volumes per route. Numerous arrival and departure routes may be used in conjunction with each runway. The geographical lay-out of the routes and the number of movements per route are important input parameters.

7.1.1 Routestructure

The accident location model provides the accident probability (given the accident) relative to the groundprojection of the intended route. The routes are dependent on the location of runway thresholds and the location of navigation beacons as well as criteria concerning noise abatement, operational convenience and safety. The routestructure data may be generated by digitizing the routes published on paper maps. However, operational reality may differ considerably from the published nominal routestructure. Aircraft often do not exactly follow the nominal routes but deviate to some extent. In addition, average deviations are usually not symmetrical. Therefore, NLR collects data from an airport surveillance radar which records tracks of arriving and departing aircraft and uses this data to define the true traffic routestructure. For each route, NLR uses the data collected over time to determine operational deviation areas and defines the middle of these as the true route. By comparing differences between true routes and the nominal routes, rules of thumb can be elicited which are used to predict how true routes will deviate from the nominal route, for instance when planning routes to and from a new runway. If no paper maps of routes or surveillance data are available and arrival and departure trajectories are defined by a written procedure, NLR utilizes a model which generates routes based on the procedure. This model includes for example aircraft performance models and pilot reaction times to derive the routes as they will occur in reality.

7.1.2 Movement data

While some routes are used very frequently, others may be used only under conditions which occur a few times per year. Therefore, the number of movements per year for each route must be specified as input data. Because different accident rates are associated with particular categories of traffic (intercontinental, regional, general aviation, etc.), and different categories of traffic may not be evenly distributed over the available routes, movement numbers must be specified per category, per route. Additionally, the average maximum take-off weight (MTOW) is usually quite different per traffic category. Since the MTOW has a large influence on the accident consequences on the ground through the accident consequence model this is another reason for discriminating traffic categories in the movement data. The movement data must be further specified into separate day and night movements. The reason for this is that societal risk (as opposed to individual risk) depends on the geographical distribution of the accident probability relative to the geographical distribution of the population. The distribution of the population around the airport is different for business hours (day) and non-business hours (night).

7.2 Airport area description

In order to calculate individual and societal risk, the local population density and the local type of terrain must be known. Therefore, an appropriate population density database and a terrain database are required.

7.2.1 Population

Although population density information for the area around the airport tends to be available in some form, this data has usually not been compiled for risk calculation purposes. The properties of the available data may consequently make it less suitable for risk calculations. For example, data aggregated for relatively large areas, such as mail zones or large grid cells renders societal risk numbers of limited accuracy. Local concentrations of people such as in schools, hospitals, public buildings and industrial complexes should be included in the database as separate entries or be integrated into a sufficiently fine grid. The geographical distribution of the accident probability may differ to a considerable extent for day-time and night-time due to the use of separate day- and night routes by airtraffic. Therefore, separate day and night population density information must be used for societal risk calculations.

7.2.2 Terrain

The size of the accident area is determined to a large extent by the local type of terrain. For example the size of the accident area in build-up terrain or wooded terrain is much smaller than in open terrain. Therefore a terrain database must be built which specifies the local type of terrain as input for the accident consequence model. Resolution preferably should be equal to the resolution of the population density information. Census data often includes information on the type of use of terrain, other sources may be used as well. If no dedicated terrain-type data is available, population density can be used as an indicator of build-up areas. If a terrain database can not be generated, build-up terrain could be assumed for the entire area around the airport. While this is not a conservative assumption (build-up terrain results in a relatively small accident consequence area and thus yields relatively low risk levels), it is probably the most relevant since risk levels in populated areas are the focus of the analysis and population concentrations coincide with concentrations of buildings.

8. Results

8.1 Individual Risk

After local individual risks has been calculated for the entire area around an airport, risk contours can be generated and plotted on a geographical map, not unlike noise contours. Figure 5 shows individual risk contours for Schiphol airport with the 5P 2015 routestructure and traffic distribution. Risk levels indicated by the contours are 10^{-5}, 10^{-6} and 10^{-7}. The highest risk levels (10^{-5}) occur close to the runway thresholds and are present in a relatively small area only. The lower risk levels occur at larger distances from the runways and the routes followed by arriving and departing traffic. The runways which are used by the majority of traffic show larger individual risk contours than those which are used less often. Individual risk contours are often used for zoning purposes. If maximum allowable risk levels have been defined, the contours can be used to check for local exceedances.

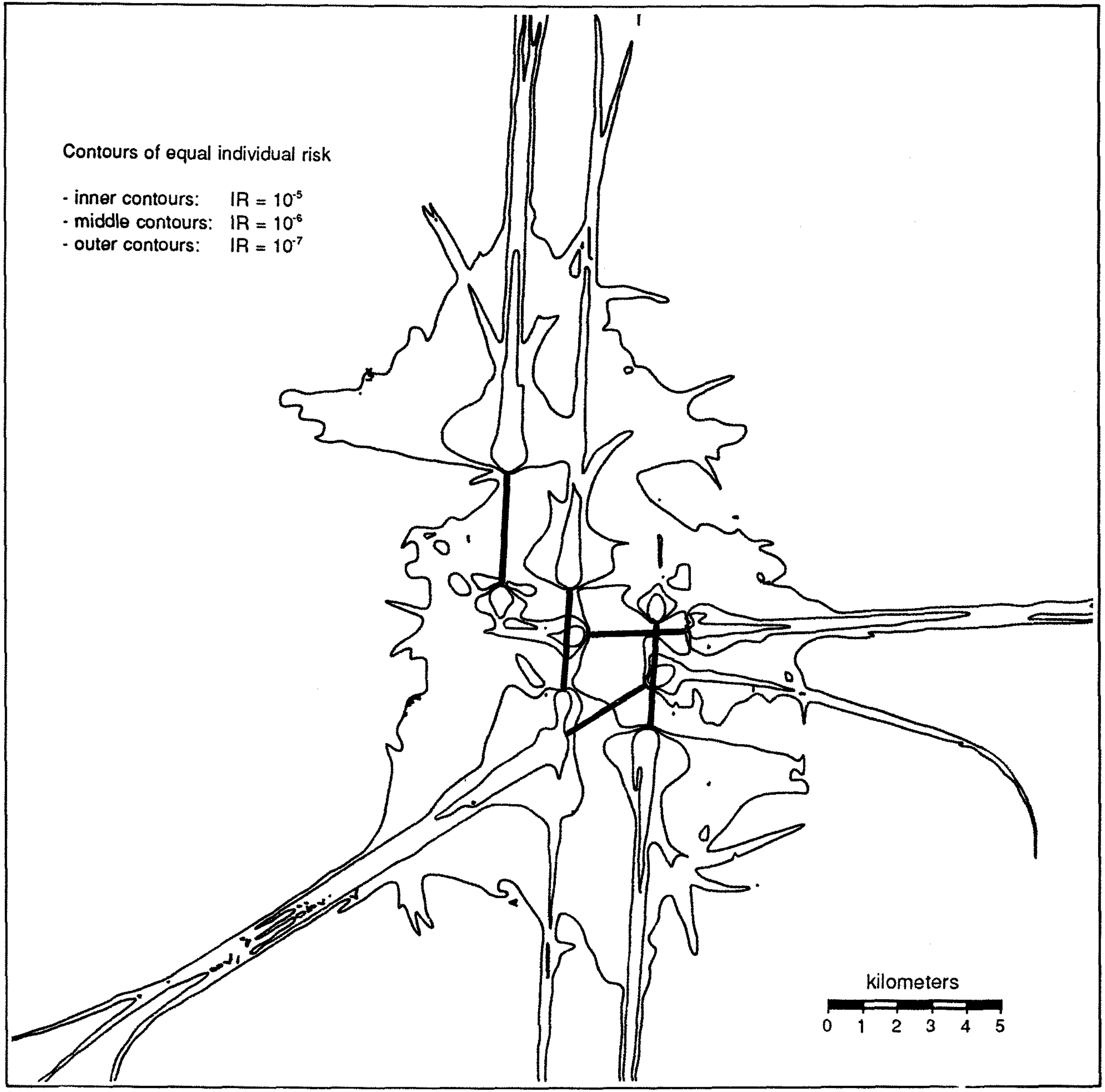

Figure 5 *Example of future (2015) individual risk contours for Schiphol airport with runway option 5P.*

A maximum allowable individual risk level of 10^{-6} is often enforced with concern to new housing projects. The contours can then be used to determine whether houses can be built at a particular location. Also, airport development plans can be evaluated with concern to their "risk-claim" on the development potential of the area around the airport. An individual risk level of 10^{-5} is often considered the maximum allowable for existing build-up areas. The risk contours are used to determine whether maximum allowable risk levels are locally exceeded when a particular airport development option is carried out. If so, either the plan must be changed, the buildings must be removed or risk reduction measures must be applied.

The individual risk contours may also be used as a basis for derived risk indicators. One example is counting the number of houses exposed to a particular risk level. Since high individual risk levels are only a problem if they coincide with population concentrations, some relation between local risk levels and population density information must be established. This is done by counting the number of houses within a risk contour, i.e. counting the number of houses exposed to a risk level exceeding a particular individual risk value. By performing these calculations for all airport development options and comparing the results, an objective evaluation of development options can be made. The option with the smallest number of houses within the contours of a particular individual risk level is the most favorable one from a risk point of view. Using this type of derived risk information, it may for example be possible to show that the relatively small improvement in risk of one development option over another option does not justify the associated increase in costs or loss in airport capacity. In evaluating different ways of increasing the future capacity of Schiphol, a number of runway configuration options were defined. Two options involve the construction of a fifth runway which may either be parallel to the nearest existing runway (option 5P) or rotated relative the nearest existing runway (option 5G). A third option is to accommodate the projected future traffic volume on the currently

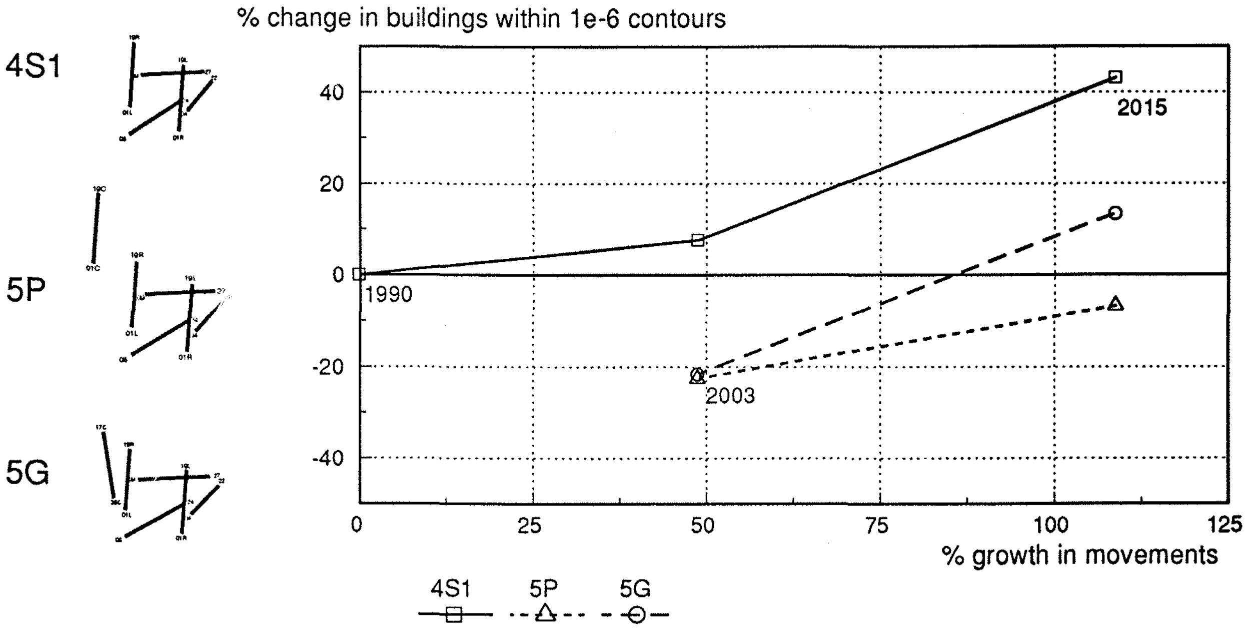

Figure 6 *Change relative to 1990 in the number of houses exposed to an individual risk level exceeding 10^{-6} for three airport development options.*

available runways (option 4S1). In order to evaluate these options in terms of risk, the development in risk around the airport were determined for each option as indicated by the number of houses exposed to an individual risk level exceeding 10^{-6}. Figure 6 shows the results. The vertical axis represents the percentage change in the number of houses exposed to risk levels exceeding 10^{-6} relative to the current situation. The horizontal axis represents the percentage increase in annual traffic for the years 2003 and 2015 relative to the current annual traffic. As is shown in the figure, not building a fifth runway and hence accommodating future traffic volumes at the currently available runways (option 4S1) is the least favorable option from a risk point of view because it results in the largest increase in the number of houses exposed to the 10^{-6} risk level. The options involving a fifth runway perform better, with the parallel fifth runway option even resulting in a slight decrease in risk relative to the current situation. This is a remarkable result in view of the fact that projected traffic volumes for the year 2015 are more than twice the current volume. The improvement is due to the fact that an additional runway allows a better distribution of traffic over the area around the airport. The figure also shows that while option 5P is better than option 5G, the relatively small difference may imply that considerations other than third party risk should prevail in the choice between option 5P and option 5G.

8.2 Societal Risk

Societal risk is a measure which is more difficult to use than individual risk. Figure 7 shows a societal risk curve for Schiphol airport. The logarithmic horizontal axis represents the number of third party victims (N) involved in a single accident. The logarithmic vertical axis, represents the probability per year (F) that an accident will occur which involves more than N victims. The curve, which applies to the entire area around the airport and hence not to a particular location provides the answer to the question: what is the probability per year that an accident occurs somewhere in the area around the airport which involves more than N third party victims. This type of risk information is of relevance for contingency planning.

Commonly adopted criteria with concern to maximum allowable societal risk levels around airports are not yet available. For third party risk around chemical industries, maximum allowable risk is often defined by $F_{max} = (10^{-3} / N^2)$ for existing situations. This function defines a straight descending line in the societal risk curve which for example intersects $F=10^{-5}$ for $N=10$ and $F=10^{-7}$ for $N= 100$, the societal risk curve should remain under this line. When comparing societal risk curves for different airport development options, it may be difficult to identify the most favorable otion if the associated risk curves intersect. Therefore, a derived metric is sometimes used which is based on a comparison of the area under the societal risk curve for different airport development options. Due to the fact that societal risk concerns the entire area around the airport it is often difficult to determine which measures will be most effective in preventing exceedances of maximum allowable societal risk levels. To allow better discrimination, societal risk is often calculated for each runway individually.

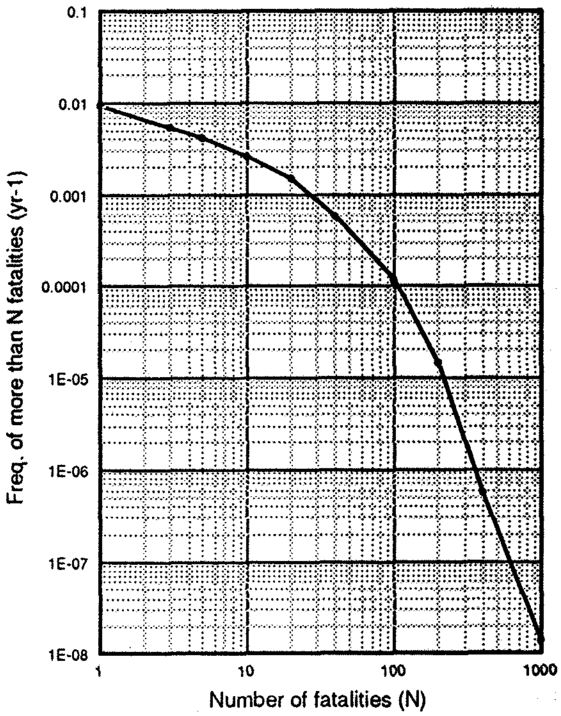

Figure 7 *Example of a societal risk curve.*

8.3 Risk perception

Risk information in and of itself is of limited utility unless its use is supported by some kind of acceptability criteria. This is also true for instances where risk information is used in a comparative way because it has to be decided whether the difference in risk between two scenarios/options justifies the associated additional cost or negative impact on issues other than risk.

One way of getting a feel for the risk levels concerned is providing other risk levels, associated with common activities, as a reference. Some examples are:

Cause	*Probability of death per year*
• bee sting	1 in 5,5 million
• lightning	1 in 2 million
• pedestrian accident	1 in 54,000
• motorcycle accident	1 in 1,000
• cigarette smoking (1 pack/day)	1 in 200

It must be noted however that it is very difficult to judge risk solely on objective criteria because the perception by the people who are exposed to the risk is of a subjective nature. A few well known dimensions of risk perception indicate the subjectiveness:

- personal benefit of risk bearing activity
- scale, nature and controllability of accident consequences
- voluntary/involuntary exposure
- knowledge concerning the risk bearing activity

It is a common oversight to embark on a third party risk analysis for an airport without at the same time initiating an activity which will result in a scheme for the evaluation of the outcomes of the risk analysis. To promote an effective decisionmaking process, it is highly beneficial to establish a way of evaluating the issue of risk among the other issues in the decisionmaking process before the results of the risk analysis are available. Unfortunately, commonly accepted risk acceptability criteria for third party risk around airports are not yet available. Government regulations with concern to chemical processing facilities may be useful for reference purposes in this regard.

9. Uncertainty of risk estimates.

9.1 Calculating uncertainty.

Risk analysis using statistical models in combination with historical data invariably involves a certain degree of uncertainty. For this reason the results of a risk analysis must be interpreted as a best estimate of the risk levels actually present. Because the results of a risk analysis may have far reaching (and costly) consequences for airport development it is important to obtain insight in the degree of uncertainty of the results. For the Schiphol analysis, uncertainty in the accident rates, accident location model and the accident consequence model were calculated and combined to allow the calculation of 95% confidence intervals for individual risk and societal risk. Because the location probability model consists of a number of two-dimensional statistical functions and the consequence model has the local type of terrain as one of its inputparameters, uncertainty in individual risk is not the same in the entire area around the airport, but differs from location to location. In order to show the uncertainty in the location of the riskcontours for a particular risk level, 95% upper and lower confidence limit risk values are

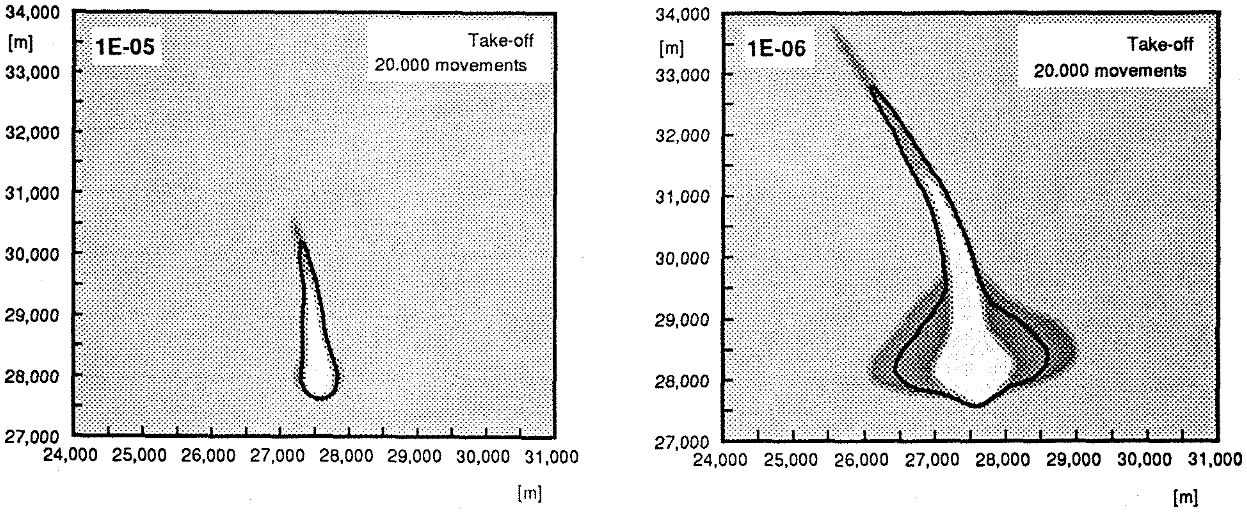

Figure 8 *95% confidence areas for individual risk contours.*

calculated in addition to the nominal risk value (the best estimate). By generating two additional risk contours, one using the 95% upper confidence limit values of individual risk and one using the 95% lower confidence limit values of individual risk, a 95% confidence area emerges for the nominal risk contour for this particular risk level. An example of the 95% confidence area for a 10^{-5} and a 10^{-6} contour for a single take-off route with 20.000 annual movements from the Schiphol analysis is shown as a shaded area in figure 8. The probability that the actual risk contours are entirely located within the shaded area is 95%. The figure shows that the confidence area is much narrower for the higher risk levels (10^{-5}) and gets wider for the lower risk levels (10^{-6}). This behavior is caused by the accident location probability model which has a steep gradient for the higher risk levels and becomes more shallow for the lower risk levels at larger distances from the route.

9.2 The interpretation of uncertainty.

Risk levels are usually calculated for a number of airport development options in order allow comparison. When differences between options are relatively small relative to the 95% confidence interval, the options are sometimes considered to be not significantly different in terms of risk. This is a misconception. Since risk levels for different airport development options are calculated using the same models with the same parameter estimations, differences between calculated risk and actual risk are approximately equal for both options. In other words, if the results of the risk analysis for option A is an overestimation of the actual risk, the results for option B are an approximately equal overestimation. For this reason, conclusions concerning differences between airport development options in terms of risk must be based on the nominal (best estimate) results of the risk analysis. Whether the differences in risk found for two airport development options should be considered such as to justify particular airport development decisions in view of the associated uncertainties, is a matter of subjective evaluation.

10. Conclusions

Because airports tend to be located close to major cities, many airport authorities are facing problems with concern to airport growth and third party risk. Particularly in Europe, an urgent need for objective and accurate risk information exists. The method described in this paper provides an adequate solution.

The method has been successfully applied to Amsterdam Schiphol and other airports. The results were used as factual information by all parties involved in the decisionmaking process and facilitated effective discussions on airport development and associated third party risk.

The results of this type of risk analysis support the identification of ways to reduce risk by providing insight into the influence of factors such as the runway layout, traffic routing and safety enhancement measures on third party risk around the airport.

Considerable improvements with regard to the quality of movement data are required in order to allow the development of detailed quantitative causal accident rate models.

The development of commonly accepted risk acceptability criteria, which are needed in support of the evaluation of risk analysis results, should receive due attention.

References

Piers M.A. et al NLR CR 93372 L

The development of a method for the analysis of societal and individual risk due to aircraft accidents in the vicinity of airports.

Piers M.A. et al NLR CR 93485 L

Analysis of external safety around Schiphol airport.