AIRPORT GROWTH AND SAFETY

A Study of the External Risks of Schiphol Airport and Possible Safety-Enhancement Measures

EAC
European-American Center for Policy Analysis

RAND

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A Study of the External Risks of Schiphol Airport and Possible Safety-Enhancement Measures

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Netherlands Ministry of Transport,
Public Works and Water Management

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PREFACE

This report was produced under a research study commissioned by the Dutch Minister of Transport, Public Works and Water Management. Three ministers asked Parliament to undertake a safety evaluation of Schiphol airport as a result of a plane crash in the Bijlmermeer. This project is one of three evaluating the external safety (risk to third parties on the ground in an accident) of Schiphol. The three parts of the external safety project are:

1. **The calculation of external risk.** This part focuses on the development of a computing model to determine individual and group risk as a function of runway configuration, air traffic levels and routes, and surrounding population.
2. **The level of acceptance of external risks.** This part studies risk standards for external risk at airports.
3. **Safety survey and safety enhancement measures.** This part, and the subject of this report, attempts to determine the current and future external safety situation around Schiphol airport and to propose measures that can improve the external safety.

There is some overlap among the projects. Evaluating safety measures and baseline safety to make comparisons required a way to quantify the effects on third-party risk. Ideally, this effort would use the model developed in the first project mentioned above. However, that model was not available in time to be used for this project and a separate quantification was used. As much as possible in the short time frame of the study, this quantification was checked against the approach of that project and much of the data are provided by the same source (the Schiphol Airport Authority—NVLS). With respect to the second project, this study does not attempt to define standards for external safety, although the discussions about the state of the art in airport external risk quantification and important uncertainties should be useful to that project. Furthermore, this report's discussion of risk and benefit perceptions and communication should be useful to the standards project.

As will be discussed in this report, airports and air traffic controllers have directly contributed to a very small fraction of aviation accidents worldwide. The focus of this study on Schiphol airport does not imply that it represents a significant causal factor in risks. Rather, because most aviation accidents occur in the vicinity of airports, we are interested in how aviation risks from all causes translate into risk to the population in the vicinity of the airport.

The work on Airport Growth and Safety was carried out under the leadership of the European-American Center for Policy Analysis (EAC), which is a part of RAND. A study support group was composed of representatives of Amsterdam Airport Schiphol (NVLS), the Department of Civil Aviation of the Transport Ministry (RLD), Air Traffic Control Services (LVB), and the major carrier at Schiphol (KLM). A high-level safety panel, composed of internationally and nationally acknowledged experts in the area of safety and flying, reviewed the findings of this study. The members of that panel are: P. van Duursen (Chairman); Professor J. A. Mulder, Technical University Delft; Professor J. K. Vrijling, Technical University Delft; B. M. Spee, NLR; R. Ashford, Joint Aviation Authorities (JAA); J. Enders, Flight Safety Foundation, USA; Admiral D. D. Engen, U.S.N. (Ret.), AOPA Air Safety Foundation, USA.

This report is one of three produced for the safety study of Schiphol. The other two are: *Airport Growth and Safety: Executive Summary of the Schiphol Safety Study,* and *Safety Study of Schiphol: Airport Security.* The latter was provided to Schiphol and the Ministry as a confidential report for obvious reasons.

Because of the need to support an impending policy decision concerning a number of transportation-related projects, the Minister requested that the work be reported by June 1993. Given the requirement for review by the safety panel, the work on this part of the study had to be completed by mid-April. The project, initiated at the end of November 1992, was carried out within a 3-1/2 month period of time. As a result, this limited the study in terms of data collection, interviews, interaction with other ongoing projects, and the ability to make quantitative assessments, generally. The numbers in the report should, therefore, be treated as supplying insights and orders of magnitude, but should not be taken as definitive. Nevertheless, the report captures the important safety issues at Schiphol and suggests appropriate safety enhancements.

The audience for this report will include the Minister and her staff as well as planners at Schiphol airport. Many of the findings in this report will also be relevant to other airports worldwide.

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SUMMARY

The Netherlands, to maintain its position as a major transporter in Europe, developed the concept of "Nederland Distributieland,"[1] which emphasizes the need for a new transportation infrastructure in the country. As part of this concept, a number of major projects are planned or under construction, including:

- A further expansion of Rotterdam seaport;
- The introduction of high-speed passenger trains;
- A dedicated freight line between the German border and Rotterdam (the Betuwe line);
- The development of a more elaborate road traffic system; and
- The expansion of Schiphol, the country's only major international airport, into a mainport. This includes, among other things, the additions of a fifth runway and a high-speed train station.

The proposed expansion of Schiphol is a central part of the Nederland Distributieland concept. Schiphol, the single international airport for a country of 15 million people, is fourth in Europe in freight traffic (after London, Paris, and Frankfurt) and fifth in passenger traffic (after the same three and Rome). Great Britain, France, Germany, and Italy each have between three and five times the population of The Netherlands and many more times the geographical area. This serves to emphasize the importance of transportation to the Dutch economy.

But, along with economic well-being, the Dutch are also concerned about environmental well-being, including safety. Schiphol is located in the middle of the most densely populated part of the country; although that has some advantages in terms of its short distance from major destinations, it also means that large numbers of people are at risk from the consequences of air accidents. As airport expansion is contemplated, so concern about increased safety risk is expressed.

The concerns about safety risk were raised to a peak by the crash of an El Al freight carrier on 4 October 1992. That airplane crashed into an apartment complex in the Bijlmermeer; although the eventual death toll was 43 persons, it was originally feared that many hundreds had died. This disaster generated sufficient arousal that a careful reexamination of safety at Schiphol was deemed necessary. The goals of the reex-

[1] The Netherlands as the shipping and receiving center for Europe.

amination are: (1) to determine to the extent possible the current safety status at Schiphol, (2) to project what additional risks to safety—if any—would be incurred by the plans to expand Schiphol to a mainport, and (3) to recommend safety-enhancing strategies to mitigate the safety risks posed by the expanding airport. The primary focus is the external or third-party risk to those people living or working in the vicinity of the airport. Of course, most aspects of safety that affect an aircraft in flight affect the external risk as well. Aspects of safety that are largely excluded in this study are causes of accidents during aircraft loading and unloading, during taxi, and during inflight cruise, which would not cause fatalities to the surrounding population of Schiphol.

THIRD-PARTY RISK

Various populations may be exposed to potential harm. Passengers on board an airplane have some control over whether or not they elect to fly. Ground populations have essentially no control over an airplane that crashes into their homes. Populations with little or no control over their exposure are those at **third-party risk.**

To best appreciate the meaning of a quantitative risk assessment, risk estimates must be stated in terms of absolute risk measures and in comparison to other, commonly understood risks. For example, the risk of dying in an automobile accident is about one in four to five thousand per year for the average American or Dutch driver, and the risk of dying from any accidental cause (for example, car accidents, falls off ladders, drowning, and so on) is about one in two thousand per year. Averaged over all people in Western Europe and North America, the likelihood of dying as a passenger in an aircraft crash is about one in a million per year, and as a third party the risk is about one in twenty to thirty million per year. These numbers depend, of course, on the population considered. Someone living near the end of an airport runway (where the majority of aircraft crashes occur) is more at risk than the average person.

ANALYTICAL APPROACH

A safety assessment is composed of technical as well as social issues and any discussion of safety must encompass the technical sense of safety in terms of probabilistic assessment of risk and the popular sense of safety in terms of the public perception of risk and whether that risk is deemed acceptable. Also, because the effects of many possible safety enhancements cannot be easily predicted in measurable quantities, this study has used an interdisciplinary approach involving risk analysis, statistical assessments, focus group interviews, review by aviation experts, safety assessment by Dutch experts, and policy analysis.

The approach involved the following steps, some of which were done in parallel:

1. **Define the International and National Context of Air Traffic Safety in The Netherlands.** To more comprehensively understand the organizations managing safety, constraints on safety management, European and Dutch cultural attitudes toward risk, and Dutch and international developments that would have an effect on safety, this definitional task used a Dutch safety expert, a consulting group (Flight Transportation Associates), and extensive interviews by RAND/EAC staff to determine the setting.

2. **Survey the Operations and Management of Safety at Schiphol Airport and Compare It to Other Airports.** This step focused on how safety is managed specifically at Schiphol and how the airport compares with others in Europe and around the world with respect to safety and its operational management. To the extent possible, we identified Schiphol- and Dutch-specific safety issues that could be addressed in the quantitative and subjective parts of the study. Some recommendations for safety enhancements were drawn directly from this task. It was conducted by the same groups used in Step 1.

3. **Study the Perceptions of Risk and Benefits of Schiphol Within The Netherlands.** Through the use of focus groups and content analysis of newspapers, this step identified concerns about Schiphol and perceptions of benefits among both stakeholders and others living near and at some distance from the airport. The purpose was to determine how safety has been communicated in the past, identify what the various groups think about safety and its management, and determine how to effectively communicate safety issues to the public in the future. This task was performed by RAND specialists in risk communication and Dutch staff of the EAC with the help of a Dutch professional group facilitator.

4. **Review Worldwide Aviation Accidents and Causes.** Considerable data have been collected by various companies and government agencies regarding aviation safety. Major aircraft companies keep databases of crash and causal data for all aircraft disasters. National and international agencies periodically publish reports that provide statistics about frequency of crashes, types of aircraft involved in crashes, etc. This step of the project investigated the various sources of data to provide inputs for a probabilistic model of third-party or external risk. The data were also used to identify leverage points for improving safety. RAND specialists in aviation risk analysis and statistics performed this task.

5. **Make Quantitative Assessments of Risk to Third Parties and the Effectiveness of Certain Safety Enhancements.** In this step, we developed and applied a quantitative risk-assessment model that probabilistically estimates group and individual risk for the Schiphol airport based on population distribution, operations data, fleet data, and historical crash rates. This model was then used to estimate the effects of certain quantifiable changes in airport operations, the effects of expansion and changing fleet mix in the future, and the effects of certain quantifiable safety enhancements. This task involved RAND and EAC modelers, risk specialists, statisticians, and various U.S. and Dutch experts including air traffic controllers (ATCs), pilots, airport officials, and government officials. The consulting firm, Flight Transportation Associates, also assisted in identifying possible safety enhancements.

CONCLUSIONS

Each of these tasks, represented by separate chapters of the report, has suggested or implied conclusions about the current and future safety at Schiphol airport as well as possible safety-enhancing measures. These are organized here into major themes and recommendations for the management of safety at Schiphol.

Schiphol Is a Modern, Safe Airport

Despite the tragedy of the El Al aircraft crash into the Bijlmermeer apartment complex, our safety survey, comparisons to other airports, and estimates of current third-party or external risk find Schiphol to have safety comparable to other modern airports in Europe and the United States. We find that safety is an important consideration for the various organizations associated with aviation management in The Netherlands and at Schiphol, including the ministry (RLD), the airport (NVLS), air traffic control (LVB), and the major airline at Schiphol (KLM). The managers of these organizations are quite aware that there are economic as well as moral and social reasons for maintaining a high standard of safety at Schiphol. Quantitative comparisons show that Schiphol's current operations and surrounding population fall within a range bounded by those at Frankfurt and London Heathrow.[2] The estimated average individual risk satisfies a standard that is under Dutch government consideration for application to airport operations, although small regions of population may exceed that standard.

Schiphol is generally perceived to be safe by the public. In our interviews of public perceptions and in the news content analysis, we found that in general, third-party risk was not a strong concern of the public before the El Al crash, and in the absence of a finding that gives the airport authorities blame in the accident, the public largely absolves the airport of responsibility and believes that mechanical failure or crew error in the aircraft was the primary causal factor. This analysis also indicates that other negatives associated with the airport have been and will probably continue to be more important, including noise, environmental damage, and, for some of those living near the airport, lower property values. For the limited sample of people we interviewed, as long as certain minimum standards of safety are maintained, the benefit of the airport balances the low external risk. Maintaining that perception, however, requires continued trust in the management of aviation safety and this may require qualitative changes in that management as well as more open information about incidents and safety-related decisionmaking.

Safety Considerations May Change as Schiphol Evolves into a Mainport

The growth projected for 2015 (2.7 times the number of passengers and 4.5 times the freight tonnage of the current operations) will increase third-party risk simply because the number of flights will increase. However, mitigating factors such as a safer fleet of aircraft, likely adoption of technological improvements in air traffic control and aircraft avionics, a new runway, and improved international control of risky airlines should keep the external or third-party risk from growing significantly. Indeed, our quantitative analysis suggests that despite the projected growth and increased number of flights implied, the third-party risk could actually decrease as the fleet becomes safer and technological advances are implemented.

However, there is also some concern that growth will increase external risks and there is a natural distrust in the hypothesis that technology will make operations and

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[2]Group risk is directly proportional to the population and the number of flight operations at an airport. With respect to the product of these two factors, Schiphol falls between Frankfurt and London Heathrow using current operations and populations. Many other factors such as flight path, distribution of population, and fleet mix affect the group risk, so this comparison is a very crude measure.

airports safer. Large changes in magnitude bring about qualitative changes that might produce unanticipated side effects from interactions of modes of transportation, taxiway and ramp traffic multiplication on the ground, increasing severity of weather-related queueing (and possible pressure to reduce safety margins), problems with volume-related incidents such as bird strikes, and risks during the airport-to-mainport transition process. There is also concern about the reduced government control implied by privatization, the effects of the European Community (EC) open employment market on standards and skills, the increase in freight flights (which generally use older aircraft), and the possible use of technology to compress operations or reduce safety margins rather than to increase safety.

Thus, the evolution of Schiphol from an airport to a mainport is seen by both experts and the lay public as generating potential risks to safety, but those risks can be mitigated if the managers of aviation safety anticipate and correct problems associated with growth before they occur and if safety has an advocacy that can balance the economic, environmental, and political aspects of growth.

Schiphol Airport Safety Must Be Taken in Context

A broad array of changes on the economic, political, and environmental fronts will affect aviation safety during the next decades. The Nederland Distributieland concept emphasizes the central importance of the transportation infrastructure and expansion of that infrastructure, including Schiphol airport, for long-term economic benefit to The Netherlands. The EC is taking on a number of responsibilities that were formerly handled by member states. For example, the EC will shortly issue guidelines and regulations that will replace national legislation on many topics, not least of which is transportation. These organizational changes will take place in an environment of growth, where Eastern and Western Europe are rapidly increasing their economic interdependence.

Environmental concerns, already dictating choices of routing to satisfy noise standards, are likely to increase as concerns about growth in air traffic, new construction projects, and increasing auto and rail traffic in the vicinity of Schiphol are realized. The political, economic, and management actions to satisfy environmental concerns will not always be consistent with improvements in external safety (for example, compression of flight operations into more acceptable time periods, or more complicated departure routes to reduce noise to residences may also be more hazardous).

Changes in international aviation that will affect aviation safety include deregulation and its possible effect on airlines and their fleets, increasing flights from new states and concern for the air safety standards of those airlines, and increasing air traffic, which leads to increasing congestion and schedule pressures. At Schiphol, there will continue to be tensions between the economic importance of expansion, the environmental effects, and safety. Some risks must be taken and there will be tradeoffs between noise and economic benefits, but this will generally be acceptable if risks are well managed and the safety implications have been considered.

There are also limits to what Schiphol and the Dutch government can do themselves. There is no effective international air regulatory body to enforce the high standards of aviation safety of Western Europe in other countries. Control of other countries' risky carriers and assurance of high standards of crew training and maintenance for all airlines using Schiphol will either require difficult decisions by the government to exercise unilateral restrictions with consequent political and economic reactions or will require regional confederations such as the EC, JAA, or even a regional coalition of airports[3] with higher standards and controls.

Safety Is an Airport-Wide Problem

Our safety survey indicates that coordination of safety is currently dealt with informally across the various operating organizations associated with aviation safety at Schiphol and within the government. An integrated safety management system/office is needed to coordinate and assess the safety procedures of the various operational organizations at Schiphol. We have identified other possible functions of this office to include that of collecting, reviewing, and acting on incident and hazard reports. The office should coordinate emergency planning and integrated emergency exercises. It would generally act as the safety advocate to balance decisions that are made on an economic or environmental basis and that might inadvertently overlook important safety concerns. It would monitor the safety aspects of the growth of Schiphol to a mainport.

The public information aspects of safety should not be overlooked. As indicated in the study of risk perception, there are rumors about incidents and hazards at Schiphol that are not effectively dispelled or explained. Misperceptions also exist about unsafe operations because of lay observations and interpretations of situations. For example, noisy takeoffs or wobbling of wings during a landing approach are sometimes interpreted as problems. Because each organization currently deals with safety internally, there is some bureaucratic reluctance within the organizations to respond openly to inquiries from the outside. Another important function of an integrated safety assurance office would be to provide information to deal with public concerns and to act as a safety spokesman.

No “Magic Bullet” Dramatically Reduces the Quantitative Risk Estimates

Throughout the report, we have discussed possible changes that could enhance aviation safety at Schiphol as it relates to third-party risk, but many of the options are not quantifiable for risk assessment. For example, we have suggested an integrated safety management system for Schiphol and have indicated some of its desired functions. Although we believe this is an important safety-enhancement measure, its actual effects on risk are not quantifiable. We have also discussed possible enhancement measures that are more quantifiable, such as the removal of risky aircraft and the use of public safety zones. Using the quantifiable measures, we have shown that actions can be taken to reduce risk now and in the future and in fact a number of these are planned (moving most of general aviation flights to other airports, for example). We have found no simple “magic bullets” in the sense of measures that make dramatic changes in the quantitative estimation of external risk. This is to be expected given the safety consciousness that already exists at Schiphol. Some measures dramatically affect the risk-estimation inputs but still make only marginal changes in the individual and group risk estimates. For example, public safety zones near the runways dramatically reduce the fatality risk in those zones, but, because

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[3]There is currently an association of Frankfurt, London, Amsterdam, and Paris airports referred to as FLAP. JAA is the Joint Aviation Authorities for Europe.

only a small proportion of the population lives in such areas now, the effect on group risk is not dramatic. Similarly, removal of general aviation significantly reduces the probability of crash for small aircraft at Schiphol, but because there are far fewer small aircraft and their crash footprint is smaller, the external risk estimates change by a much smaller amount. An important aspect of the quantitative risk-assessment model used in Chapter Six is the ability to measure enhancements in context. But, even when measures are evaluated as a group, the effects are limited because they are not necessarily additive.

Airport Third-Party Risk Assessment Is Not a Well-Developed Science

Although the quantitative aspects of risk-assessment models are fairly well developed and have been used for other areas of risk for many years, there are components of airport third-party risk assessment that are still in a somewhat primitive stage. A key problem is that the complete data for risk estimation are either not collected or are very difficult to obtain from available sources (particularly for a short-term risk assessment). Fortunately for safety, there are few accident data points, but this also means that statistical estimates suffer from large uncertainties. For example, the sparcity of accident data by aircraft type or airport means that the data across aircraft types and airports must be aggregated to have any statistical significance. Despite the fact that many aviation accidents are well documented, the specific causal chains for those accidents are frequently missing, either because they were indeterminate or they have been suppressed because of sensitivity. (Under the rules of the International Civil Aviation Organization (ICAO), the responsibility for accident investigation lies with the country in which the accident occurred, and in some countries there is little open discussion of blame.) The data regarding aviation incidents are even less complete and not systematically collected. We have discussed in this report some of the other data difficulties that make it difficult to assess the probability of crash, the locational distributions of crashes with respect to flight paths, and the effects of crashes in an arbitrary built-up area. Judging by a review of several airport risk models,[4] there does not seem to be a consensus among the community of experts as to how to represent various aspects in the estimation of risk.

The data uncertainties can easily swamp estimates of risk and make definitive estimates difficult. There are other important uncertainties, described in appendixes of this document, such as the fact that in many cases once the cause of an accident has been determined, the aviation industry takes steps to remove it as a possible future cause, thus at the same time improving safety and reducing the prediction value of the historical crash data.

The recognition of these broad uncertainties in airport risk assessment is important both for this study and for future actions predicated on the ability to predict risk. Although we state the absolute risks from our calculations and compare the influence on this risk of various scenario changes and safety-enhancement options, we believe that these should be considered primarily in terms of the comparative assessments and possible directions of improvement. And, the variance in the results should be explicitly stated and considered.

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[4]Kenneth A. Solomon, "Airplane Crash Model," *Journal of Hazard Prevention,* Vol. 11, No. 5, May/June 1975. Edward Smith, *Risk Analysis of Aircraft Impacts at Schiphol Airport,* Technica Consulting Scientists and Engineers, England, May 1990.

The uncertainties have implications for risk standards. As stated in the introduction, risk standards make the most sense when there is an ability to reasonably predict the risk definitively. In the case of airport risk assessment, our results indicate that there is some doubt about this definitiveness. The uncertainties also make it more difficult to argue that certain possible safety enhancements are worth the costs and possible political consequences. These include the building of safety barriers, zoning, designing of flight paths to reduce risk, etc.

It is well known that the perception of risk is important and that this may swamp the quantitative considerations. For this reason we relied heavily on the safety survey, the interviews, and the content analysis to understand how external risk was perceived and how it is currently balanced against other factors. This aspect of a risk assessment, used before by RAND/EAC in The Netherlands in the case of flood risks associated with riverdikes,[5] provides an important complement to quantitative assessments and helps to address issues that cannot be addressed with quantitative risk calculations, particularly when there are large uncertainties.

We also believe that additional research at the international level is both desirable and possible to improve the state of airport risk assessment. Much more could be done in assessing the dimensions, applicability, and underlying models of the aviation accident data.

RECOMMENDATIONS

Throughout the body of the report we suggest certain safety-improvement options. These are outlined below.

Safety Management

The safety survey suggests that in accordance with the growth of Schiphol airport to a mainport, the informal nature of aviation safety management and coordination associated with Schiphol should be replaced by an integrated safety management system/office that can perform the following functions:

- Coordinate and assess the safety procedures of the various operational organizations at Schiphol.
- Develop and coordinate airportwide emergency exercises, training, and plans. This includes joint exercises with controllers and pilots involved.
- Centrally collect and review incident and hazard reports from all operating organizations at Schiphol. Develop actions and track their implementation based on the review. Collect and review incident and accident data from other sources, including U.S. and international aviation safety organizations, airlines, aircraft, and manufacturers.
- Perform ongoing reviews of operating decisions and Schiphol expansion plans as a safety advocate to balance economically, politically, and environmentally

[5] Warren Walker et al., *Investigating Basic Principles of River Dike Improvement: Safety Analysis, Cost Estimation, and Impact Assessment*, RAND, MR-143-EAC/VW, 1993.

based decisions. Examples of safety issues and practices that should be reviewed by this office include:

— The low fuel pricing discussed in Chapter Three.

— The use of a single controller for both approaches and departures.

— The safety aspects of new SIDs and STARs.

— Fleet management including the outplacement of general aviation, etc.

- Provide information and act as a spokesman for safety to the public.

This integrated office should be implemented at Schiphol and consideration should be given to the establishment of an associated safety advisory panel of aviation safety experts, which is independent of the airport management. The advisory panel would have no executive power but its advice would be made public.[6]

Maintaining and Enforcing High Standards

Schiphol and the Dutch organizations managing aviation safety already have high safety standards but some areas can be improved. It was observed during the safety audit that of the major European airports visited, Schiphol is the only one without a formal airport or aerodrome certification process. The procedures for government certification and reexamination of air traffic controllers after privatization await acceptance by Parliament. As stated earlier, the government, while withdrawing in favor of decentralization and privatization, must still bear the responsibility for setting and verifying high safety standards. We have suggested that relevant certification programs be developed.

The small size of The Netherlands and the economic and political dependence of the Dutch on the rest of Europe and the world make it difficult to enforce aviation safety standards with respect to foreign carriers, particularly when those standards exceed the minimum international standards (ICAO). We discuss in Chapter Three the problem of restricting operations of suspected risky carriers, or of verifying unsafe operations of foreign aircraft and airlines. We also discuss how the United States has taken a more proactive stance in this regard. Because this is an important area of aviation safety (and will be even more important with growth and increasing flights from the new countries of Eastern Europe and the CIS), it is important that The Netherlands begin examining ways to identify risky carriers and considering the appropriate coalition within which to enforce limitations on them.

Currently, only two groups can report hazards and incidents anonymously or confidentially with respect to Schiphol and aviation safety in general. These are Dutch pilots and air traffic controllers, respectively. However, such reports are held and acted on independently by their respective organizations. There are no similar channels for other groups at Schiphol, such as the dispatchers, maintenance workers, and emergency teams. Because the lack of such a process is likely to result in some important safety-related incidents being unreported for fear of retribution, it is important that procedures be developed to permit anonymity to all possible re-

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[6]Because public perception is such an important part of risk, this structure should enhance the public confidence that airport safety is well managed.

porters of aviation hazards and incidents and to assure that such is the case for the existing two processes.

Public safety zoning is another aspect that the government should address. Because the majority of historical aircraft crashes have occurred in a relatively tight region near the ends of runways, it is possible to create public safety zones that mitigate some of the highest individual third-party risk associated with the airport. This is currently done in the United Kingdom but in The Netherlands, only residential noise zoning limits development in these risky areas. Furthermore, because even these standards do not apply to businesses, it is possible for the business population to increase in these important areas of risk. The government should consider creating public safety zones in the regions near runway approach and departure points as discussed in Chapter Five.

Although it is understood that levels of safety and risk must often be traded off against costs and other benefits, it should also be clear that safety is a first consideration and is not unnecessarily or unconsciously subordinated. In other words, the management should set "safety first" as a goal of all organizations associated with Schiphol.

The government should also exercise caution in setting standards for external risk at Schiphol. We have noted in several places in this report some of the potential problems with standards, most notably that there are tremendous uncertainties in our ability to predict the external risk definitively. The benefits and risks associated with Schiphol are different in scale and type from those in other industrial facilities and therefore common standards that lump the airport with such facilities may not be appropriate.

Implementing Other Safety Enhancements

A number of potential safety-enhancement measures are discussed in the body of the report that have not been included in the recommendations so far. Technical measures such as the installation of GPWS in all classes of aircraft are not within the purview of the government but for such developed technology, it is possible for the RLD to advance recommendations to carriers or to propose ICAO initiatives that advance the timetable and comprehensiveness of implementation. The additional runway was shown by our risk model to possibly reduce third-party risk. This should be examined in more detail with the NLR risk model. We have concluded through sensitivity testing with our risk model that optimization of SIDs and STARs for external risk reduction does not have high payoff once the effects of a new runway have been considered. This result depends on the model and data assumptions and should be verified by additional testing with the NLR model. If upheld, then we would recommend that the primary safety consideration of SID and STAR design be that associated with reducing complexity and workload for pilots and ATC. We also mentioned the practice of Cockpit Resource Management as a possibly important safety enhancement because of the frequency of aircrew causes in accidents. Although we are aware that KLM currently practices CRM, it is possible for the government to be more proactive by requiring all Dutch operators to practice CRM and to advance an ICAO initiative that all international carriers include CRM in aircrew training.

Informing the Public and Maintaining Trust in Safety Management

Chapter Four, which describes public perceptions about airport risk at Schiphol, indicates that there are concerns about growth, misperceptions about what constitutes risk in flight operations, and a belief that the various organizations are not telling the whole truth about some risks. Although it is not generally believed that there is a conspiracy to withhold information, it is clear that there is a perception of a bureaucracy that is not open to the public. Although there are valid concerns by the various organizations about disclosing information that cannot be judged in context, or that may lead to further misperceptions or exaggeration of risk, in Chapter Four we suggest some ways that a more open exchange might be achieved. The existing stakeholder and neighborhood groups, which meet periodically with Schiphol authorities, provide one forum for discussions of risk. An integrated safety management office described above would provide another. The important point is that the trust engendered by openness is critical to the acceptance and discussion of risks associated with expansion of the airport to a mainport.

In addition to more open communication, the public view of independence in the management of safety issues is important. If an integrated safety management system is not viewed as independent of organizational pressures on important safety matters, then the public perception of airport safety management will be tainted by skepticism. For this reason, the government should consider the use of an independent safety services panel to act in an advisory (nonbinding but public) capacity in conjunction with the proposed integrated safety management system.

Additional Research

Important research should be undertaken at the international level. There should be more definitive studies of historical crash data to better understand the accident causes and crash location distributions, as well as the crash rates associated with risky carriers, third-world airlines, older aircraft, and airports of various sizes. These all have important implications for predicting risks for public safety zoning and standards, routing of arrivals and departures, limiting risky carriers or operations, and setting international standards. Research is needed on how to identify and control risky airlines, and how to collect, analyze, and disseminate incident data; and international or regional databases for airport risk determination should be developed. The various approaches and assumptions used in modeling airport risk should be published and debated in an open forum. It would also be useful to perform additional international airport safety comparisons to highlight alternative approaches to safety management and measure their effectiveness. The Netherlands could advance an EC initiative to perform this type of research for the enhancement of European aviation safety.

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Professor Arnold Barnett (MIT Department of Operations Research); Ms. Dayl Cohen (Dayl Cohen Associates); Mr. William Hoffman, FTA president; Professor Amedeo Odoni (MIT Department of Operations Research); Professor Robert Simpson (MIT Department of Aeronautics and Astronautics); Mr. Ken Wallace, FTA Senior Aviation Analyst, and Mr. Raymond Ausrotas (MIT Department of Aeronautics and Astronautics).

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ACRONYMS

AAA	Amsterdam Advanced ATC
ACC	Area Control Center
ACT	Aerodrome Control Tower
ADS	Advanced Decision Systems
AIP	Aeronautical Information Publication
AISL	Aviation Information System Limited
AOA	Air Operations Area
APP	Approach Control Facility
APU	Auxiliary Power Units
ASMS	Aviation Safety Management System
ASR	Airport Surveillance Radar
ASRS	Aviation Safety Reporting System
ATA	Air Transport Association
ATC	Air Traffic Control
ATS	Air Traffic Services
CAA	Civil Aviation Authority
CAIR	Confidential Aviation Incident Reporting
CFIT	Controlled Flights into Terrain
CIS	Commonwealth of Independent States
CRM	Crew Resource Management
CTA	Control Area
DALDA	Dutch Airline Dispatchers Association
DH	Decision Height
DME	Distance Measuring Equipment
DoT	Department of Transportation
DVOR	Doppler VHF Omnidirectional Radio Range
EAC	European-American Center for Policy Analysis
EAT	Expected Approach Time
EC	European Community
ECAC	European Civil Aviation Conference
FAA	United States Federal Aviation Administration
FAF	Final Approach Fix
FANS	Future Air Navigation System
FAR	Federal Aviation Regulation
FIR	Flight Information Region
FIS	Flight Information Service
FMS	Flight Management System
FOD	Foreign Object Damage
FSU	Former Soviet Union

FTA	Flight Transportation Associates, Inc.
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GPWS	Ground Proximity Warning System
IAF	Initial Approach Fix
ICAO	International Civil Aviation Organization
IF	Intermediate Fix
IFR	Instrument Flight Rules
ILS	Instrument Landing System
JAA	Joint Aviation Authorities for Europe
JAR	Joint Aviation Regulations
KLM	Royal Dutch Airlines, the main Dutch carrier
LF	Low Frequency
LI	Dutch Aeronautical Inspection Directorate
LVB	Netherlands Air Traffic Control Organization
MLS	Microwave Landing System
MTOW	Maximum Takeoff Weight
NASA	National Aeronautics and Space Administration
NAVAIDS	Navigational Aids
NDB	Non-directional Beacon
NLR	Nationale Lucht en Ruimtevaart Laboratorium (National Aerospace Laboratory)
NLRGC	A division of NLR
nmi	Nautical mile/s
NSC	National Safety Council
NTSB	National Transportation Safety Board
NVLS	Schiphol Airport Authority
OJT	On-the-job training
PIRA	Provisional Irish Republican Army
PSZ	Public Safety Zone
RLD	Netherlands Department of Civil Aviation
RNAV	Area Navigation
RVR	Runway Visual Range
SAM	Surface-to-Air Missile
SEM	Safety-Enhancement Measure
SID	Standard Instrument Departure
SMR	Surface Movement Radar
SOP	Standard Operating Procedure
SPL	Schiphol Airport
STAR	Standard Terminal Arrival Route
TCAS	Traffic Collision Avoidance Systems
TMA	Terminal Control Area
UHF	Ultra-high Frequency
VFR	Visual Flight Rules
VHF	Very High Frequency
VOR	VHF Omnidirectional Range
VROM	Dutch Ministry of Housing, Physical Planning and Environment
WAAS	World Airline Accident Summary

Chapter One

INTRODUCTION

SAFETY AT SCHIPHOL IN CONTEXT

As the twentieth century draws to a close, the transportation infrastructure of Western Europe is undergoing a number of changes. Among such changes are the use of high-speed passenger trains, the Alptransit railway network, the rail tunnel connecting Great Britain and the European continent, and the development of a European inland waterway network, as represented by the newly opened Rhine-Main-Danube channel. Each of these and other developments has implications not only for the particular innovation put in place but for other parts of the transportation system. For example, high-speed passenger trains mean that for some trips (e.g., Amsterdam to Frankfurt or Paris), ground transportation may take less time and cost less money than air.

In addition to technical change, there is also an ongoing organizational change. The European Community (EC) is taking on a number of responsibilities that were formerly handled by member states. National legislation on many topics, not the least of which is transportation, is being harmonized within the Community through EC guidelines and directives. These organizational changes take place in an environment of growth, where Eastern and Western Europe are rapidly increasing their economic interdependence.

One consequence of these changes is a centralization of transportation. A commonly accepted vision of future transportation includes a limited number of "mainports"—large airports that are also road and rail transportation hubs. For passengers, these mainports will serve as gateways to the hinterland through intermodal feeder lines on transportation corridors. For freight, the air mainports in conjunction with equally centralized maritime ports (such as contemporary Rotterdam) will similarly serve as distribution centers for import and export.

Nederland Distributieland

The Netherlands has throughout its history been a nation of traders. Its geographical location made it a natural route for trade between Northwestern and Southwestern Europe, and its seafaring tradition made it a sometimes-dominant world power, from the days of the Dutch East India Company at Hoorn to today's oil-receiving center at Rotterdam.

To maintain its position as a major transporter in Europe, The Netherlands developed the concept of "Nederland Distributieland,"[1] which emphasizes the need for a new transportation infrastructure in the country. As part of this concept, a number of major projects are planned or under construction, including:

- A further expansion of Rotterdam seaport;
- The introduction of high-speed passenger trains;
- A dedicated freight line between the German border and Rotterdam (the Betuwe line);
- The development of a more elaborate road traffic system; and
- The expansion of Schiphol, the country's only major international airport, into a mainport. This includes, among other things, the additions of a fifth runway and a high-speed train station.

The technological projects described above are accompanied by organizational changes within The Netherlands. In concert with developments at the level of the European Community, privatization and deregulation have been introduced. Various government agencies concerned with air, shipping, labor, and mining are undergoing reorganization and are concerning themselves with certification of skills and expertise. The Dutch air traffic control services, formerly a government agency, was privatized effective January 1993.

This development of the transportation infrastructure is not without debate in The Netherlands. A major concern for both the technological and organizational changes to the transportation infrastructure is the possible environmental, social, economic, and technological effect of the proposed projects. Topics such as the allocation of land use in crowded inhabited areas and the noise, pollution, and safety risk imposed upon the population are all debated in the media, at community gatherings, and within the government. For example, the Rotterdam port introduced a "green charter" and a rating system for safe and environment-friendly vessels, which offers discounts in harbor fees. Although safety per se has not occupied a central role in the public debate, it is fair to say that the issue of safety has been present in one way or another in virtually all discussions.

Safety and International Aviation

At the same time as economic and political forces push for a consolidation of air transportation in Western Europe, the entire international aviation industry is undergoing rapid changes. Similar to the merging of carriers following deregulation in the United States, some European carriers are merging into multinational companies in response to deregulation, open skies policies, competition for passengers and freight, and the expected global increase of traffic flow. For example, last year the Dutch national carrier KLM substantially merged with the American carrier Northwest Airlines, and just recently British Airways and USAir announced their merger.

[1] Netherlands Distribution land.

Just as the international aviation industry amplifies the economic and political pressures for the expansion of Schiphol to a mainport, so aspects of the changes in international aviation have consequences for safety. These consequences appear in many guises.

- Deregulation, a major driver of the aviation industry, focuses on cost reduction and tends toward pushing economic margins. As a result, economics may dominate safety in decisionmaking. Examples of this might be laxness in maintenance and status monitoring, keeping aged aircraft in the fleet beyond their time,[2] and operating at more than capacity.
- Smaller and less-industrialized countries are not always capable of coping with the requirements for crew and aircraft to participate safely in modern air traffic.
- Increased traffic leads to increased congestion, not only in the air but also on the ground. When congestion interacts with delays caused by weather, the pressures to maintain strict timetables may influence safety.
- Increases in traffic and technological sophistication may lead to increases in pressure on pilots, ground crew, air traffic controllers, dispatchers, and all others who have some responsibility for safety. This increasing production pressure and mental workload could pose additional risks to safety.

Safety at Schiphol

The proposed expansion of Schiphol is a central part of the Nederland Distributieland concept. Schiphol, the single international airport for a country of 15 million people, is fourth in Europe in freight traffic (after London, Paris, and Frankfurt) and fifth in passenger traffic (after the same three and Rome). Great Britain, France, Germany, and Italy each have between three and five times the population of The Netherlands and many more times the geographical area. This serves to emphasize the importance of transportation to the Dutch economy.

The importance of Schiphol airport is provided by historical and projected work force and added value figures in Table 1.1.

But along with economic well-being, the Dutch are also concerned about environmental well-being, including safety. Schiphol is located in the middle of the most densely populated part of the country (see Figure 1.1); although that has some advantages in terms of its short distance from major destinations, it also means that large numbers of people are at risk from the consequences of air accidents. As airport expansion is contemplated, so concern about increased safety risk is expressed.

The concerns about safety risk were raised to a peak by the crash of an El Al freight carrier on 4 October 1992. That airplane crashed into an apartment complex in the Bijlmermeer; although the eventual death toll was 43 persons, it was originally feared that many hundreds had died. This disaster generated sufficient arousal that a careful reexamination of safety at Schiphol was deemed necessary. The goals of the

[2]Some older aircraft will be phased out because they will not be able to meet noise restrictions, however.

Table 1.1

Employment and Economic Benefit of Schiphol

	1988	2003	2015
Work force	78,000	110,000	150,000
Added value	Mfl 7,500	Mfl 15,000	Mfl 35,000

SOURCE: Numbers were provided by Schiphol Airport Administration. It should be noted that The Netherlands Central Planning Bureau has developed several alternative scenarios for growth called "balanced growth," "European renaissance," and "global shift," reflecting some uncertainty in long term prediction. The growth reflected for Schiphol in terms of passengers, freight, and economic prediction is based on the "balanced growth" scenario and is the only one considered in the study. Added value is a measure of the economic benefit (beyond employment) gained by the community as a result of the airport and its operations.

NOTE: Mfl = millions of Dutch guilders.

reexamination are: (1) to determine to the extent possible the current safety status at Schiphol; (2) to project what additional risks to safety—if any—would be incurred by the plans to expand Schiphol to a mainport; and (3) to recommend safety-enhancing strategies to mitigate the safety risks posed by the expanding airport.

Safety as discussed here is a subjective experience. Almost everybody accepts that air flight is just about the safest form of transportation known; however, because the consequences of an accident are often many lives lost, air mishaps are prominent in the public eye and are less tolerable than a simplistic cost-benefit calculation might indicate. In part for this reason, any discussion of safety must encompass both the technical sense of safety in terms of a probabilistic risk assessment and the popular sense of safety in terms of the public perception of risk and whether that risk is deemed acceptable. Throughout this report, we will switch back and forth between the technical and popular view of risk, integrating the two as much as possible, but always striving to keep both in view as we examine safety at Schiphol airport.

FOCUS OF THE STUDY

This study evaluates the current and future safety of Schiphol airport, considering expansion plans, evolution of commercial aviation, and projected changes in the population surrounding the airport. The primary focus is the external or third-party risk to those people living or working in the vicinity of the airport. Of course, most aspects of safety that affect an aircraft in flight affect the external risk as well. Aspects of safety that are largely excluded in this study are causes of accidents during aircraft loading and unloading, during taxi, and during inflight cruise, which would not cause fatalities to the surrounding population of Schiphol.

The study also evaluates a number of safety-enhancement measures in terms of their effect on external safety. These measures are derived from various sources including interviews with the Dutch organizations concerned with air safety.

The study is not an accident investigation. We have had no information about the ongoing El Al crash investigation other than what is available to all in the newspapers.

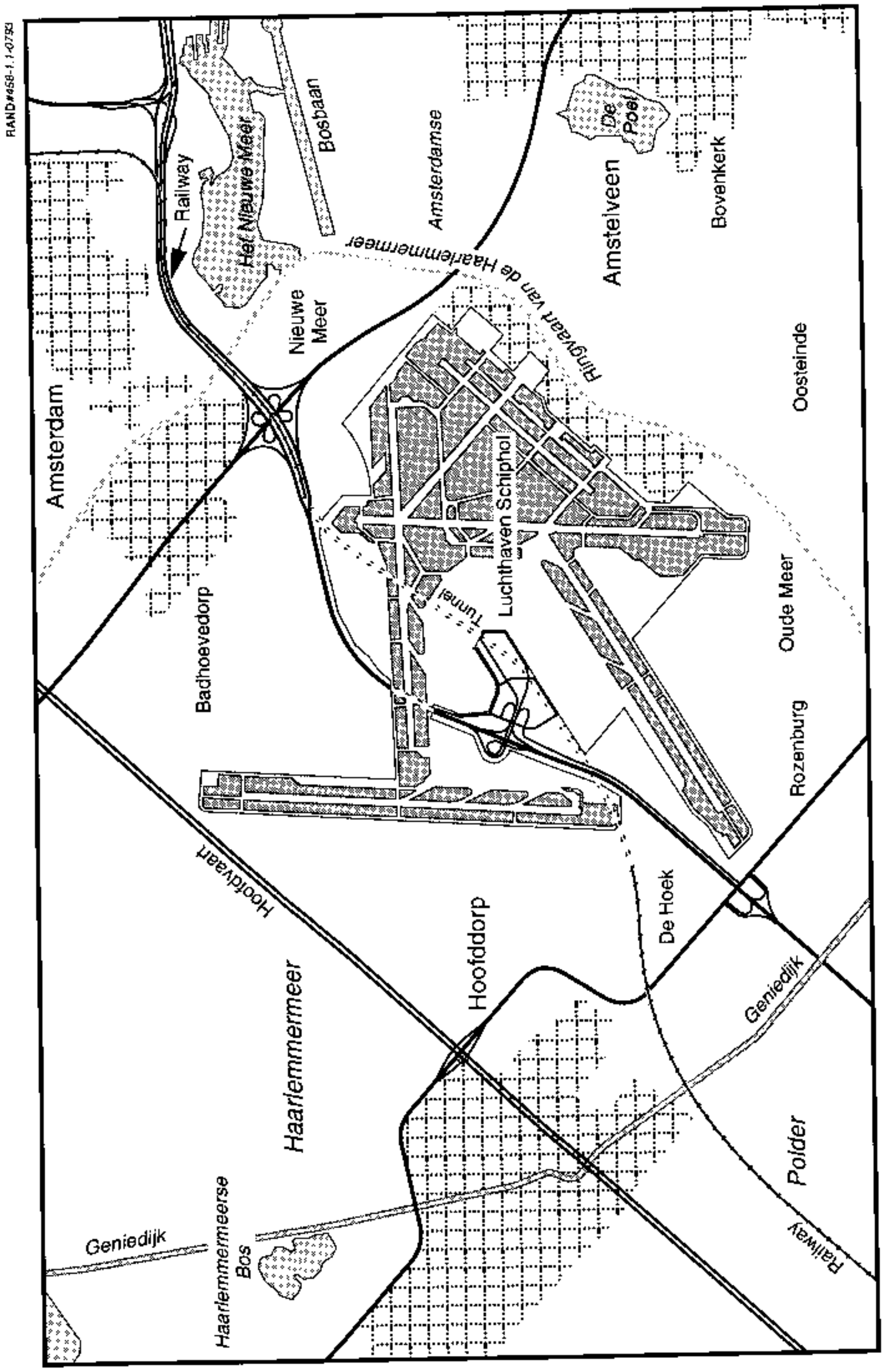

Figure 1.1—Schiphol Airport and Vicinity

The study does not attempt to set standards for external safety at Schiphol. Although we comment briefly on standards, the choosing of limits should be done by the Dutch people and their government with open debate about the balance between risks, uncertainties in measuring risk, and benefits of Schiphol expansion to a mainport.

DEFINING RISK

Measures of Risk

There is no single common measure or metric of risk. Risks can be measured in terms of fatalities or in terms of injuries and injuries that have varying degrees of severity. For the purpose of this study, however, we are concerned primarily with fatality as the measure of risk. Risk is commonly defined as the product of the probability or likelihood of an event and the consequence or magnitude of that event integrated over all events being considered. For example, based on historical records since 1970, the crash probability per commercial, scheduled aircraft in the Western hemisphere is about 0.05 fatal crashes per 100,000 hours flown.[3] If an average individual flies a single two-hour trip per year, then the probability that this average individual will be in an airliner crash is one in a million per year. If the probability of dying given involvement in a crash is 0.8, then the probability that this average person will die in an airline crash is one in 1.25 million per year. This measure is called the **individual risk.**

As another example of individual risk, we can estimate the risk to people on the ground from an aircraft crashing on them. According to a compilation by Boeing Aircraft,[4] 879 people on the ground died as a result of commercial jet airline crashes from 1970 through 1992. Assuming a world population of four billion people (average of the 23 years), the probability of third-party fatality is about one in a hundred million per year.[5]

The risk measure must also take into account other considerations. One hundred single fatality car accidents are not perceived to be equivalent to a single accident that kills one hundred people. The single high-consequence accident is viewed as more significant than the sum of the low-consequence accidents. We are therefore also interested in the probability of large numbers of fatalities, so we would state the risk as the probability that more than a given number of people are killed in an accident during a specified time period such as a year. This **risk-consequence distribution**—a second way of measuring risk—is useful in comparing risks in terms of how they are perceived psychologically.

A third metric of risk is the expected number of fatalities in a specified group in a given time period. By example, if there are ten million hours of commercial airliner

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[3]See National Transportation Safety Board (NTSB), *Annual Review of Aircraft Accident Data: U.S. Air Carrier Operations*, Table 14, Washington, D.C., 1992. The accident rate for all aircraft accidents including fatal ones averages 0.32 crashes per 100,000 flight hours.

[4]Boeing Aircraft of Seattle, Washington, compiled the total number of crew, passenger, and ground population fatalities from 550 commercial jet aircraft accidents from 1970 through 1992.

[5]This is the average individual risk across the world population. For those in the vicinity of an airport, it is likely to be higher, as we will discuss below.

(air carrier and air taxi) flights per year in the United States and the average number of fatalities in a crash is 50, then the expected number of fatalities in the group of all people who fly airlines is 250 per year.[6] This is called the **group risk.**

Another example of group risk can be drawn from the ground population risk discussion above. Eight hundred and seventy-nine third-party fatalities from 1970 through 1992 translates to an average annual group risk of about 40 fatalities per year for the world population group.

Third-Party Risk

Various populations may be exposed to a potential harm. Each of those populations exposed may have varying degrees of control over their exposure to the harm. For example, the driver of a car is under direct control of his own safety. His passengers have a lesser degree of control. The driver has willingly volunteered to expose himself to a risk. If he is intoxicated, the passengers can elect not to ride in the car. If an otherwise safe driver has a temporary lapse of performance, the passengers may have relinquished their control. A person sleeping in his bedroom has essentially no control over the fact that a driver could lose control of his car and drive off the road and into the house. Passengers on board an airplane have some control over whether or not they elect to fly. Ground populations have essentially no control over an airplane that crashes into their homes. Populations with little or no control over their exposure are those at **third-party risk.**

Often, those people who have little or no control over the risky situation have not voluntarily accepted the exposure. *Although a primary characteristic of third-party risk is lack of control, a secondary characteristic is often involuntary exposure to the risk.*

Third-party risks associated with transportation can be measured. In automobile accidents, the driver and his passengers are not at third-party risk. The pedestrian (excluding, perhaps, pedestrians who elect to jaywalk) hit by a car is at third-party risk. Third-party group risk (expressed as expected annual fatalities) to a ground population adjacent to airports has been estimated around Los Angeles International Airport as about 0.4 and around Burbank Airport (about 50 kilometers northeast of Los Angeles International Airport) as 0.2.[7]

Third-party risks are an important part of any consideration in the siting of houses, businesses, and other population centers in and around airports. Although the absolute quantitative value of the risk to an individual on the ground is quite small relative to other risks to which he or she is normally exposed, the number of people living near an airport is often large (one or more millions of people within a 25 kilometer radius), and any consequence of an aircraft crash—no matter how unlikely—could affect hundreds or more people.[8] Hence, any decisions involving the operation of an airport must consider third-party risk.

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[6]NTSB (1992), op. cit.

[7]Kenneth A. Solomon, et al., *Airplane Crash Risk to Ground Populations*, UCLA-ENGR-7424, University of California, Los Angeles, March 1974.

[8]The third-party risk around an airport is relatively low compared to other third-party risks. The automobile accident fatality rate in a region encompassing, say, two million people surrounding Schiphol is

Comparative Risks

To best appreciate the meaning of a quantitative risk assessment, risk estimates must be stated both in terms of the absolute risk measures expressed above and in comparison to other, commonly understood risks. For example, the risk of dying in an automobile accident is about one in four to five thousand per year for the average American or Dutch driver, and the risk of dying from any accidental cause (for example, car accidents, falls off ladders, drowning, and so on) is about one in two thousand per year. Averaged over all people in Western Europe and North America, the likelihood of dying as a passenger in an aircraft crash is about one in a million per year, and as a third party the risk is about one in twenty to thirty million per year. These numbers depend, of course, on the population considered. Someone living near the end of an airport runway (where the majority of aircraft crashes occur) is more at risk than the average person.

As a way to compare airline occupant and third-party fatalities to all other accident fatalities, we refer to Figures 1.2 and 1.3. Figure 1.2 compares the accidental death rate across 27 countries for 1990. This figure demonstrates at least three points. First, a one in a million chance of death to an airliner occupant is very small compared to the risks from all accidents—from 180 to 800 in a million depending on the country. Second, the third-party risk to people on the ground of one in twenty to thirty per million is especially small. And, third, the aircraft occupant and third-party risk is especially small when compared to how significantly accidental risks vary across countries.

Figure 1.3 compares the accidental death rate by cause of accident. The dominant accident cause is transportation-related accidents. And, the dominant transportation accident vehicle is the automobile.

Considering transportation risks, travel by scheduled airline and by intercity and transit buses are the safest form of transportation. Travel by car is roughly fifty times more risky in terms of the likelihood of fatality per mile traveled (Figure 1.4).

Travel by large airlines and commercial airlines is considerably safer than travel by general aviation, as illustrated in Figure 1.5.

Later chapters provide additional comparative risk assessments for third-party risk near airports.

Important Uncertainties Associated with Airport Risk

Risk assessment is as much an art as it is a science. Risk assessments rely on two somewhat distinct methodologies (analytic based and empirical based) used to varying degrees in a particular assessment depending on the nature of the problem and the availability of the data. When nuclear reactor safety is assessed, the analyst typically relies on historical or *empirical* data to learn about the failure rates of

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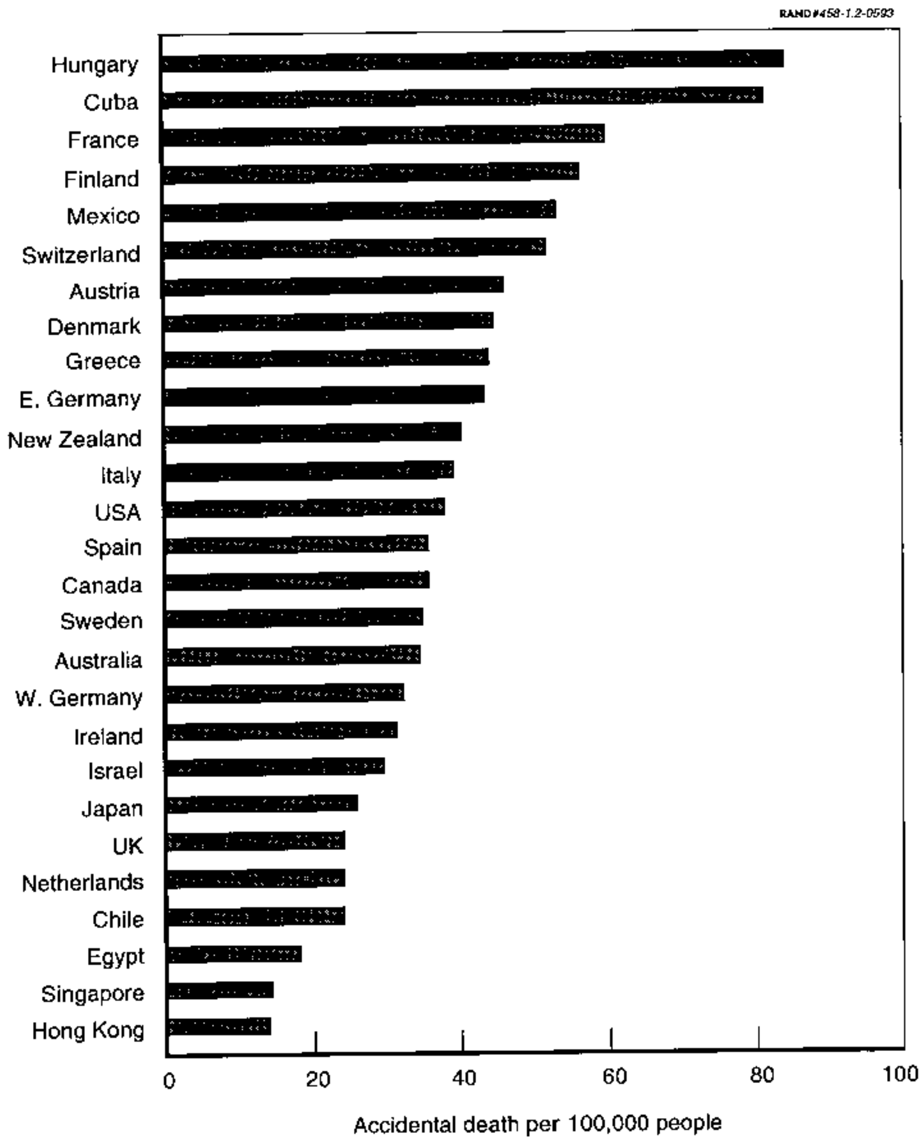
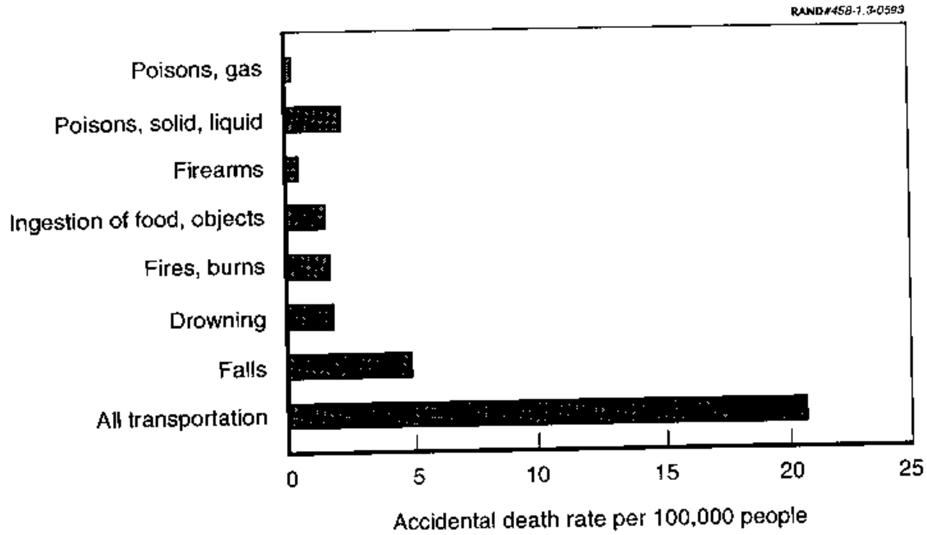
about 200 people per year. Of those fatalities, about 20 percent or about 40 are likely to be pedestrians (pedestrians are exposed to a third-party risk). By comparison, the third-party risk from potential aircraft crashes (expressed as expected annual fatalities) might be only about 0.2 or 0.5 *percent* the number of pedestrians at risk in the same time frame and in the same region.



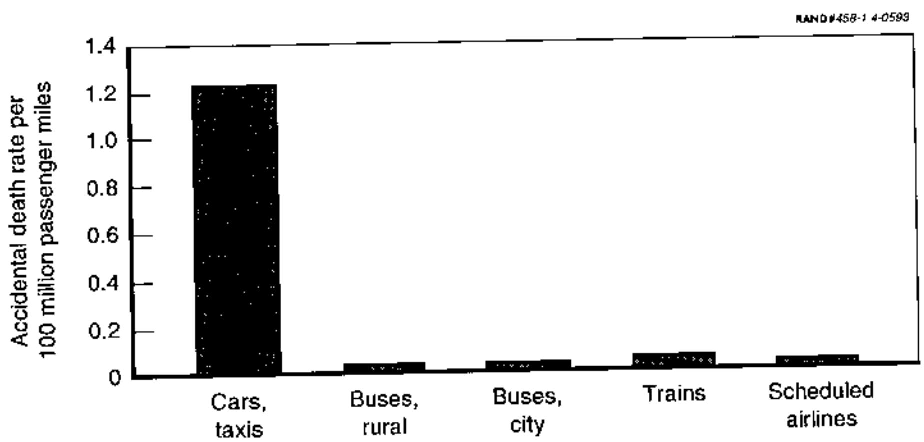
SOURCES: *The World Almanac and Book of Facts, 1993*, St. Martins Press, New York, 1993; National Safety Council (NSC), *National Safety Council Bulletin 1993*, Washington, D.C., 1993; NSC, *Accident Facts 1992*, Washington, D.C.; and the *National Highway Institute of Safety Public Bulletins*, 1990, 1991, 1992, and 1993.

Figure 1.2—Accidental Death Rate by Country, 1990



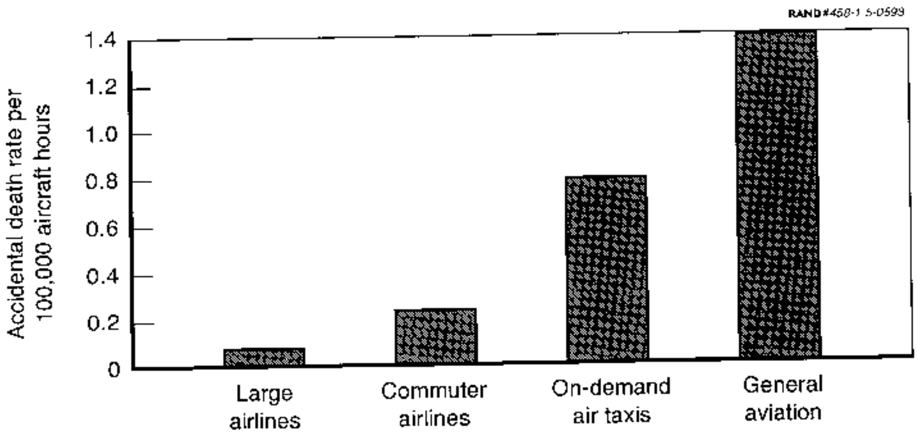
SOURCES: *The World Almanac and Book of Facts, 1993*, op. cit.; NSC, *National Safety Council Bulletin 1993*, op. cit.; NSC, *Accident Facts 1992*, op. cit.; and *National Highway Institute of Safety Public Bulletins*, op. cit.

Figure 1.3—Accidental Death Rate by Cause of Accident, 1988-1992



SOURCES: *The World Almanac and Book of Facts, 1993*, op. cit.; and the *National Highway Institute of Safety Public Bulletins*, op. cit.

Figure 1.4—Accidental Death Rate per 100 Million Passenger Miles by Type of Transportation, United States, 1989-1992



SOURCES: NTSB (1992), op. cit.; NSC (1992), op. cit.; and NTSB, *Annual Review of Aircraft Accident Data, U.S. General Aviation, Calender Year 1987*, Washington, D.C. December 12, 1989.

Figure 1.5—Accidental Death Rate per 100,000 Aircraft Hours by Type of Air Service

individual components in the reactor system. Component failure rates such as the failure rate of a valve or a pipe are generally well defined. Then these failure rate data are used along with *analytic tools* such as event trees to determine the course of events that contribute to an accident and fault trees to determine the reliability of systems. Technologies rich in technical components and well-defined events lend themselves well to risk analyses that rely on both analytic and empirical tools.

However, this risk assessment does not evolve from a technology that has a well-defined set of sequences that could lead to an accident. Unlike a nuclear reactor accident, hundreds of uncertain variables play a role in determining the likelihood of a plane crash, where it crashes, and the effects of that crash. Our current risk assessment becomes especially difficult when we consider the vast amount of uncertainties present in the crash rate data, in the crash distribution, in the consequence assumptions, and in our ability to predict the timeliness and effectiveness of safety enhancement measures.

Uncertainty arises from the fact that aircraft crashes are relatively infrequent and those factors that determine where a plane will crash are many. So we are dealing with very low probability statistics and wide-ranging consequences. As such it is necessary to aggregate data.

Specific uncertainties and their likely effect on our results are detailed below. In summary, these uncertainties are:

- No two accidents are alike and historical accident data fail to distinguish precisely the causes of past and thus the predictability of future ones. We address this problem in part by reviewing the applicability of a broad set of accidents to Schiphol and rule out many of these accidents because they just would not apply.

- Often when the cause of a past accident is determined, the problem becomes more recognized and thus less likely to happen in the future. So the nature of the accidents in the future is not always the same as the ones in the past.
- Accidents have many known and unknown causes that contribute to the likelihood, location, and severity of an accident. Because of these many variables and infrequent occurrences, inferring characteristics of future accidents from past ones is challenging at best.
- During the course of this study, we identify and to the extent possible quantify the effect of applying safety-enhancement measures. Many of these measures are not quantifiable by their very nature. Others that lend themselves to quantification cannot be quantified in sufficient detail to justify a precise calculation.

Although these uncertainties limit our ability to calculate a precise third-party risk, they do not prevent us from demonstrating general safety trends and the relative effects of various safety-enhancement measures.

Risk Standards in The Netherlands

One approach towards the management of external risks is to define numerical standards of acceptability. A site or an activity is considered to have acceptable risk if the likelihood of the hazard is below a specified level. Examples of this approach are the "Delaney Amendment" passed by the U.S. Congress in 1965. It demanded a zero risk of cancer from certain foodstuffs and probabilities of radiation release from nuclear reactors set forth by the U.S. Nuclear Regulatory Commission.[9] A more recent example is the expected likelihood in any given year that Dutch river dikes will not contain floods.[10]

The Dutch government has recently promulgated a single standard for major accidents, exposure to substances, and radiation, such that the combined probability of mortality for these three hazards should not exceed 1 in 100,000 per year. For each activity or substance, the maximum acceptable level has been set at 1 in 1,000,000 per year.[11] Although these standards apply to activities and substances associated with fixed sites (such as toxic emissions from a factory), the Dutch government is currently considering applying the same (or similar) standards to transportation activities, to include Schiphol airport.

The imposition of single standards such as the Dutch regulation is not without debate.[12] Among the objections to uniform standards are:

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[9]S. Salem, K. A. Solomon, and M. S. Yesley, *Issues and Problems in Inferring a Level of Acceptable Risk*, RAND, R-2561-DOE, August 1980.

[10]W.A. Walker, J. Abrahamse, J. Bolten, et al., *Investigating Basic Principles of River Dike Improvement: Safety Analysis, Cost Estimation, and Impact Assessment*, RAND, MR-143-EAC/VW, 1993.

[11]Directorate General for Environmental Protection at the Ministry of Housing, Physical Planning and Environment (VROM), *Premises for Risk Management: Risk Limits in the Context of Environmental Policy*, VROM, The Hague, 1991.

[12]C.A.J. Vlek, *Beslissen Over Risico-Acceptatie [Decision Making About Risk Acceptance]*, Gezondheidsraad, The Hague, 1990.

- Uniform standards do not take into account the benefits of the substance or activity. People may accept greater risk for highly beneficial activities.
- Uniform standards do not take into account social inequities that result when the risks are imposed only on segments of the population.
- Uniform standards assume that the numerical risks are validly and reliably measured—a questionable assumption for many risks that result from complicated technologies.
- Uniform standards tend to be mechanically calculated and do not take into account the human factors that can either greatly multiply the risk or greatly reduce it.

Many proponents of risk standards acknowledge these criticisms but maintain that even a flawed standard is superior to no standard at all.

ANALYTICAL APPROACH

A safety assessment is composed of technical as well as social issues and any discussion of safety must encompass the technical sense of safety in terms of probabilistic assessment of risk and the popular sense of safety in terms of the public perception of risk and whether that risk is deemed acceptable. Also, because the effects of many possible safety enhancements cannot be easily predicted in measurable quantities, this study has used an interdisciplinary approach involving risk analysis, statistical assessments, focus group interviews, review by aviation experts, safety assessment by Dutch experts, and policy analysis.

The approach involved the following steps, some of which were done in parallel:

1. **Define the International and National Context of Air Traffic Safety in The Netherlands.** To more comprehensively understand the organizations managing safety, constraints on safety management, European and Dutch cultural attitudes toward risk, and Dutch and international developments that would have an effect on safety, this definitional task used a Dutch safety expert, a consulting group (Flight Transportation Associates), and extensive interviews by RAND/EAC staff to determine the setting. This setting is described in Chapter Two.
2. **Survey the Operations and Management of Safety at Schiphol Airport and Compare It to Other Airports.** This step focused on how safety is managed specifically at Schiphol and how the airport compares with others in Europe and around the world with respect to safety and its operational management. To the extent possible, we identified Schiphol- and Dutch-specific safety issues that could be addressed in the quantitative and subjective parts of the study. Some recommendations for safety enhancements were drawn directly from this task. It was conducted by the same groups used in Step 1. Chapter Three describes the survey results and implications.
3. **Study the Perceptions of Risk and Benefits of Schiphol Within The Netherlands.** Through the use of focus groups and content analysis of newspapers, this step identified concerns about Schiphol and perceptions of benefits among both stakeholders and others living near and at some distance from the airport. The purpose was to determine how safety has been communicated in the past, iden-

tify what the various groups think about safety and its management, and determine how to effectively communicate safety issues to the public in the future. This task was performed by RAND specialists in risk communication and Dutch staff of the EAC with the help of a Dutch professional group facilitator from KPMG. Chapter Four describes these perceptions.

4. **Review Worldwide Aviation Accidents and Causes.** Considerable data have been collected by various companies and government agencies regarding aviation safety. Major aircraft companies keep databases of crash and causal data for all aircraft disasters. National and international agencies periodically publish reports that provide statistics about frequency of crashes, types of aircraft involved in crashes, etc. This step of the project investigated the various sources of data to provide inputs for a probabilistic model of third-party or external risk. The data were also used to identify leverage points for improving safety. RAND specialists in aviation risk analysis and statistics performed this task. Chapter Five describes this review.

5. **Make Quantitative Assessments of Risk to Third Parties and the Effectiveness of Certain Safety Enhancements.** In this step, we developed and applied a quantitative risk-assessment model that probabilistically estimates group and individual risk for the Schiphol airport based on population distribution, operations data, fleet data, and historical crash rates. This model was then used to estimate the effects of certain quantifiable changes in airport operations, the effects of expansion and changing fleet mix in the future, and the effects of certain quantifiable safety enhancements. This task involved RAND and EAC modelers, risk specialists, statisticians, and various U.S. and Dutch experts including ATCs, pilots, airport officials, and government officials. The consulting firm, Flight Transportation Associates, also assisted in identifying possible safety enhancements. The quantitative results are reported in Chapter Six with additional detail about the model and data described in Appendixes A and B.

6. **Develop Overall Conclusions and Recommendations Regarding Third-Party Risk and Possible Safety Enhancements at Schiphol.** Each of the Steps, 1–5, suggest possible safety issues and possible areas of improvement at Schiphol. This step involved putting these together in several coherent themes and suggested directions of improvements in the management of safety at Schiphol. This is the topic of Chapter Seven.

IMPORTANT CAVEATS

Before describing the details of the analysis it is important to remind the reader of important limitations of this study.

Time Duration of the Study

This has been a 3.5-month study initiated at the end of November 1992, interrupted by the Christmas holidays, and completed by the end of March. This narrow time frame placed certain restrictions on the study, including limitations on the number of focus group discussions and interviews (and follow-up discussions), limitations on the amount and depth of quantitative analysis that could be performed, and limitations on our ability to analyze causal data regarding historical aircraft crashes and relate that data to Schiphol. Although there are a number of aspects that could therefore be investigated in more depth, we do believe that we captured the salient aspects of safety at Schiphol. We also understand that there is work under way to perform some of the quantitative investigations in more detail than done here.

Uncertainties in Data

These are discussed in some depth later. Some of these uncertainties, such as the joint distribution of the locations of historical crashes with respect to flight path and offset, could possibly be determined with considerable additional review of individual crashes (although even this would be subjective with respect to the exact timing of the failure causing the crash and intended path of the pilot). Other data are likely to remain uncertain regardless of the depth of investigation. For example, it is very difficult to predict footprint size and lethality of crashes, because they depend on how and where and in what configuration an aircraft crashes. The cumulation of these data uncertainties limits the ability to predict risk with certainty.

Limited Investigation of Runway Alternatives

We are aware that there are several alternative configurations of runways and additional runways that have been proposed and studied. For this study, we have considered only the expansion plan involving the addition of a parallel fifth runway in the location and configuration described by Schiphol authorities.

No Access to the Ongoing El Al Crash Investigation

We have not had access to information from the investigation of the El Al crash and the report of that investigation was not released before the completion of this study. If significant safety issues at Schiphol are identified in that investigation as contributing to the accident, then some conclusions of this study might be modified.

Limited Ability to Predict Low-Probability Events

The probability of an airline crash is very small and the probability of an airline crash that causes third-party casualties is even lower. The ability to predict when and where a future accident might occur is, as a result, also very low. Despite the quantitative estimates provided in this study indicating low external risk, a crash is still possible, as evidenced by the El Al crash on 4 October 1992.

DESCRIPTION OF THE CURRENT INTERNATIONAL AND NATIONAL MANAGEMENT OF AIRPORT SAFETY

BRIEF OVERVIEW OF AVIATION OPERATIONS

The modern international airport is a complex transportation hub used by aircraft, passengers, cargo, and surface vehicles. Airport components consist of Airside facilities, landside facilities, and terminal facilities, which serve as an interchange between the previous two (Figure 2.1).

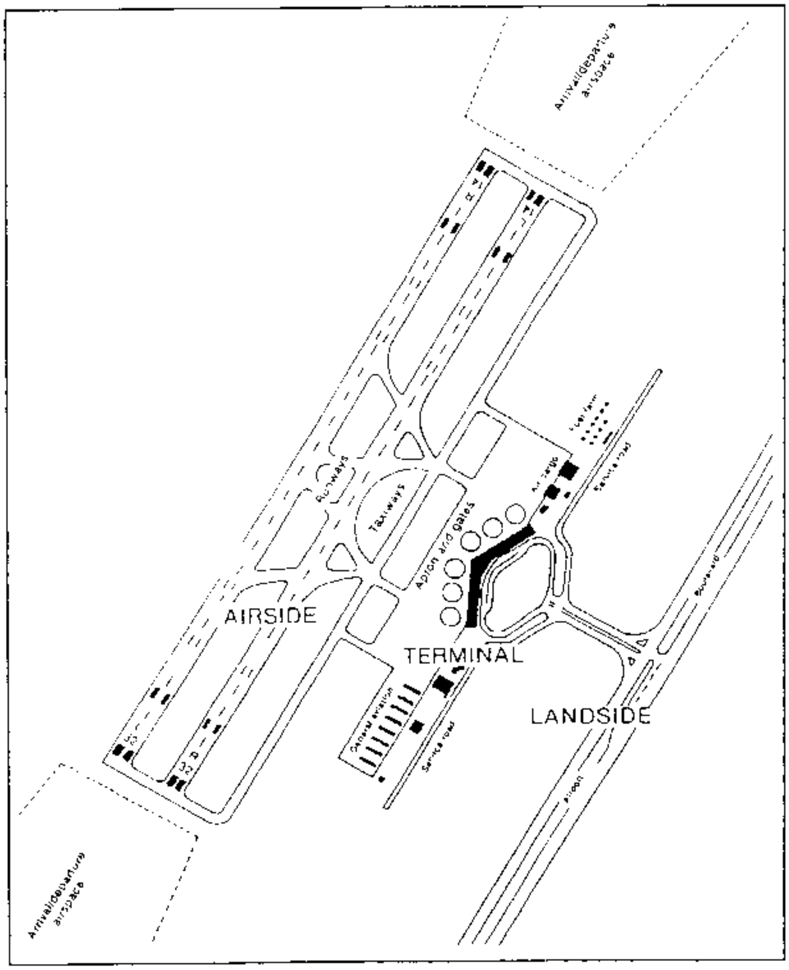
The Airside facilities (also known as aeronautical surfaces or the airfield) are those on which aircraft operate. These include the runways where aircraft take off and land, the taxiways used to move aircraft between the runway and the terminal, and the apron and gate areas where aircraft are parked and passengers disembark and embark. It is customary to include terminal area airspace, which contains the approach and departure paths, as part of the Airside.

Landside facilities are the parts of the airport devoted to surface transportation. They begin at the curbside of the terminal area and include roadways, parking facilities, and sometimes rail and rapid transit lines and stations.

The terminal facilities consist of the buildings serving passengers and contain passenger loading and waiting areas, ticket counters, baggage handling areas, restaurants, car rental facilities, shops, etc. Air cargo and mail loading, handling, and storage areas are also part of the terminal.

Aircraft have had the major effect on Airside design. As advances in technology led to longer-range and higher-payload capability, airports have had to progressively increase runway length and pavement strength to accommodate these aircraft (Figure 2.2).

As the volume of traffic and productivity has risen (Figure 2.3), the terminal and landside facilities of airports have also had to expand to keep pace. To channel the flow of air traffic, and to obtain the necessary degree of orderliness and safety, a system of airspace has been established to protect an aircraft's flight path from takeoff to landing. The two primary divisions of airspace are controlled and uncontrolled. Normally, commercial aircraft operate only in controlled airspace—on the airways to and from airports and in the airspace surrounding the airport itself. Two primary divisions of controlled airspace exist: en route and terminal. En route airspace contains operations on the airways and terminal airspace contains



SOURCE: Office of Technology Assessment, *Airport System Development*, OTA-571-231, U.S. Congress, Washington, D.C., 1984.

Figure 2.1—Airport Components

operations near the airport. The safe separation of aircraft within this airspace is accomplished with the help of air traffic controllers. Figure 2.4 shows the phases of a flight (departure, en route, and arrival) within en route and terminal airspace.

THE INTERNATIONAL CIVIL AVIATION ORGANIZATION

The air transportation system has evolved expeditiously because of rapid technological improvements in aircraft, growth in the world economy, and global safety standards set by the International Civil Aviation Organization (ICAO). ICAO was created in 1944 when representatives from 52 countries met in Chicago to discuss the future of civil aviation and signed the Convention on International Civil Aviation (the

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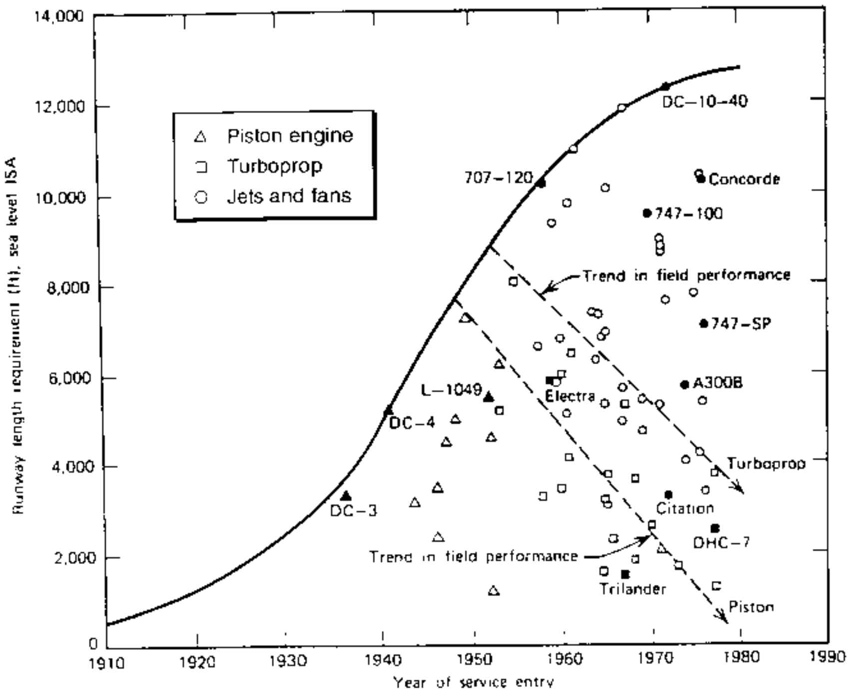


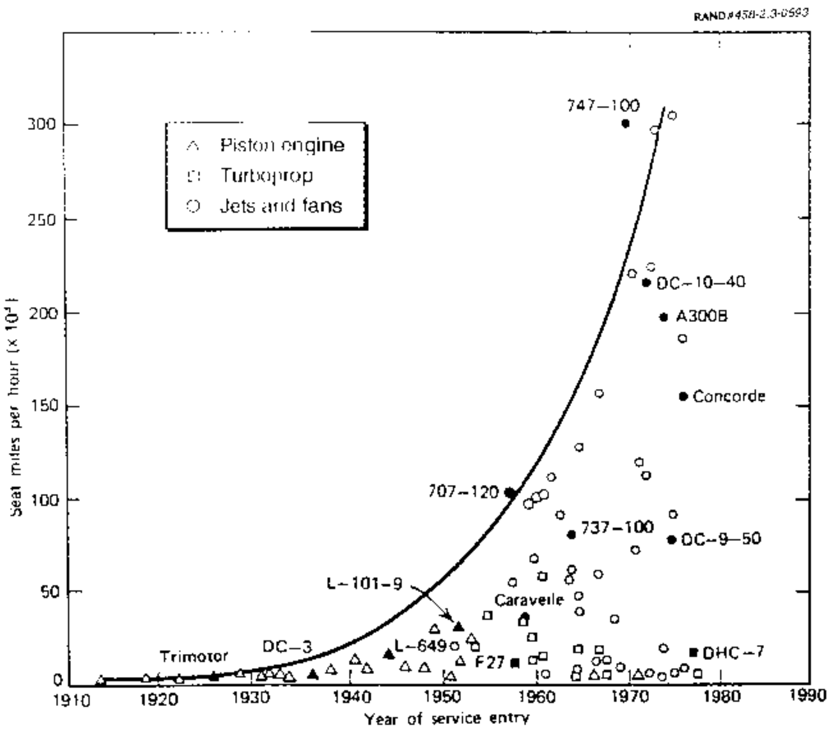
SOURCE: Norman Ashford and Paul H. Wright, *Airport Engineering*, John Wiley and Sons, Inc., New York, 1979. Copyright © 1979 John Wiley and Sons, Inc. Reprinted by permission of John Wiley and Sons, Inc.

Figure 2.2—Trends in Runway Length for Aircraft with Piston Engines, Turboprops, and Jets and Fans

"Chicago Convention"). Subsequently, ICAO developed and adopted 18 technical annexes to the Chicago Convention, which contain minimum standards that each ICAO member country and carrier must meet. These standards involve such technical fields as aeronautical communications, airworthiness, environmental protection, meteorology, operations, and security (Table 2.1). By the end of 1992, 173 countries had signed the Chicago Convention and agreed to meet these standards, which promote the functioning of international civil aviation in an efficient, orderly, and safe manner.

ICAO standards apply only to the international operations of the member states. Member states may have their own standards for domestic operations, which in many cases exceed those of ICAO.[1] For example, there are 35,000 airports and other landing facilities (heliports, seaports, etc.) around the world, of which about 1,200 are

[1]Some states do not meet ICAO standards for domestic operations and this is one explanation for higher accident rates in some countries.



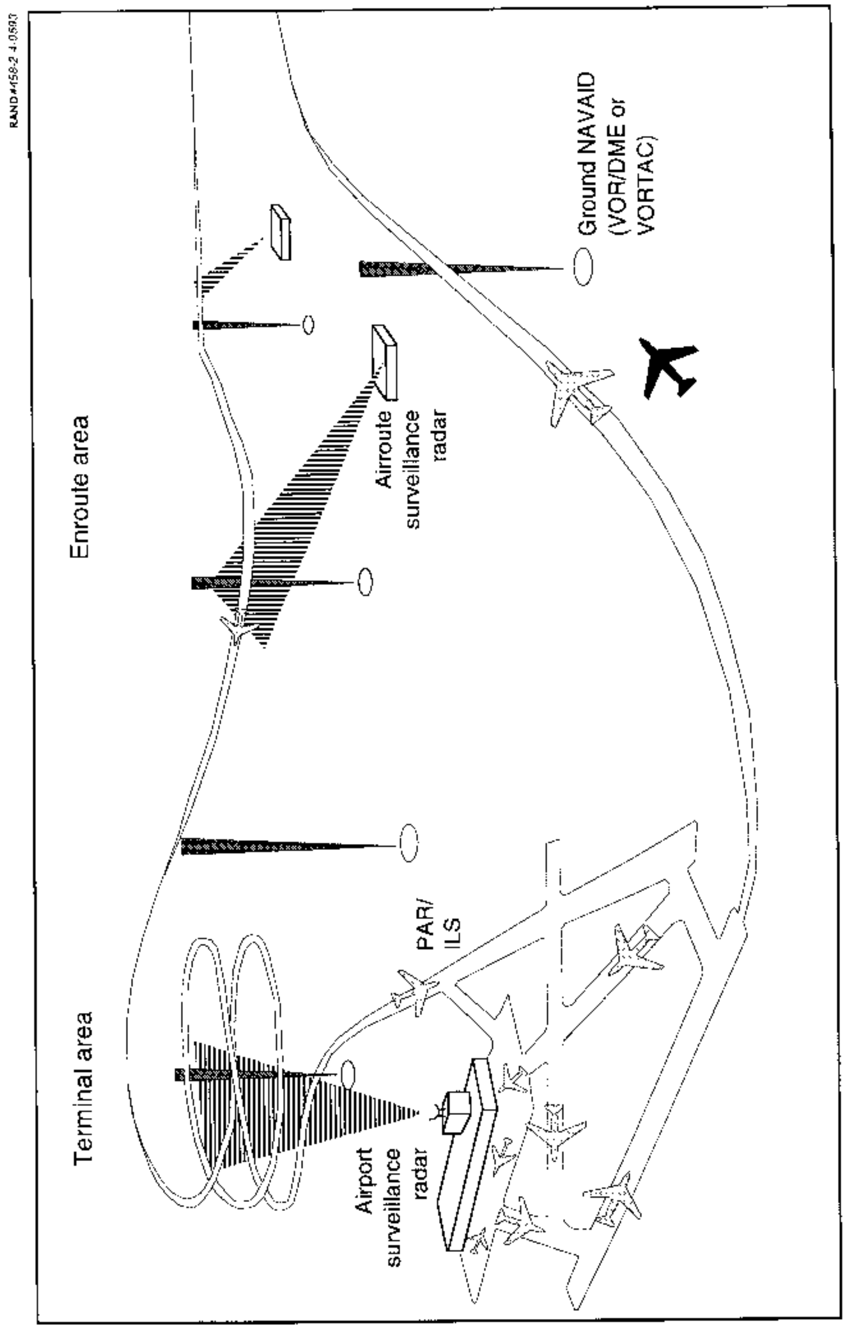
SOURCE: Ashford and Wright (1979), op. cit. Copyright © 1979 John Wiley and Sons, Inc. Reprinted by permission of John Wiley and Sons, Inc.

Figure 2.3—Trends in Productivity in Terms of Passenger Seat Miles per Hour for Aircraft with Piston Engines, Turboprops, and Jets and Fans

designated as international airports to which ICAO specifications apply. Globally, there are 3,000 air routes of which about 1,500 are designated as international and to which ICAO air navigation provisions apply.

A primary requirement for fostering safety in international civil aviation is Article 26 of the Chicago Convention. Article 26 places an unconditional responsibility on any member state within which an accident occurs involving an aircraft of another state, and in which a death or serious injury is involved. Such a state is obligated to conduct an investigation into the accident and must give the state in which the aircraft is registered the opportunity to participate in the investigation. When the investigation is completed, the state must communicate the final report and its findings to the state in which the aircraft is registered. Annex 13, *Aircraft Accident Inquiry*, sets the standards for all such investigations.

Another requirement of the Chicago Convention is that member countries recognize as valid the airworthiness certificates and licenses of other member states. The issuing country must certify only that it meets international standards. Thus, if a carrier



SOURCE: Paul G. Thomas, "Controlling Air Traffic," *Space/Aeronautics*, Vol. 5, p. 77, May 1968.

Figure 2.4—Air Traffic Flow

Table 2.1

Annexes to the ICAO Convention on International Civil Aviation

Annex	Covers
1. Personnel licensing	Licensing of flight crews, air traffic control officers, and aircraft maintenance personnel
2. Rules of the air	Rules relating to the conduct of visual and instrument flights
3. Meteorology	Provision of meteorological services for international air navigation and reporting of meteorological observations from aircraft
4. Aeronautical charts	Specifications for aeronautical charts for use in international aviation
5. Units of measurement to be used in air-ground communications	Dimensional systems to be used in air-ground communications
6. Operation of aircraft Part I—international commercial air transport Part II—international general aviation	Specifications that will ensure in similar operations throughout the world a level of safety above a prescribed minimum
7. Aircraft nationality and registration marks	Requirements for registration and identification of aircraft
8. Airworthiness of aircraft	Certification and inspection of aircraft according to uniform procedures
9. Facilitation	Facility support and services
10. Aeronautical telecommunications	Standardization of communications equipment and systems (Vol. 1) and of communications procedures (Vol. 2)
11. Air traffic services	Establishment and operation of air traffic control, flight information, and alerting services
12. Search and rescue	Organization and operation of facilities and services necessary for search and rescue
13. Aircraft accident inquiry	Uniformity in the notification, investigation, and reporting of aircraft accidents
14. Aerodromes	Specifications for the design and equipment of aerodromes
15. Aeronautical information services	Methods for the collection and equipment of aerodromes
16. Aircraft noise	Specifications for aircraft noise certification, noise monitoring, and noise exposure units for flight operations
17. Security	Specifications for safeguarding international civil aviation against acts of unlawful interference
18. The safe transport of dangerous goods by air	Carriage, handling, and storage of dangerous goods

wishes to operate within a foreign state, the foreign state generally relies on and accepts the carrier's home government license as evidence that it can operate safely. An exception to this blanket approval occurs in the United States. In August 1991, the Federal Aviation Administration (FAA) began to assess the oversight of foreign operators when new carriers applied for licenses to operate in the United States. The goal is to determine whether these countries meet ICAO standards. According to the

U.S. government, this type of inspection of a foreign carrier is permissible under the Chicago Convention.[2]

Thus, the ICAO Chicago Convention and its 18 Annexes (as continuously updated and amended) form the backbone of international civil aviation safety. ICAO's 1993 European membership consisted of 32 states, 16 of which belonged to the Joint Aviation Authorities.

AVIATION AUTHORITIES

Every nation has a Civil Aviation Agency (CAA), which is responsible for the regulation and safety of aviation operations and operating organizations within its borders. Most operating organizations have developed some form of internal safety program to monitor activities and ensure compliance with national safety regulations issued by the CAA. The coordination of activities across airlines, airports, and ATC organizations in each country is managed by the CAA.

A number of European CAAs work together through the European Civil Aviation Conference (ECAC) formed in the 1970s. One result of ECAC has been the creation of a formalized grouping of aviation authorities called the Joint Aviation Authorities (JAA).[3] Through the *Arrangements Document* (1989) these Authorities have committed themselves to cooperate and work with industry to develop a comprehensive set of Joint Aviation Requirements (JARs). The JARs (Table 2.2) embody a range of aviation activities including common procedures, practices, and safety regulations covering aircraft design, certification, airworthiness, and operational standards. The intent of the JARs is to establish enforceable European-wide aviation standards acceptable to all participating nations. To a great extent, the JARs are based on U.S. requirements (Federal Aviation Regulations (FARs)). At this time, however, adherence to JARs is voluntary and national codes take precedence. JARs that are completed are mandatory for EC countries and have been voluntarily agreed on in the other JAA countries. The JAR codes so far completed have been adopted by the EC into legislation as of January 1, 1993, and the remaining codes will be progressively added. A JAA treaty is being drafted that should give JAA a further legal base. The Netherlands is a part of the EC, ECAC, JAA, Eurocontrol, and ICAO.

MANAGEMENT OF AVIATION SAFETY IN THE NETHERLANDS

This section describes the organizations involved in ensuring the safe operation of aircraft at Schiphol airport. It is a brief overview intended to provide an understanding of aviation safety management in The Netherlands and allow some comparison with other countries and airports. It also explains the relationships between the organizations.

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[2]As will be discussed below, this approach is more difficult for The Netherlands to exercise in a unilateral manner. A foreign carrier inspection in the United States is possible only because the United States specifies in every new or renewal bilateral agreement a paragraph where mutual inspection of the visiting airliner is made possible. No paragraph implies no agreement. Although the United States has the power, manpower, and money to do this, such a process in Europe would probably require a coalition of countries.

[3]There are currently 22 JAA member states.

Table 2.2

Joint Aviation Requirements

Purpose	Code	Status
Definitions and abbreviations	JAR 1	Existing
Large aircraft design	JAR 25	Existing
All-weather operations	JAR AWO	Existing
Engine design	JAR E	Existing
Propeller design	JAR P	Existing
APU design	JAR APU	Existing
Sail planes and powered sail planes	JAR 22	Existing
Very light aircraft design	JAR VLA	Existing
Approved maintenance organizations	JAR 145	Existing
Equipment—joint technical standard orders	JAR TSO	Existing
Rulemaking	JAR 11	Future
Light aircraft and commuter design	JAR 23	Existing
Helicopter design (large), (small)	JAR 29, JAR 27	Existing
Certification procedures	JAR 21	Future
Operations (commercial air transportation)	JAR-OPS Part 1	Future
Certifying staff qualifications	JAR 65(E)	Future
Recreational aircraft maintenance	JAR 91	Future
Operators maintenance	JAR 121(L)	Future
Operations (helicopters)	JAR-OPS Part 2	Future
Operations (other than public transport)	JAR-OPS Part 3	Future
Airworthiness Directives	JAR 39	Future
Retroactive airworthiness requirement	JAR 26	Future
Emissions	JAR 34	Future
Noise	JAR 36	Future
Flight crew licensing	JAR FCL	Future
Certifying staff	JAR 65	Future

Four key organizations are involved in aviation safety at Schiphol:

1. Rijksluchtvaartdienst (RLD): The Department of Civil Aviation;
2. Luchtverkeersbeveiliging (LVB): The Air Traffic Control Services Organization;
3. NV Luchthaven Schiphol (NVLS): Amsterdam Airport Schiphol; and
4. The airlines and operators.[4]

The last three are operating organizations; the first is the governmental agency responsible for ensuring safety in aviation operations in The Netherlands and has oversight of the activities concerning safety management in each of the operating organizations. It has limited oversight over foreign aircraft operators.

Department of Civil Aviation: RLD

The Dutch Aviation Act serves as the basis for governmental supervision of aviation activities within The Netherlands. According to the Act, the Minister of Transport, Public Works and Water Management is responsible for civil aviation and air traffic safety. RLD has been created by the Ministry to carry out the tasks associated with this responsibility. The primary duty of the RLD is to supervise and promote civil

[4]KLM Dutch Airlines is the largest operator at Schiphol.

aviation and air traffic safety, although aviation infrastructure, politics, environmental issues, and rule-making are all within the scope of RLD's responsibilities.

Aeronautical Inspection Directorate: LI. The division of the RLD in charge of flight safety is the Directie Luchtvaartinspectie (Aeronautical Inspection Directorate [LI]). There are seven departments within LI: General Affairs, Airworthiness, Flight Affairs, Aircraft Manufacture and Maintenance, Environment, Aerodromes, and Projects and Information. Within each of these areas, LI ensures that Dutch pilots, airports, aircraft, and aircraft maintenance organizations meet the minimum standards necessary for a safe aviation environment. This is accomplished through a program of inspection and certification of Dutch aviation facilities and examination and licensing of Dutch pilots and aviation personnel.

The regulatory authority that LI exercises over Dutch aviation organizations and personnel does not extend internationally. For matters of safety related to foreign air carriers, maintenance organizations and aviation personnel, LI participates in a number of international organizations, including ICAO, JAA, and ECAC. Each of these organizations promotes the safety of international aviation through the development of common standards and practices.

Aircraft or aircraft parts manufactured in The Netherlands must meet standards set by the LI. These include the quality of companies, their equipment and final products, and the skills of personnel. Random inspections of the final product are performed and, in the case of Dutch-registered aircraft, certificates of airworthiness are issued. Dutch aviation maintenance organizations are also inspected and certified. For foreign aircraft, The Netherlands generally accepts the airworthiness certifications of other nations as specified under international agreements.

For aviation personnel, LI defines the requirements for the examination and licensing of pilots, aircrew members, air traffic controllers, and aircraft maintenance engineers, among others. Once licensed, some aviation personnel must undergo recurrent proficiency training and evaluations to maintain their license. This is currently true for pilots and other aircrew members but awaits passage of legislation for air traffic controllers. A system of proficiency monitoring for controllers will be mandated by this legislation; the manner in which this will be accomplished is under discussion. The qualification and proficiency of foreign pilots on foreign airlines is the responsibility of their home nations.

All aerodromes in The Netherlands, including small airports and heliports, must meet minimum standards. The Aerodromes Division of LI inspects the layout, equipment, and use of these facilities. Specialties in several areas are required including visual aids, rescue and fire fighting, runways and taxiways, and obstacle restriction. Inspections are held on a regular basis (typically once a year). There is, however, no formal system of aerodrome certification in place as exists in some other countries.

The enforcement of Dutch aviation safety regulations is carried out through LI's process of inspection, certification, and licensing. Aircraft designs that are not considered safe or aircraft with maintenance problems that affect airworthiness will not be certified. Pilots or other aviation personnel who fail to meet minimum standards or retain proficiency will not be licensed.

Other Nations in Brief: CAA. The role and organization of the RLD is not unlike that of other national aviation authorities both in Europe and in the United States. In the United States, the FAA is responsible for the promotion and safety of civil aviation. The organization of the FAA differs from that of the RLD in that it is divided into regions because of the size of the area for which it is responsible. Within each region of the FAA, divisions similar to those of the RLD exist. However, the FAA is also responsible for providing air traffic control services at most of the controlled airports in the United States. Most air traffic controllers are trained by the FAA, and all must be licensed by the FAA. Requirements exist for the formal annual evaluation of air traffic controller proficiency.

Differences between the Dutch RLD and other West European national aviation authorities are not as dramatic. Most are of a comparable size to the RLD with similar responsibilities. One major difference is that most countries have established a formal airport certification program. A few countries have also established formal quality or safety-assurance programs. These programs require that airports and air traffic control organizations maintain internal quality-control systems (stressing safety and security) and periodically produce output that demonstrates the results of their systems.

Amsterdam Airport Schiphol: NVLS

The primary responsibility of NVLS is the safe and profitable operation of Schiphol airport. The airport is governed by a board of directors and organized into business units. There are five such units consisting of Landside, Terminal, Airside, Facility Management, Projects, and a central staff. Of primary concern in this report is the Airside unit.

The business unit Airside is, in the Airside area, responsible for the effective traffic flow on Airside, with as favorable an exploitation as possible, and taking into account the safety standards, security measures, and environmental consequences. The Airside area is the movement area, consisting of the maneuvering area for aircraft and the aprons. The unit is responsible for the Airport Emergency Plan and the state of readiness of the airport.

The General Manager has the overall responsibility of the business unit. The Manager of Operations and Planning is responsible for the daily operation on Airside as well for the Airside development and long-term planning.

The Manager of Operations and Planning is also the Airport Commandant, who is responsible for airport safety. National regulations hold the Airport Commandant responsible for safe Airside facilities and the operational organization, procedures, supervision, and coordination between the airport and air traffic control.

A separate staff position, the Safety Advisor, reports directly to the Airport Commandant and provides recommendations, trend information, and advice on all aspects of Airside operational safety.

All operators of ground vehicles on Airside must be licensed by the Airside Operations unit. The maneuvering area is only accessible for trained and licensed staff. Access will be approved by the Operations Duty Manager, after a briefing and under control of ATC when on a runway. Training for apron access is carried out by the individual company (airlines in the case of baggage handling, for example), but the training scheme must meet minimum standards as determined by Airside Operations.

To protect aircraft operating on the taxiways and runways, minimum weather and visibility standards have been set. This applies both to aircraft and ground vehicles. The runway surfaces and adjacent areas are consistently checked for foreign objects that may damage aircraft; for the presence of birds; and for any condition of the surfaces themselves that might affect a plane's braking action. The primary reference used to determine which actions are necessary and how they may be accomplished is the ICAO *Airport Operational Services Manual Part 8*. Incidents that occur in spite of these efforts are recorded and investigated. Trend analysis is completed by the Safety Advisor and provides an informal means of identifying potentially hazardous situations, procedures, or practices.

Coordination and communication are integral parts of the safety-management process. The goal is to provide high standards and encourage the idea that safety is a team effort for which all personnel are responsible. Several standing committees and working groups exist on the local level to facilitate this process. They are divided into program, development, and operational levels. For all levels, there are regular meetings on overall operations issues and bird control. Bird control is an especially critical issue, since Schiphol is near the ocean and beneath major migratory routes. The existing bird control program (which includes 24-hour patrols, attractant elimination/reduction, dispersal, and occasional culling) is considered to be one of the highest quality and most effective in existence. On the operations and development levels, team meetings, briefings, and committee meetings occur on a regular basis on apron, snow and ice removal, and emergency planning issues as well as bird control and overall issues.

Coordination and communication are also maintained at both the national and international levels. The Airport Commandant, Head of Airside Operations, and Operations Duty Managers meet to discuss issues such as bird strikes, ramp safety, winter weather preparation, and emergency exercises.

Air Traffic Services: LVB

According to ICAO Annex 11, *Air Traffic Services*, the objectives of air traffic service are to prevent collisions between aircraft during the flight; to prevent collisions between aircraft on the runways, taxiways, and apron movement areas and to prevent obstructions on those areas; expedite and maintain an orderly flow of air traffic; provide advice and information useful for the safe and efficient conduct of flights; and notify appropriate organizations regarding aircraft in need of search and rescue aid and assist such organizations when required.

Air traffic services are divided into three categories: air traffic control service, flight information service, and alerting service. Air traffic control service is further divided into area control service, approach control service, and aerodrome control service. Area control service deals with aircraft that are en route and approach control service is provided to aircraft that are arriving or departing. Both of these services typically use radar. Aerodrome control service consists of the services provided to aircraft in the immediate vicinity of an aerodrome (usually within 5 nmi) where visual observation of aircraft is possible and to aircraft on the ground during landing, departure, and taxiing. Recently privatized, LVB is tasked with providing all of these services within Dutch airspace. Of primary concern for this report are the approach and aerodrome control services.

For Schiphol airport, LVB must provide the equipment and staffing necessary to carry out these responsibilities. LVB is responsible for the structuring of the airspace in the Amsterdam Flight Information Region (FIR), inclusive (around Schiphol), establishing traffic routings, and developing procedures for both arriving and departing aircraft. Procedures known as STARs (Standard Terminal Arrival Routes) and SIDs (Standard Instrument Departures) are designed and published by LVB and approved by RLD. These provide standard routes that can be assigned to aircraft, allowing for reduced ATC workload. The major considerations in the design of such routes are flight safety and noise concerns. Alternative procedures also exist that may be used in the event of failure of navigation, communications, or surveillance systems.

Organization of LVB. Before January 1, 1993, LVB was a division of the RLD. Since that time, LVB has been privatized and is now supervised by a board that reports directly to the Minister of Transport, Public Works and Water Management. The appointed board is composed of a Minister's representative, Defense Ministry representative, a representative of The Netherlands' airports, two representatives of the airlines, and an independent chairman. Reporting to the board is the Director of LVB, who has overall authority over the seven divisions within LVB. These divisions include ATS Operations, Navigation and Airport Strategy and Environment, Engineering and Maintenance, and ATC System Development. The ATS Operations Division is responsible for air traffic operations at Schiphol.

ATS Operations consists of a Manager and Deputy Manager of Operations and five separate operational units. The units are organized by responsibility: Amsterdam Area Control Center (ACC), Schiphol Tower and Approach, Beek Tower and Approach, Eelde Tower and Approach, and Rotterdam Tower and Approach. Two staff bureaus are attached to the Manager of Operations: ATS Training and ATS Procedures. There are also a Military Approach Control Center (Nieuw-Milligen) and additional approach and aerodrome facilities administered by the military, which are completely separate from the civil ATC units and come under military authority.

Recruitment, Training, and Proficiency of Air Traffic Controllers. Twice a year approximately 300 applications for ATC positions are received by LVB. Of these 300, approximately 120 will be selected to undergo evaluation by NLR. This includes batteries of psychological and aptitude tests. The goal is to have approximately 24 candidates for admission to the Air Traffic Control school. The Air Traffic Control school is six months in duration and successful students meet ICAO Annex 1 standards for ATC certification. Classroom and simulator instruction are scheduled after these first 6 months and take about four months. Approximately 11 of the 24 students admitted to the school complete the courses successfully after these 10 months.

The next phase is on-the-job training (OJT). Graduates are introduced to "the real world" of air traffic control through a three- to six-month program of performing as an assistant at Schiphol or other regional airports. There is a 90 percent success rate in this phase of training.

Finally, controllers assigned to Schiphol begin an OJT program for the ground control position. This progressive training program continues until the controller is qualified in all positions in both radar and tower. After successfully completing OJT in a particular position, there is a "rest" period during which the controller is allowed to act as a journeyman without further training in another position. OJT for each position varies in length from six to twelve months whereas the journeyman period lasts from six to eight months.

The simulation of emergency aircraft or ATC systems failures is according to ICAO recommendations and courses in other countries. Typically, the ATC viewpoint is that emergencies are so varied in nature that specific training in emergency procedures would not be practical or prove to be useful.

Once a controller is qualified, the formal system to measure proficiency is as follows: Supervisors are held responsible for ensuring the proficiency of controllers. Every six weeks, a supervisors' meeting is held to discuss current problems and issues. This may include discussions concerning the proficiency of a particular controller and the need for refresher training.

RLD and LVB are currently working to define a more elaborate system of proficiency monitoring. One difficulty in establishing such a system is the local nature of air traffic control. The only representative position to evaluate the controller proficiency adequately is the on-the-job position, which is a worldwide principle. Moreover, the only controllers qualified to evaluate the performance of an aerodrome controller at Schiphol would be those who are qualified in that position themselves. General knowledge of the area and ATC regulations may be tested through oral or written exams, but application of that knowledge may often be seen only in the actual position. Radar simulators are available that can be used to evaluate radar controllers to a certain extent, but at this time no equivalent cost-effective system exists to evaluate tower controllers.

The RLD is directly involved in controller proficiency in two areas. Current law stipulates medical requirements for all air traffic controllers including an annual physical. A list of prescription drugs that may affect performance exists, but it seems to have been developed informally. There is no requirement for controllers to submit to random checks for the use of illegal drugs.

LVB has established a set of internal rules that have been approved by RLD for determining when a qualified controller must undergo recertification. This applies mainly to controllers who, for one reason or another, have been unable to perform their normal duties in an active position. This may be due to illness, assignment to a special project, or annual leave. Controllers may also voluntarily enroll themselves in refresher training.

LVB has also internally established minimum standards of proficiency for managers. For example, watch supervisors must spend at least 50 percent of their time in active ATC positions. Upper-level managers must spend at least 20 percent of their time performing ATC duties. In addition to the above, a series of activities exists for keeping or improving the proficiency. First, during the introduction of new equipment, controllers are permitted to train and provide comments on systems before their activation. This also applies to the introduction of new procedures. About 10 percent of the controllers' time is used for these activities. A second activity, continuing education, consists of an annual two-day course provided by LVB. This course normally covers a variety of issues and an annual one-day simulator course and exercise. These sessions cover issues such as how to handle arrival delays, particular emergency situations, systems degradation modes, and airspace reorganization aspects. A third activity is that all controllers have to follow a cockpit training course, including 20 hours of actual flying on a light aircraft, to improve the pilot-controller understanding. A fourth educational element (in Europe as well as the United States) is that all controllers have to perform one or two duty flights per year in an airline cockpit and visit the control centers. Finally, all instructors are sent to the Eurocontrol institute in Luxembourg to participate in an instructor course of one to three weeks.

For both qualification (OJT) training and continuing education, the major issue is staffing. The philosophy is to provide a high level of training in both areas. Such programs require participation by a significant number of personnel—about 60 percent of the controllers conduct on-the-job training. Special instructors are needed to operate the simulators and administer the programs.

One other aspect of ATC training should also be mentioned. There are by nature a limited number of operating positions at any ATC facility. These positions must be staffed by qualified controllers at all times. When a trainee is placed in an active position, a qualified controller must remain alert and be responsible for that position, meaning, in effect, that a large number (60 percent) will at some time serve as trainers. A system is in place to ensure that all qualified controllers are permitted to work a minimum number (about 50 percent) of hours without a trainee in position. As technology advances, fewer personnel should be required to operate simulator systems and the fidelity (for visual tower simulators as well) should increase dramatically. The current emphasis placed on simulator training is for development of basic principles; time in active positions, however, is used to qualify controllers at the local facility.

Other Nations in Brief: ATC. The management structure of other European ATS units is similar to that of The Netherlands. Most have privatized or are planning to privatize all or a part of their ATC systems. Usually, government maintains regulatory and licensing authority over air traffic controllers. In some nations such as the United States and Britain, the government or the primary national organization provides basic training for the majority of air traffic controllers. Of those countries that have privatized ATC, most do not have a formal system of controller proficiency checks. It should be noted, however, that most countries (e.g., Germany, Britain, and France) in this situation are planning to implement some type of proficiency check system in the future. Only a few countries involve air traffic controllers in full-scale emergency exercises.

Since the economic resources and technological capability of nations vary, so does their ability to provide advanced air traffic control equipment and automation. Within Europe, attempts are being made to integrate and harmonize the existing individual systems. This is beginning in the Benelux, Germany and Eurocontrol integration project, which aims to make all sectors of these centers operate as though they belong to one center. In The Netherlands, Raytheon has been contracted to supply the Amsterdam Advanced ATC (AAA) system. Planned to become operational in the second half of 1995, this system will provide areawide ATC and central flight planning as well as terminal ATC for Schiphol and Rotterdam. The system is based on distributed processing, uses software written in high-level programming language, consists of the latest technology in display, and will be able to interface with all adjacent centers, including Eurocontrol.

Airline Operators at Schiphol

Airline and aircraft operators from all over the world use Schiphol. They include large international scheduled carriers such as KLM, British Airways, Northwest, and Japan Airlines; small scheduled carriers; unscheduled passenger and cargo carriers; commuter and air taxi operators using smaller transport aircraft; military aircraft; and a small number of privately owned general aviation aircraft. Dutch pilots are trained in a program approved by and licensed by the RLD and military authorities in The Netherlands, but foreign pilots are not. Although Dutch pilots are familiar with Schiphol and its procedures, foreign pilots will have prepared and trained using the resources available in their home countries and the quality of training available in foreign nations will likely vary.

For a major airline, operational safety is of paramount importance. Usually, a strong internal safety group exists for both the flying and maintenance operations. Safety activities often exceed the minimum requirements of civil aviation regulations. This involves extensive investment in equipment and training of personnel by the airline. But airlines recognize that such costs are insignificant compared to the potential cost of a major accident, both directly from loss of life and equipment, and indirectly through potential loss of traffic. At KLM, for example, there is one aircraft simulator for every eight aircraft in the fleet. Pilots undergo training several times per year in emergency procedures (such as loss of an engine or hydraulic system, or a cargo compartment fire), and for familiarization with ATC procedures on a new route. Simulator training may also be used to evaluate and train air crews in effective cockpit management.

For mechanics and maintenance engineers, a variety of instructional methods are used to maintain currency and to train for new equipment or procedures. Aircraft manufacturers offer regular courses for their customers, or provide on-site instructors to teach (or even to learn about locally developed) modified approaches to maintaining the aircraft.

These internal activities require highly qualified personnel and substantial investment. There may not be similar training capabilities at small, less-profitable airlines, especially in less-developed nations. There, the manufacturers of airline aircraft, worried about the reputation of their products, may play a continuing role in teaching, advising, and assisting the flight operations and maintenance personnel of their customer airlines in an attempt to bring them up to a level of safety comparable to large airlines. Since aircraft flight simulators are expensive, the smaller airlines around the world may lease the facilities and instructional capabilities of the major airlines to provide their pilots with good training. (In fact, such arrangements can be a prior condition to obtaining hard currency loans to purchase the aircraft, and similar conditions can apply to maintenance activities.) There is an interchange of information and activities between all of the world's airlines in an effort to maintain high levels of safety throughout the industry, and in some cases, the working relationships are quite close on operational and maintenance matters.

AVIATION ACCIDENT INVESTIGATION

An important component of aviation safety management is competent, independent accident investigation when an accident or serious incident occurs. This assures that, where possible, the causes will be identified and steps taken to rectify those causes to avoid that type of incident in the future. In the United States, this function is the responsibility of the National Transportation Safety Board (NTSB). The NTSB was created by the U.S. Congress because of the major interests that were often at stake. Accident investigations that seek to learn from the errors made and increase future safety often do not square with economic and political interests. In The Netherlands and in most of Europe there is no equivalent body. In the smaller countries of Europe, major accidents, fortunately, do not occur very often and such permanent accident boards are considered unnecessary. Internationally, ICAO places the responsibility for an accident investigation in the hands of the country in which the accident occurred. If another country is involved in the accident, then it is generally invited to participate in the investigation and it receives the accident report.

In The Netherlands, there is a permanent Council for Civil Aviation (Raad voor de Luchtvaart). This council is responsible for aviation accident investigation according to ICAO Annex 13. Before the new Aviation Accident Investigation Law (Luchtvaartongevallenavet) became effective on February 1, 1993, the Director of the Aeronautical Inspection Directorate (RLD/LI) was automatically the accident investigator, working under the Council. In the new law, which was passed to bring Dutch law in line with the ICAO standard, the investigator has to be explicitly appointed by the independent Council.

SAFETY SURVEY OF SCHIPHOL

PURPOSE OF THE SURVEY

The survey described in this chapter is intended to give an impression of how Schiphol compares to other airports in terms of size, operations, and safety-related issues. It begins by describing the current and projected future operational practices at the airport, then makes some comparisons with other airports, and finally identifies some Schiphol safety-related issues and potential solutions.

HOW THE SURVEY WAS PERFORMED

The survey was performed initially by Flight Transportation Associates through a series of interviews with various aviation management stakeholders and visits to several other West European airports. The description of operational practice, current and future, in this chapter includes much of the description reported by FTA to RAND/EAC during the study. This description was supplemented and modified based on additional in-depth interviews by Dutch-speaking researchers of the EAC, by a series of security interviews by a RAND specialist in security and terrorism, and by gathering data regarding the populations surrounding other airports and levels of flight operations at those airports.

DESCRIPTION OF CURRENT OPERATIONAL PRACTICES AT SCHIPHOL

Basic Air Traffic Flows in the Terminal Area

Aircraft begin and end their flight within airspace near airports known as the terminal area. Flight in the terminal area involves changes in speed, altitude, and direction of flight. Arriving aircraft must exit the airway system, descend, and maneuver to align with the runway in use. Departing aircraft must climb and intercept their assigned airway. The airways and most other routes flown by aircraft are formed from radio signals emanating from ground-based systems known as navigational aids (NAVAIDS). The principal NAVAID forming the airway system is the very high frequency (VHF) Omnidirectional Radio or VOR, which provides course information. VORs may be collocated with Distance Measuring Equipment (DME), which provides distance information as well. Such a facility is known as a VOR-DME.

Beyond the terminal area is the en route area. It is in this airspace that aircraft level off at the assigned altitude and cruise toward their destination. Modern aircraft are equipped such that pilots may use the NAVAID facilities to navigate to and from an airport without assistance from ground personnel such as air traffic controllers. However, to ensure separation between aircraft and to maintain an efficient flow of arrivals and departures, air traffic control is required.

The controllers responsible for the terminal area surrounding Schiphol include those in the Approach Control Facility (APP) and those in the Aerodrome Control Tower (ACT). The controllers responsible for Dutch en route airspace are found in one of two Area Control Centers (ACCs). Other agencies, such as Flight Information Centers, can provide the pilot with important information such as the status of navigational aids or the runways at a particular airport.

Normally two types of flying may occur in the terminal area: visual and instrument. In visual flying, Visual Flight Rules (VFR) dictate that the pilot must see and avoid other aircraft and obstacles. When weather conditions prevent this, Instrument Flight Rules (IFR) apply. Most commercial aircraft operate using IFR even if the weather allows VFR flight. This provides a higher margin of safety, since flying IFR requires the use of NAVAIDS and the participation of air traffic control to provide sequencing and separation services. In the special case of Schiphol, no VFR flights are permitted in the SPL-TMA. This eliminates possible conflicts between controlled IFR flights and noncontrolled/nonradio ones.

For IFR arrivals into the terminal area, four segments of flight may be defined. Aircraft normally leave the en route airway system via a NAVAID at the edge of the terminal area known as the Initial Approach Fix (IAF). At this point, responsibility for the aircraft transfers from the en route controllers to the terminal controllers. From the IAF, the aircraft will descend into the terminal area along the *initial approach segment*. At some intermediate point, a change in direction will also likely be made to align with the runway. This point is known as the Intermediate Fix (IF). From the IF, the aircraft will follow the *intermediate approach segment* to the Final Approach Fix (FAF). Here is where the aircraft begins its final approach to the runway. The *final approach segment* is aligned with the runway and is the last flight segment of an inbound aircraft. Typically, the final approach segment is formed from the Instrument Landing System (ILS).

In some cases, landing will not be possible because of weather, obstructions on the runway, or for other reasons. In this event, a missed approach may be flown. The route taken by an aircraft executing a missed approach is often similar to that of a departure and is known as the *missed approach segment*. Of all four segments, only the final approach segment is required; the other segments may be formed by air traffic controllers assigning magnetic headings known as radar vectors.

Aircraft flying under IFR normally execute a precision instrument approach for the final approach segment. Precision approaches provide both lateral and vertical guidance to the runway. A nonprecision approach provides only lateral guidance. The current world standard for precision approaches is the ILS. The ILS ground equipment and the aircraft ILS receiver are certified for different minimum weather conditions in which aircraft may fly the procedure. These minima define the lowest altitude to which an aircraft may descend (decision height (DH)) on the approach, and the minimum visibility in which the approach may be flown. If the DH is reached before the pilot sights the runway, a missed approach must be executed. However, some ILS systems are so accurate that there is no minimum decision height. Even with such an accurate system, a minimum visibility must be defined. This is not so much for the approach itself but for taxiing off the runway and to the gate.

ILS ground equipment can be said to consist of four parts:

1. Guidance information: a localizer provides azimuth guidance by means of a radio beam aligned with the runway to a range of approximately 20 nmi. A glide slope provides vertical guidance by means of fixed angle of approach 2.5° to 3.0° above the runway plane to a range of approximately 10 nmi (Figure 3.1).
2. Range information: marker beacons indicate when they are overflown; distance measuring equipment (DME) provide the distance information.
3. Visual information: consists of approach, runway, and taxiway lights.
4. Visibility information: transmissometers provide Runway Visual Range (RVR).

Three categories of ILS approaches are defined based on the accuracy of the ground equipment. For each category, basic minima are defined, but these may be affected by the equipment in the aircraft, experience level of the pilot, and the components and status of the ground equipment.

1. Category I—minimum DH 60 meters and RVR 550 meters.
2. Category II—minimum DH 30 meters and RVR 350 meters.
3. Category III—no minimum DH and RVR 75 meters.

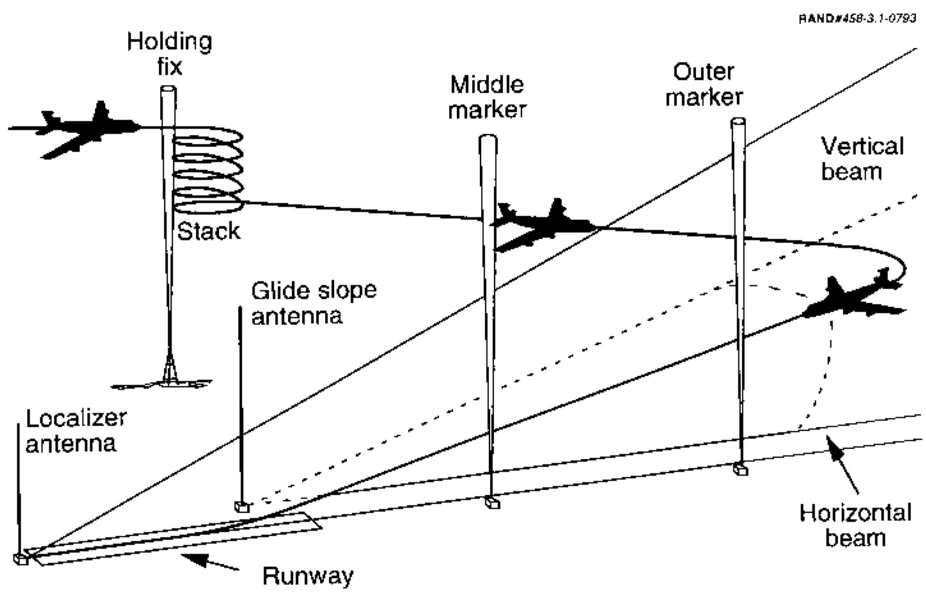

Figure 3.1—Schematic Diagram of an Instrument Landing System (ILS)

Departures from the terminal area are typically a much simpler operation. Aircraft depart the runway on an assigned heading or follow a published route until intercepting the desired airway. Separation between arriving and departing aircraft is often achieved through the use of assigned routes that are separated from each other laterally, by altitude, or both. The arrival and departure procedures described above will vary from airport to airport depending on the level of operations and available equipment.

Surface Operations

The number of available runways and the manner in which they are used affects both ground and air operations. There are currently five runways available at Schiphol airport (shown in Figure 3.2). Runways are given two separate designations based on the magnetic compass direction in which they point. At Schiphol, the runways are: 01L/19R, 01R/19L, 09/27, 06/24, and 04/22. Runway 04/22 is reserved for use by small aircraft. At Schiphol, only one end of every runway is used. There is limited use of Runway 27. It is used for takeoff upon special request in addition to 09/27, for example, when the wind direction dictates it and during peak hours when 09/27 is being used as a second arrival or departure runway.

Of course, all the runways are not used simultaneously. The normal configuration consists of two runways: one for takeoff and one for landing. The configurations are chosen from among the available runways depending on wind, weather, demand, and other operational constraints such as noise considerations. The preferred configuration is landing on Runway 06 and takeoff from Runway 01L. This and other configurations are shown in order of preference in Figure 3.3. All runways are inspected at regular intervals by Schiphol operations for surface conditions and foreign objects before runway configurations are changed.

Arriving aircraft must taxi from the runway to the gates, and departing aircraft from the gates to the runway. As can be seen in Figure 3.4, the use of the taxiway system is segregated between arrivals and departures. Many of the taxiways are unidirectional and there are no taxi routings associated with any configuration that requires crossing an active runway. This is unusual at a major airport, where such crossings can be a source of accidents and incidents.

Before a departing aircraft may exit a gate and enter a taxiway, the pilot must be given a push-back clearance. This allows air traffic control to regulate the flow of departure traffic and prevents queues on the taxiways. Ground controllers (located in the ACT) assign taxi routes based on the departure runway or, for arrivals, the assigned gate. Arriving aircraft are assigned gates by the apron control unit. NVLS is responsible for the traffic in the immediate vicinity of the gate. This includes the aircraft and any other vehicles in this area. A system of training, licensing, and pavement markings helps to ensure safe ground operations near the aircraft gates. The taxiways themselves are considered movement areas and permission of ground control is required for their use by either aircraft or ground vehicles.

Arrival Operations

There are three VOR-DME NAVAIDS in the Amsterdam area: Schiphol (SPL) on the airport, Spykerboor (SPY) about 16 nmi to the north, and Pampus (PAM) about 13

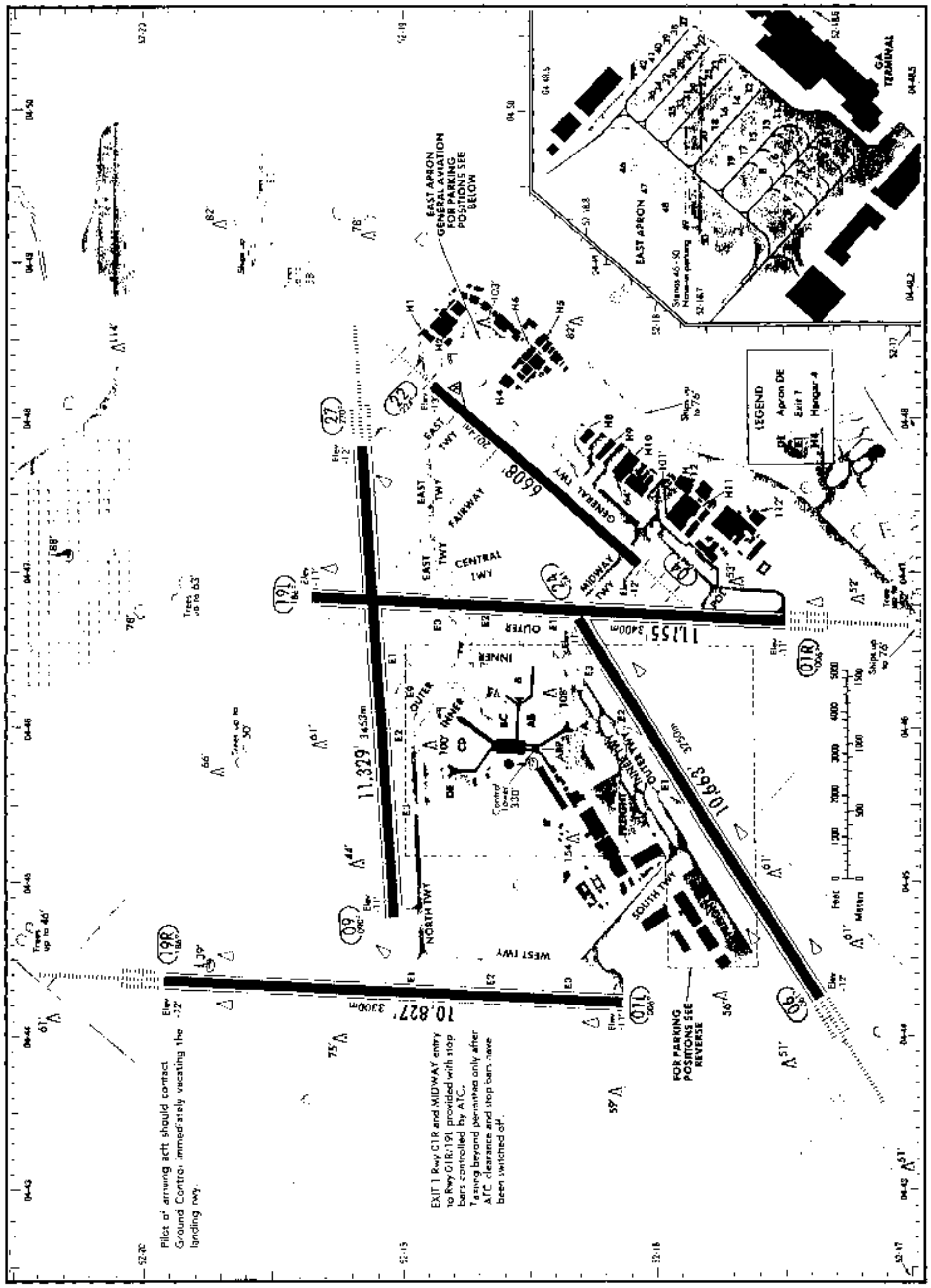

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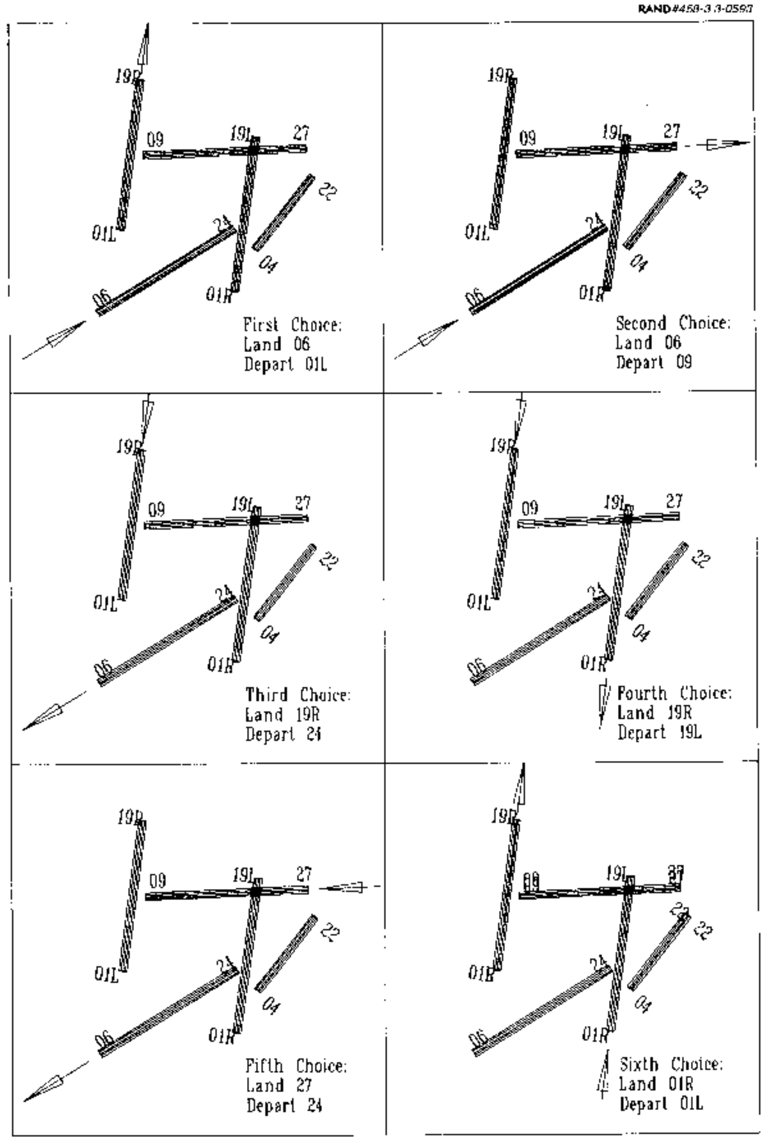
Figure 3.2—Schiphol Runways



SOURCE: Flight Transportation Associates, Inc., *Schiphol Airport Safety Study: A Review of Aviation Safety Management Systems*, Cambridge, Massachusetts, April 1993.

Figure 3.3—Preferential Runway Choices at Schiphol

nmi to the east. Based on these NAVAIDS, there are five pairs of one-way airways that radiate from the Amsterdam area (Figure 3.5):

1. B5 outbound and B1 inbound to the northwest.
2. B5 inbound and B1 outbound to the southeast.
3. R12 inbound and R1 outbound to the southwest.

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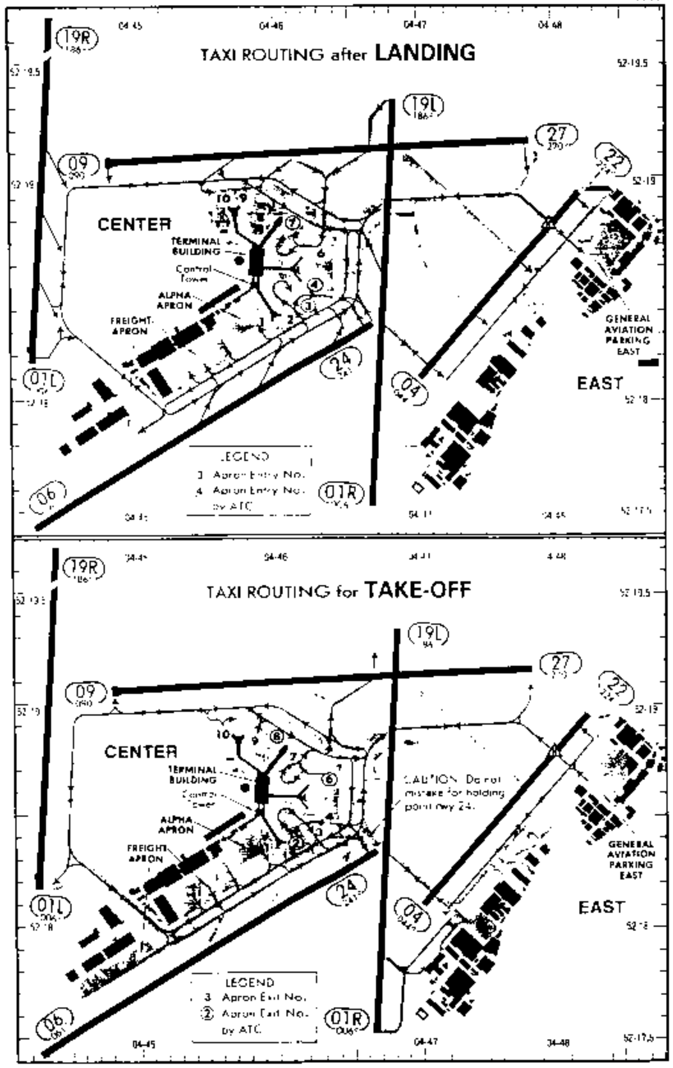

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Figure 3.4—Schiphol Taxiway System

4. R12 outbound and R1 inbound to the northeast.
5. A5 inbound and B31 outbound to the south-southwest.

Aircraft arriving in Amsterdam airspace begin to descend from these airways roughly 80 nmi from the airport in airspace delegated to the Amsterdam ACC. Before this descent, the aircraft will be under the control of the London, Copenhagen, Bremen, Brussels, Maastricht, or Düsseldorf ACC. Amsterdam ACC directs the aircraft

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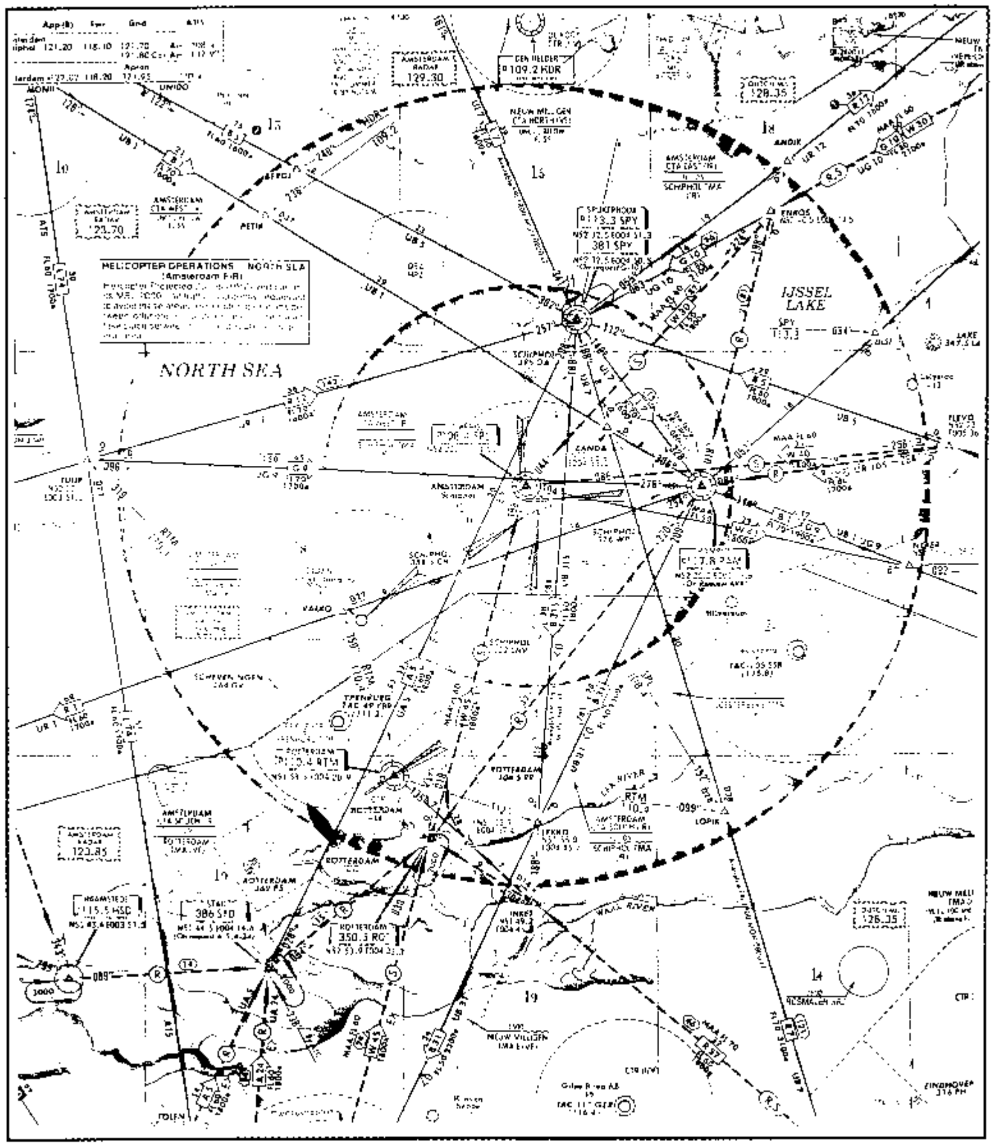

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Figure 3.5—Airway System Surrounding Schiphol

through one of three entry points (the IAFs) located approximately 30 nmi from Schiphol where three holding stacks are established: at SUGOL over the North Sea; RIVER on the coast in the Rhine estuary; and LAKE to the northeast on the polders. Which IAF is used depends on the direction from which each aircraft originates. Within the Schiphol APP, the planning controller uses a computerized metering system to inform the en route controllers of the desired landing acceptance rate for Schiphol. The computer system provides an exit time from the IAF (or holding stack if holding is required) called an expected approach time (EAT). Aircraft are kept above 7000 feet until this point and airspeeds are 250 knots, unless holding is required when speeds are reduced to 220 knots. Normally, the metering software allows creation of a smooth arrival flow into Schiphol by providing revised estimates for the IAFs. These revised estimates are achieved by instructing aircraft to adjust their airspeeds. In some cases (such as a sudden deterioration in the weather) speed adjustments alone will not be sufficient to meter the arrival flow and holding over the IAF may be required.

As aircraft pass the IAF and clear the holding area, they enter the terminal area and are transferred to the approach controller. At this point, the pilot will have been assigned a STAR. There are several published STARs for Schiphol airport. Which one is assigned depends on which runway is being used and which IAF the arrival is overflying. All of the STARs at Schiphol incorporate radar vectors once the aircraft is 15 nmi from the airport. Figure 3.6 shows a typical STAR for Schiphol. The approach controller directs aircraft from all three IAFs to the current landing runway using paths similar to those shown in Figure 3.6 and instructs them to descend to 3000 feet. Typically, aircraft speeds are reduced to 220 knots 15 nmi from Schiphol as aircraft are merged into the landing sequence. The approach controller is responsible for merging arrivals from all of the IAFs into a landing sequence for the runway in use. When weather conditions permit, the approach controller may inform pilots of the aircraft they are to follow so that visual separation may be applied. In poor weather, the approach controller must ensure that the proper amount of radar separation is maintained between aircraft.

Once an initial heading has been assigned and the arrival sequence determined, aircraft are transferred to the arrival controller. The arrival controller directs aircraft to the intercept altitude for the ILS (2000 feet), vectors them to intercept the localizer, and reduces their airspeeds to 160 knots. The task of the arrival controller is to maintain the spacing between aircraft achieved by the approach controller. When an aircraft is safely spaced and established on the final approach course, it is transferred to Schiphol Tower.

Four runway ends at Schiphol are equipped with an ILS. Runways 19R, 06, and 27 are certified Category III and Runway 01R is certified Category II. This provides for very low-visibility operations and automatic landings (computers on board the aircraft fly the approach) with the highest degree of safety (to qualified aircraft operators). Although the standard minimum radar separation is 3 nmi between successive arrivals in good weather, it is increased to 8 nmi when visibility falls below 600 meters, to 10 nmi below 400 meters, and to 12 nmi below 200 meters. This reduces the landing capacity during poor visibility and may cause delays. All approaches require that aircraft fly a straightline path and glideslope to the runway threshold over the last several miles in poor weather. This practice is also maintained in good visibility conditions to have uniform procedures and to ease transition to poor weather operations.

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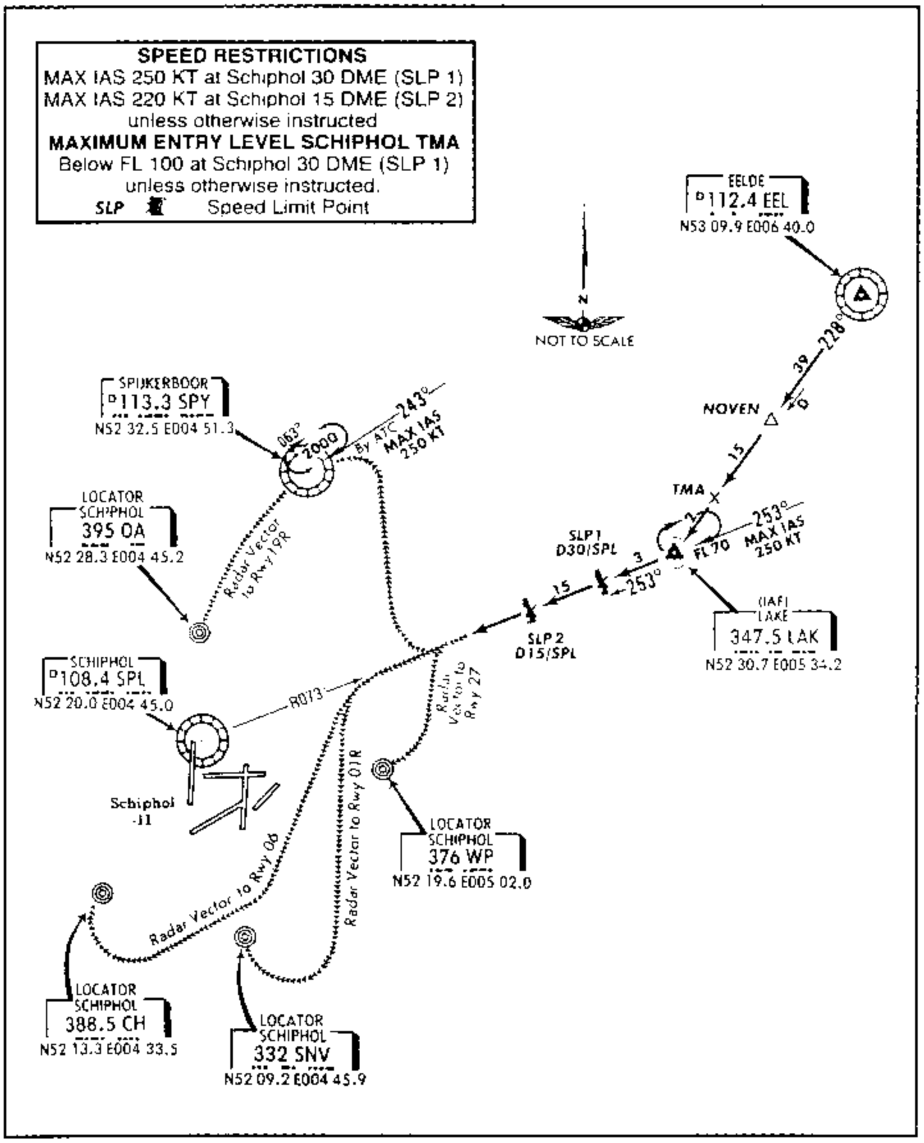

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Figure 3.6—Typical Standard Arrival Route

In the event of a missed approach, the pilot initiates a climb straight ahead to 2000 feet, informing Schiphol Tower, which will transfer the aircraft back to the arrival controller. The aircraft will then be vectored under radar control to reenter the arrival sequence for another approach to landing.

In the ACT, the aerodrome controller visually surveys the runways and the airspace surrounding the airport. The aerodrome controller provides the pilot with a landing clearance after ensuring that the runway is free from other operations or obstructions. Once the aircraft has landed, the aerodrome controller provides the pilot with a recommended taxi exit and will transfer the aircraft to ground control when it clears the runway. Radar is also used in the tower, but only to provide information rather than separation services. Aerodrome controllers use a daylight display of the APP radar to verify the position and sequence of aircraft under their control. Ground controllers may use the Surface Movement Radar (SMR) to verify the position of taxiing aircraft.

There are two surveillance systems used at Schiphol: a primary radar with a collocated secondary surveillance radar and an autonomous secondary surveillance radar. Furthermore, information from the long-range radars (one primary with a collocated secondary and one secondary radar only) with coverage as low as 200-400 feet is available. This redundancy makes the complete loss of radar surveillance unlikely and justifies the reliance on efficient radar procedures around the airport.

Departure Operations

Departure paths at Schiphol are designed to avoid overflying nearby residential areas by using turns immediately after takeoff on every runway. Compared to other airports, Schiphol is unusual in that there are no straightout departures. All departure paths turn within 1 nmi of the runway. At peak traffic times, it is standard procedure for a second departure runway or a second landing runway to be put into use by ATC (two departure runways and one landing runway or one departure runway and two landing runways). This is the usual indicator of the need for more departure capacity at any airport. Busy airports in the United States may operate two landing runways and three or four takeoff runways simultaneously.

There are numerous exit points from the Amsterdam Terminal Area. They lie about 30 nmi from Schiphol between the three holding stacks over the IAFs. For each runway, there is a set of SIDs that an aircraft can follow to reach these exit points and reenter the airways, although radar control may be used to expedite any departure. The approach controller handles arrivals and departures at Schiphol. At most busy airports, there is a separate departure control position. By preference, the Schiphol approach controller works both arrivals and departures although separate radio frequencies are provided. Entering the airways (shown in Figure 3.5) takes place at VALKO or REFSO for R1 to the southwest, at BERGI for B5 to the northwest, at SPYKEBOOR for R12 to the northeast, at PAMPUS or NYKER for B1 to the southeast, at LEKKO for B31 to the south, etc.

The details of typical SIDs to the exit point LOPIK are shown in Figure 3.7. Notice that departures commence turns within 1 nmi of the runway as soon as the aircraft reaches an altitude of 500 feet. Various navigation aids in the Amsterdam-Rotterdam area are used to provide guidance to departure aircraft. The SIDs are assigned to

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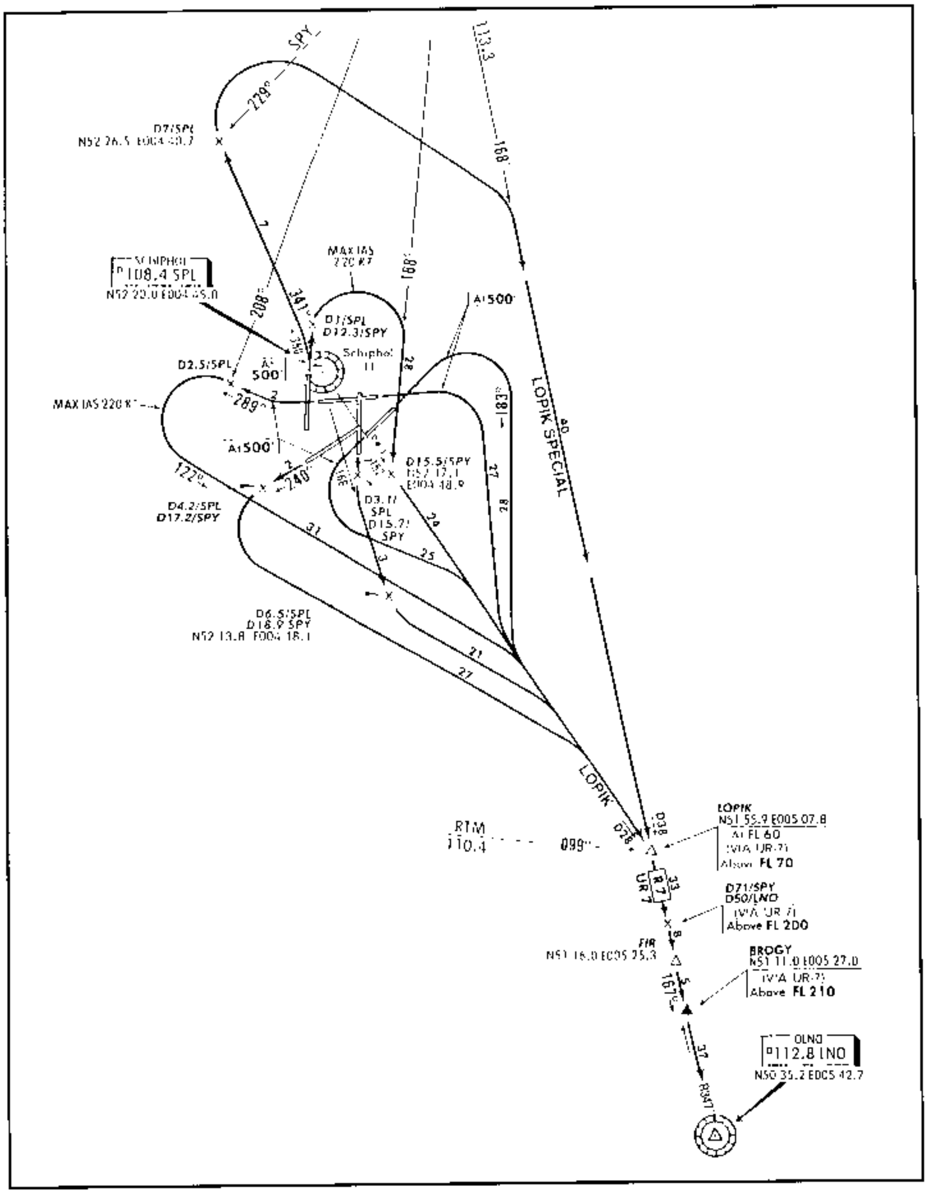

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Figure 3.7—Typical Standard Instrument Departure Route

each aircraft before push-back from the gate by the ATC clearance delivery position. With newer digital autopilots called Flight Management Systems (FMS), the SIDs can be flown automatically by aircraft allowing better conformance, even in strong winds, than can be expected from normal pilotage by a crew busy with their departure workloads. Such improved performance will become more common in the next 10 years.

Takeoff from Schiphol is controlled by the aerodrome controller. Upon reaching 2000 feet, pilots will (unless otherwise instructed by the controller) contact the Schiphol departure controller (the approach controller on the departure frequency) who will monitor their conformance to the SID, or may intervene if necessary to redirect the departure's path or altitude to avoid bad weather or other aircraft. Although they may appear to be complex, the SIDs are segregated from the STARs and there is little interaction between arrival and departure traffic flows.

It is expected that all IFR-qualified pilots will be familiar with the SIDs and STARs at Schiphol and can fly them correctly (or insert them correctly to their autopilot/FMS) so that the flight paths will conform to the desired routes. Any change in a published procedure at Schiphol must be disseminated around the world ahead of its implementation to all airlines and pilots who will be flying to the airport after its effective date. This publication and dissemination is the responsibility of the Dutch RLD and the international aviation community. Every pilot visiting Schiphol should have the latest set of published procedures on board the aircraft and should be familiar with them, although there is no way of guaranteeing this for foreign operators.

Emergency Operations at Schiphol

The prior sections described routine operations for aircraft arriving or departing at Schiphol. A variety of emergency situations can occur, creating the need for a coordinated emergency response from a wide set of agencies (e.g., LVB, NVLS Schiphol, airlines, and local fire fighting and medical agencies). At Schiphol Airport, because of this variety of precautionary and emergency situations, the coordinated response is laid down in the "Airport Emergency Plan." The Airport Commandant is responsible for preparing and maintaining an emergency plan for Schiphol and ensuring a continuous state of readiness. This requires a constant review of coordination plans and training and instructional activities, and an annual execution of a full-scale exercise, monthly desktop exercises and weekly system checks.

The nature of emergency operations can be classified as to their location and degree of criticality. Emergencies can occur either while an aircraft is airborne or on the surface of the airport. If airborne, they can occur in the immediate vicinity of the airport during arrival or departure, or in the en route phase of flight. There may be a degree of urgency in getting the aircraft safely back on the ground at Schiphol if there is an on-board fire, injury to crew or passengers, or the threat of loss of control over the aircraft's flight. In some situations, such as a terrorist bombing, a midair collision, or a serious structural failure, the aircraft may have completely lost control over its flight path and may crash at a random location. If flight control is retained and the emergency procedure is not time-critical, the emergency response will ensure that sufficient preparations are made to minimize the risks of the upcoming emergency operation. In many cases (such as bird strikes or bomb threats), the emergency is actually a precautionary operation where it is prudent to land the aircraft to inspect the situation.

The Schiphol airport emergency plan accounts for all these situations. There are three classes of emergencies: aircraft, nonaircraft, and security. Each class has five levels of response: full alert, internal full alert, minor alert, standby, and assistance.

In the Schiphol emergency plan, there is a command structure under the Operations Duty Manager on behalf of the Airport Commandant to declare the class and level of the emergency and to coordinate the desired response and activities to all parties involved.

Operations managers of parties involved will normally meet upon the initiative of the Operations Duty Manager or the National Police in the Crisis Team (Consultative Commission). When this team meets, the Airport Commandant is informed. Operational decisions are made by this team. If there is a need for emergency policy, the Airport Commandant or the Crisis Team will invite the Emergency Committee for a meeting to develop the needed policy.

Under specific circumstances in relation to security threat, the General Operational Command of the National Police will coordinate the state emergency policy and controls the leading police officer on the emergency location.

In case of a serious disturbance of public order or major disasters involving Schiphol, the policy center of the major/public prosecutor can be advised by the Airport Management.

At Schiphol, an airport emergency plan (Alarmregeling) is prescribed in the Emergency Plan. Because of the variety of precautionary and emergency situations that can occur, the coordinated response is prescribed in the emergency plan. The Airport Commandant is in charge when an emergency occurs and he is responsible for preparing and maintaining the plan and the efficient organization therein. This requires a conduct review of coordination plans, the conduct of training and instructional activities, and the execution of drills, full-scale exercises, desktop exercises, and system checks.

These activities are primarily aimed at handling the occurrence of an actual accident on (or nearby) the airport but may be activated ahead of the potential accident if it is appropriate. The capabilities at Schiphol for fire fighting, crash rescue, and medical handling of injured passengers and crew are unmatched in The Netherlands. In light of this, faced with a non-time-critical and fully controlled emergency landing, it is advisable from the viewpoint of the aircrew to land at Schiphol rather than another airport.

Another level of longer-term emergency management is concerned with the improvement and maintenance of the emergency plan and exercising it annually. Two groups carry out this work. First, the Airport Commandant and the general managers at Schiphol are members of the Policy Group Emergency Plan to determine policy, the year's schedule of activities, and its budget. Second, a Control Group Emergency Plan exists consisting of the Airport Commandant and the Head of Airside Operations, Terminal Operations, Contingency Services, Traffic and Airport Security, Training at Schiphol, and representatives of the Amsterdam Ambulance and Health Services. The control group has two working groups: one on coordination, which prepares the annual emergency drill, and another responsible for annual instruction/training activities.

It is noted that the Air Traffic Control Service (LVB) is *not* represented in the emergency plan. As described above, the emergency plan does not include situations for handling an airborne emergency. There is no equivalent planning, training, annual exercises or coordination between the aircraft operators, aircrews, and the Schiphol ATC personnel to prepare themselves for typical airborne emergencies.

The legal position in aviation is that the owners of the aircraft (and their agents, the aircraft captains) are responsible for the safe operation of the aircraft. It is recognized worldwide that the captain of an aircraft is the final decisionmaker on emergency airborne actions, and that ATC and airport personnel on the ground are responsible for providing information and expert advice relative to the emergency. The captain is responsible for declaring the emergency and requesting any needed information that might be available from ATC or from technical experts at his airline. Airline pilots at major airlines (such as KLM) receive simulator training several times per year to cover a wide variety of emergency conditions that might occur in the aircraft they are currently flying. This allows the cockpit crew to practice as a team in resolving or minimizing the consequences of such emergencies.

Air Traffic Control procedures are created with the knowledge that various types of airborne emergencies might occur,[1] and some general contingency planning is usually part of the curriculum for training air traffic controllers. It is considered that most emergency requests by a captain can be safely accommodated by the controllers, but it is clear that no annual simulation training for such emergencies is currently available to controllers. There exists some coordinated planning between LVB and Schiphol. Further coordinated planning might ensure that a variety of information concerning the nature of alternatives available to a captain with an airborne emergency at Schiphol is rapidly available through the LVB, and that good communications between LVB and the Operational Control Center of Dutch (or other) airlines operating at Schiphol is maintained and exercised annually. There is no "airborne" emergency plan equivalent to the current "ground" emergency plan at Schiphol.

Today, the airborne emergency is handled by ATC based upon requests and information received from the pilot. They are prepared to respond to an emergency request immediately after takeoff, if necessary. Other air traffic may be diverted from takeoff and landing operations at the airport until the emergency is resolved. The air traffic controller may ask the captain for his intended path and altitude, or may suggest an area and altitude that the aircraft might use while the aircraft's crew deals with the emergency. Observation of the aircraft's progress on radar allows the ground controllers to keep other aircraft away from the emergency aircraft. The ATC system is designed to be able to stop all arriving traffic at the holding stacks, and can stop takeoffs immediately and direct those aircraft to vacate the areas around the runways by returning them to the ramp areas of the airport. ATC supervisors can execute these actions by advising the various ATC controllers.

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[1] Besides the airborne emergencies there are possible ATC emergencies; backup systems/procedures are identified in the ATC planning.

If it is critical to get the aircraft back on the ground, the captain has the final decision on selecting a landing runway. The ATC controller may suggest another runway and provide information, but only the captain can balance the various time-critical factors in getting the aircraft safely back to the airport. Once the runway is chosen, ATC must advise the Operations Duty Manager so that the fire-fighting/crash rescue vehicles can position themselves appropriately.

This is the normal handling of airborne emergencies at airports around the world. Every takeoff is dispatched with knowledge of a contingency plan if an emergency occurs shortly after takeoff. At some airports, the existence of high terrain or obstacles make such takeoff planning more complicated than at Schiphol. If takeoff weather precludes an immediate visual landing, the pilots understand that the emergency might mean a flight to another airport, or the execution of a low or zero visibility landing (if possible) at the takeoff airport, which will require more local flying time.

SECURITY AT SCHIPHOL AIRPORT

Terrorism and Commercial Aviation

International terrorism and commercial aviation have long shared a common history.[2] The advent of what is considered modern, contemporary, international terrorism in fact began with an international terrorist act involving a passenger aircraft. On 22 July 1968, three armed Palestinian terrorists hijacked an Israeli El Al commercial flight en route from Rome to Tel Aviv. Although commercial aircraft had been hijacked before—this was the twelfth such incident in 1968 alone—the El Al hijacking differed significantly from all previous ones. First, its purpose was not simply the diversion of a scheduled flight from one destination to another—as had been the case since 1959, when a seemingly endless succession of homesick Cubans or sympathetic revolutionaries from other countries commandeered passenger aircraft simply as a means to travel to Cuba—but a political statement. The three terrorists who seized the El Al flight had done so with the express purpose of trading the passengers they held hostage for Palestinian prisoners imprisoned in Israel. Second, unlike previous hijackings, where the choice or nationality of the aircraft involved did not matter, so long as the plane itself was capable of transporting the hijackers to a desired destination, El Al—as Israel's national airline and by extension, a symbol of the Israeli state—had been specifically targeted by the terrorists.

The success of the hijacking sent a powerful message to terrorists everywhere. For both tactical and strategic reasons, commercial aviation was viewed as an attractive and potentially lucrative target. The comparative ease with which a plane could be seized, the confined space that could be readily controlled, the seated hostages who could be easily intimidated and managed, and the inherent drama and media attention a hijacked planeload of innocent civilians carried with it was evident to terrorists

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[2]See, for example, Brian Jenkins, *The Terrorist Threat to Commercial Aviation*, P-7540, RAND, March 1989; C. J. Visser (Netherlands Institute of International Relations), "Civil Aviation and the Aircraft Bomb," Flight Safety Foundation, *Flight Safety Digest*, October 1990, pp. 1-13; "Aviation Statistics: An Update of Worldwide Airport Security Systems," Flight Safety Foundation, *Flight Safety Digest*, November 1989, pp. 9-12; and E. A. "Jerry" Jerome, "Recent Hijackings, Bombings Accelerate Security Concerns," Flight Safety Foundation, *Flight Safety Digest*, July 1985, pp. 1-9.

and others who, during the succeeding 17 months, carried out an additional 89 acts of air piracy, bringing the number of airline hijackings between 1968 and 1969 to a total of 100.[3]

The installation of metal detectors (magnetometers) and attendant preboarding inspection of passengers and their carryon items that became standard after 1973 began to prevent and deter aircraft hijackings.[4] Only nine hijackings occurred in 1973, for example, compared to 30 in 1972. The annual number of hijackings similarly declined from an average 50 per year for 1968-1969 to 18 per year for both the 1970s and 1980s. Indeed, according to a study published in 1979, the likelihood of a commercial aviation passenger being hijacked in the United States, for example, dropped from 3.5 chances in 100,000 before the installation of metal detectors in 1973 to just 1 in 100,000 after.[5] Additional measures, such as "profiling" of passengers at check-in by specially trained security personnel, which was pioneered by El Al and has since 1986 has been adopted by other "high-risk" national carriers (i.e., United States airlines), has further reduced the number of hijackings to an average of only 10.6 per year thus far during the 1990s.[6]

Viewed from another perspective, during the late 1960s, hijacking of passenger aircraft was among terrorists' favorite tactics, accounting for 33 percent of all terrorist incidents worldwide. However, as security at airports improved, the incidence of airline hijackings declined to just 7 percent of all incidents in the 1970s and only 4 percent in the 1980s. These measures were successful in reducing airline hijackings, but they did not stop terrorist attacks on commercial airlines altogether. Instead, prevented from smuggling weapons on board to hijack aircraft, terrorists merely continued to attack commercial aviation by means of bombs hidden in carryon or checked baggage. Although terrorist bombings or even attempted bombings of aircraft while in flight have been comparatively rare—amounting to a total of only 15 incidents between 1970 and 1979 and just 12 between 1980 and 1989[7]—the dramatic loss of life and attendant intense media coverage have turned those few events into terrorist "spectaculars"—etched indelibly on the psyches of commercial air travelers everywhere.[8] It should be noted, however, that since passenger baggage reconciliation practices (i.e., where a positive match is effected before takeoff between all baggage in the cargo hold with every passenger) were instituted in 1985 following the inflight bombing of an Air India flight that year, where all 328 persons perished, a total of some 14 billion pieces of baggage have been screened and matched with only two bombs—with admittedly tragic results—having failed to be detected. This prac-

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[3]See, for example, the RAND chronology of international terrorism, K. Gardela and B. Hoffman, *The RAND Chronology of International Terrorism for 1988*, RAND, R-4180-RC, 1992, among others.

[4]"Aviation Statistics: An Update of Worldwide Airport Security Systems," Flight Safety Foundation, *Flight Safety Digest*, November 1989, p. 9.

[5]William Landes, "An Economic Study of United States Aircraft Hijacking, 1966-1976," *Journal of Law and Economics*, Vol. 21, 1978, pp. 1-31.

[6]According to *The RAND Chronology of International Terrorism*, a total of 100 hijackings were recorded between 1968 and 1969; 163 between 1970 and 1979 (97 of which occurred before 1973, when metal detectors were first installed); 167 between 1980 and 1989; and 32 between 1990 and 1992.

[7]*The RAND Chronology of International Terrorism.*

[8]Among the most recent incidents, for example, are the 1985 inflight bombing of an Air India passenger jet, which killed all 328 persons on board; the bombing of Pan Am flight 103 in 1988, which killed 278 persons; the 1989 inflight bombing of a French UTA flight, which killed 171; and the inflight bombing in 1989 of a Colombian Avianca aircraft, on which 107 persons perished.

tice has also saved airlines an estimated half a million dollars a year in compensation for lost baggage.[9]

One principal difficulty in assuring the safety of air travelers throughout the world is the fact that no worldwide standard governing the diverse nature of airline security requirements—perimeter security and terminal access, passenger profiling and weapons detection, baggage reconciliation and airport employee background checks—currently exists. As the *Report of the United States President's Commission on Aviation Security and Terrorism* lamented in the wake of the 1988 inflight bombing of Pan Am flight 103:

> There is no uniform international civil aviation security system in place to assure a consistent level of security for passengers. Many nations have adopted the standards of the International Aviation Organization (ICAO), a United Nations body, which recommends standards and practices for aviation security. However, the ICAO standards prescribe a very basic or low level of security that is inadequate for high threat international airports. ICAO lacks any oversight authority or ability to impose sanctions for noncompliance.[10]

Or, as one expert in aviation security more succinctly and bluntly explained, the entire counterterrorism effort in commercial aviation is a "story of missed opportunities."

Schiphol Airport Assessment

Judging by a site visit and analysis conducted at Schiphol airport, The Netherlands' principal passenger and cargo air facility and the fourth largest in Europe, during the week of 15 February, the security arrangements, measures, and procedures appear extraordinarily sound. The comprehensive nature of the Schiphol airport authorities' approach to counterterrorism measures in particular and security in general is perhaps best evidenced by the fact that no act of terrorism has occurred at, or taken place on board an aircraft that departed from, Schiphol since July 1973.[11]

The rules and regulations governing security at Schiphol airport are codified in legislation enacted by the Dutch government as part of the Aviation Act (Regulations on Airport Security), which was last amended in 1991.[12] The 1991 amendments were

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[9]Presentation by Rodney Wallis, former President of the International Aviation Organization, at the "Seminar on Technology and Terrorism" held at St. Andrews University, Scotland, 24-27 August 1992.

[10]*Report of the United States President's Commission on Aviation Security and Terrorism*, Washington, D.C., 15 May 1990, p. 27.

[11]On 20 July 1973, a Japan Airlines Boeing 747, carrying 145 passengers, was seized by one Japanese and three Arab hijackers shortly after it took off from Schiphol. The hijackers ordered the plane flown to Dubai, Damascus, and then Benghazi, Libya, before the hostages were released and the plane blown up by the terrorists. The only other terrorist act to have originated from Schiphol took place in September 1970 when, as part of a well-coordinated plan, members of the Popular Front for the Liberation of Palestine hijacked three New York-bound flights from various European cities. A fourth hijacking, of an El Al flight en route to London from Amsterdam, was foiled when a security guard on the plane shot and killed one of the hijackers and wounded another. An attempt by Pakistani nationals to hijack a flight of their country's national carrier, Pakistani Air, was foiled by Dutch police in 1982 and in May 1970 a firebomb that was to have been placed aboard an Iberian Air Lines plane departing for Spain exploded prematurely at Schiphol. *(The RAND Chronology of International Terrorism).*

[12]Upper House of the States-General, Session 1990-1991, No. 151. Further amended bill amending the Aviation Act (regulations on airport security), 8 April 1991, p. 3.

passed after eight years of parliamentary investigation and discussion. They were undertaken not in response to some specific act of air terrorism (i.e., as the 1988 in flight bombing of Pan Am flight 103 resulted in considerable modification to the U.S. FAA's rules and regulations governing air security and safety)[13] but as part of a comprehensive review of Schiphol airport's ability to provide for the safety and security of all airport operations, arriving and departing passengers, flight crews, as well as ground staff and employees in anticipation of continued development and expansion of airport traffic. The amendments were also deliberately designed to go beyond existing international security standards, already implemented at the Schiphol,[14] and thereby define specifically the "duties of the government with respect to security at airports and the powers at its disposal to enable these activities to be carried out." To ensure the "safety of international civil aviation," the Act assigns direct responsibility for airport security to the Dutch government (and its appropriate ministries) and further imposes a tax or surcharge on all passengers departing from Schiphol airport of NLG 6.50, which is used to "fund the security measures to be taken by the State."[15] These security measures encompass, essentially, four broad areas:

- Passenger screening and profiling.
- Baggage inspection and reconciliation.
- Perimeter and terminal access.
- Background checks and histories of airport staff and employees.

As part of the security review each of these areas was examined in detail, leading to the conclusions in the following subsection.

Conclusions on Schiphol Security

The security measures, arrangements, and procedures at Schiphol Airport are in many respects a model of airport security. Many of the protective and safety requirements are specifically stipulated in Dutch law and rigorously followed by airport authorities—in many cases in excess of even the U.S. FFA's stringent standards. At the same time, however, total protection against terrorism at any potential target—much less one with as much activity, diversity, and density of persons as an international airport—can never be attained. Indeed, a defense that would preclude every possible attack by every possible terrorist group for any possible motive is not even theoretically conceivable. Moreover, no organization or facility, no matter how ingeniously protected, can operate without some trust in the persons it employs at all levels. Beyond a certain point, security considerations in hiring, guarding, control-

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[13]Interview with Schiphol Airport security officials, February 1993.

[14]For example, article 38 of the Chicago Convention (Netherlands Treaty Series 1973, 109), under which ICAO and ECAC were set up.

[15]Upper House of the States—General, Session 1990-1991, No. 151. Further amended bill amending the Aviation Act (regulations on airport security), 8 April 1991, pp. 1-2. See also the analysis of the Act written by J. R. H. Maij-Weggen, The Minister of Transport, Public Works and Water Management; E.M.H. Hirsch-Ballin, the Minister of Justice; M.J.J. van Amelsvoort, the State Secretary for Finance, Lower House, 1990-1991, session 21 947, No. 3.

ling, and checking people can become so cumbersome as to impede the operation of the facility they are meant to protect from intrusion and interference.

This problem illuminates the central problem inherent in the terrorist threat to commercial aviation: one bombing or one successful hijacking crime is, for those charged with preventing and defending against such attacks, one too many. The number of persons who travel on commercial aircraft, the lives at stake not only in the skies, but potentially on the ground as well, and the potentially horrendous consequences should a terrorist act cause a plane to crash, imply that one cannot be satisfied with adequate, or even very good, security. Those charged with the security of airports and airliners, therefore, can be satisfied only by doing the best they can, on the basis of the best and most complete available knowledge of all potential threats and adversaries. The situation confronting these security officials is one of constant flux: terrorist technology continues to improve, motivations change, new groups arise, and the sensitivities of public opinion change in unpredictable ways. The defense and attendant security measures must therefore be dynamic, to respond as effectively as possible under the most difficult circumstances and to keep all possibilities in mind at all times, so as to avoid surprises and be prepared for all contingencies.

Improving Security at Schiphol

So far as current security practices in force at Schiphol airport are concerned, only two principal recommendations to improve security seem appropriate. The first would involve extending the special security measures, described above, that are currently applied primarily to designated high-risk carriers (i.e., El Al and U.S. carriers) to *all* airlines. However, such an expansion would be extremely costly and manpower-intensive and may not in fact be warranted given the low likelihood or nonexistent terrorist threat to many air carriers, and, indeed, Schiphol airport's excellent security record in this regard. Indeed, the way decisions are made to increase or upgrade security—determined case by case depending on available intelligence information and the external political environment—may be the most cost-effective and realistic approach. However, such an approach depends entirely on the quality, timeliness, and efficient dissemination of intelligence and the assumption that it will be both duly received and acted upon by airport security officials—and, thus, despite the best intentions, the approach inevitably still contains an element of chance. A more comprehensive approach that would ensure commensurate levels of security for all air traffic at Schiphol airport would both standardize and institutionalize a coherent across-the-board security program designed to counter *all* threats against *all* commercial aviation using the airport, not just those of selected national carriers.

The second recommendation pertains to the development of countermeasures against potential terrorist use of surface-to-air missiles (SAMs). Given the fact that the arsenals of some 80 countries throughout the world now contain the technological equivalents of the American Stinger and former communist bloc SAM-7; that countries as diverse as Egypt, China, Brazil, South Africa, and Sweden currently are at various stages of producing their own technologically equivalent man-portable

SAMs;[16] and that such weapons can already reputedly be purchased on the international arms "black market" for as little as $80,000, terrorist and guerrilla use of these weapons is likely to increase in the future.[17] Accordingly, a range of countermeasures to combat SAM use is not only appropriate but may be necessary in that time.

FUTURE OPERATIONAL PRACTICES AT SCHIPHOL

Improvement in air transportation operational safety is expected to continue over the next twenty years. This improvement will depend on advances in technologies for communication, navigation, surveillance, meteorological sensors, cockpit and ATC automation, which are now in development, have already been initiated, or have been introduced on a small scale.

These improvements cannot be introduced at Schiphol alone, and they cannot be introduced quickly. The international aviation community must test and adopt better equipment, certify it as safe, and then together develop new procedures that can be adapted to Schiphol. After agreement on such new equipment and procedures is reached, there is usually a transition period of at least seven years as aircraft operators, airports, and ATC operators reequip their aircraft, airports, and ATC systems. During the transition period, old and new operational practices will have to coexist at an airport.

Future Navigation and Communications Technology

Today's operational procedures at Schiphol depend on ILS, radar, and ground-based navigational stations called VOR/DMEs. VOR/DME provides range and azimuth information accurate to the order of 1 nmi. Radar surveillance is used to create displays of aircraft position accurate to within roughly ± 0.5 nmi, and to estimate speed/direction to an accuracy of ± 10 knots/degrees. The performance of these systems allows aircraft to be guided using the aircraft headings and airspeeds, with intermittent corrections by pilots/controllers to compensate for the effect of wind. Aircraft are separated by 3 or more nmi in the horizontal dimension, and their conformance to planned tracks can exceed 1 nmi. Today, the ATC controller has no information on the aircraft's predicted path. Experience must be used to gauge where a descending aircraft will level off, where a turning aircraft will complete its turn, or when a decelerating aircraft will reach its new target speed.

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[16]See David Isby, *Sons of SAM*, pp. 30-31; Robert Fox, "Arms sales ready to rocket," *Daily Telegraph*, London, March 6, 1990; and Michael R. Gordon, "C.I.A. Sees a Developing World with Developed Arms," *New York Times*, February 10, 1989. Indeed, agents acting on behalf of the Medellin cocaine cartel have attempted to obtain U.S.-made Stinger surface-to-air missiles. Dee Emile Lounsberry and David Pallister, "IRA rocket launcher seized," *The Guardian*, London, July 15, 1989; Business Risks International, *Risk Assessment Weekly*, Vol. 6, No. 33, August 18, 1989; "Irish face weapons charges in US," *The Guardian*, London, January 15, 1990; Business Risks International, *Risk Assessment Weekly*, Vol. 7, No. 3, January 19, 1990; Michael Isikoff, "Two Colombians Arrested in Scheme to Buy Missiles," *Washington Post*, May 8, 1990; and Jeff Garth, "F.B.I. Said to Foil Missile Smuggling to Colombia," *New York Times*, May 7, 1990.

[17]U.S. officials, for example, are already concerned that Stinger missiles provided to Afghani *mujahedeen* for use in their struggle against Soviet occupying forces are now either appearing on the black market or being sold to Islamic radicals in other countries. See Steve LeVine, "U.S. now worries terrorists may get Stingers," *Washington Times*, December 31, 1991; Robert S. Greenberger, "Afghan Guerrilla Leader Armed by U.S., Hekmatyar, Could Prove Embarrassing," *Wall Street Journal*, May 11, 1992; and Richard S. Ehrlich, "For Sale in Afghanistan: U.S.-supplied Stingers," *Washington Times*, May 21, 1991.

Tomorrow's operational procedures at most airports worldwide will depend upon satellite-based technologies. In September 1991, ICAO approved the report of its FANS (Future Air Navigation System) committee, which recommended an accurate GNSS (Global Navigation Satellite) for aircraft navigation (± 100 meters), and the adoption of three forms of digital data links to support air/ground communications, e.g. by: (1) a multi-aircraft data link through a new form of ground radar called Mode S, which will be used around airports such as Schiphol; (2) a VHF data link to be used en route over land; and (3) a satellite data link for oceanic routes (and possibly everywhere else if useful).

The Human Operator

Many of the errors by today's human operators (pilots/controllers) are due to omissions and lapses in short-term memory in the transfer of vital data between ground and air. The newer transport aircraft today have a digital FMS (Flight Management System) which, if linked to the ground via Mode S, can provide very accurate data including actual speeds and track directions; and intended altitudes, directions, and speeds for controllers and for automated decision aids used by controllers. This may significantly improve the safety and performance of operational procedures.

Although the human operator will always be an essential part of tomorrow's procedures, many of the sources of today's errors will be mitigated by the newer systems, since they provide more accurate and reliable information and allow better information displays, consistency checking between air and ground, and a means to introduce high-quality alerting systems. It is expected that the high peaks in workloads for pilots and ATC controllers, which occur at arrival/departure operations, will be reduced to cope with a higher demand.

New equipment that will greatly increase the automation capabilities of LVB is planned to become operational in the last half of 1995. This equipment will reduce controller workloads and increase the capacity of the airspace system. Enhanced flight plan processing, horizontal and vertical flight track monitoring, and simulation capabilities are planned. The system will also include experimental color displays for evaluation of new ways to display information for the controller.

Schiphol Airport Improvements

Several projects are planned by NVLS to enhance the capacity, efficiency, and safety of Schiphol operations considering the inevitable future increases in demand. Strategies considered by NVLS include outplacement, noise mitigation, and optimization of existing facilities.

Outplacement. Under this proposal, general aviation and commuter flights would be encouraged to use airports other than Schiphol. Further development of Lelystad airport would assist in this plan. These types of operations typically involve small propeller aircraft, which are slower than jets and require increased separation behind jet operations. Small aircraft operations reduce the capacity of a major airport both in terms of the number of operations and passenger flow. Additionally, NVLS plans to limit the number of practice flights permitted at Schiphol such that, within five years, the number of these operations will be half that of 1985.

Noise Mitigation. By 1995, a standard noise zone will be established. This zone will identify areas that are exposed to noise, and as a result, the number of homes will be reduced. Stated goals include a maximum of 10,000 affected homes in the zone, to be reduced to 9,000 by 2015. An additional buffer zone will also be identified in which no new housing will be permitted.

Noise is most noticeable at night when background noise levels are low. NVLS plans to use the runways in a manner that will keep flights over populated areas to a minimum between midnight and six a.m. Of course, this is already the policy of NVLS, but future improvements in the runways will allow continued night operations with even fewer overflights of populated areas.

Optimization. Optimization of the current runway system at Schiphol involves several possible projects. It is planned to extend Runway 06/24 by 250 meters to allow less frequent use of Runway 09/27. To decrease the number of flights over Aalsmeer, more frequent use of Runway 01L for approaches is planned. Use of 01R will be given a low priority, and this runway will be used at night only when Runway 06/24 is not available because of existing wind. As aircraft flights have increased, some airports have had to adopt "good weather" procedures, which delay aircraft severely in bad weather. To avoid congestion during periods of reduced visibility and to avoid adopting "good weather" procedures, the government approval for landings on runway 01L will be important.

The "Fifth" Runway. The single major change planned for Schiphol is the future construction of the "fifth runway."[18] This will provide some increase in peak capacity at Schiphol, will permit better noise mitigation, and, as we will indicate below, could reduce third-party risk by reducing flights over populated areas.

COMPARISON OF SCHIPHOL TO OTHER AIRPORTS

It is useful to compare the various airports of Europe and some in the United States to Schiphol's current and planned levels of operations. Table 3.1 gives the current operations levels of several other airports for passenger traffic and freight movement as well as the current and planned future levels for Schiphol. We are not able to give projections for the future for the other airports. Some of the other airports have similar future aspirations but some are also limited in terms of expansion capacity. Schiphol future operations show a significant growth that exceeds most current operations in Europe but some airports, such as Chicago O'Hare, already exceed the planned growth at Schiphol. It has been beyond the scope of this study to survey these other airports in detail but it should be of future interest to Schiphol to consider carefully any significant differences between its current approach to safety management and that of an airport such as Chicago O'Hare, which already has the large number of operations attributed to a mainport.[19]

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[18]The fifth runway is planned to be operational in 2003. For the near future (1996/1997), the southern use of the "Zwanenburg runway" is planned. The southern use of the Zwanenburg runway will also increase the landing capacity in bad weather conditions. The fifth runway could increase the landing capacity in bad weather, depending on its final configuration. Some configurations are designed primarily for noise mitigation.

[19]There is a hypothesis that larger airports are *relatively* safer than small airports but an investigation into data regarding this was not within the scope of the study. Even if the data uphold this view, it is necessary to understand the cause before inferring that Schiphol would become safer with more operations.

Table 3.1

Comparison of Passenger and Freight Operations at Airports

Airport	Passengers/yr (Million)	Tons Cargo/yr (Million)
Schiphol-current [future]	17[45]	.6[4.5]
Charles de Gaulle	22	.6
Frankfurt	28	1.2
London Heathrow	40	.7
JFK	27	1.3
LAX	46	1.1
Chicago O'Hare	60	1.0

SOURCE: Airports Association Council International, *Worldwide Airport Traffic Report*, Calendar Year 1991, pp. 17 and 25; and Ministry of Housing, Physical Planning and Environment et al., *Summary of the Draft Plan of Action Schiphol and Environs*, p. 2.

NOTE: Numbers in brackets are projections for 2015.

It is also of interest to compare these other airports in terms of surrounding population at risk. Table 3.2 shows this comparison in terms of the population with regions defined by similar lateral and longitudinal distances from the runways. Again, it is seen that Schiphol, although within a fairly populated region, is not the worst nor the best on this measure of comparison. Figures 3.8, 3.9, and 3.10 show the actual distribution of the population with respect to the runways and approach and departure routes. All routes overfly populated areas although the routes attempt to avoid this as much as possible (generally for noise reduction purposes). Schiphol is shown on each figure for comparative purposes.

COMPARISON OF SAFETY PRACTICES AT AIRPORTS

As part of the review of safety practices at Schiphol airport, FTA visited several other European airports and gathered written information on organizational structure and operating procedures for airports in Europe and North America. The airports visited

Table 3.2

Comparison of Dwellings in the Vicinity of Several Airports

Airport	Dwellings
Schiphol	235,000
Frankfurt	100,000
London Heathrow	305,000
Charles de Gaulle	125,000

SOURCE: ADECs, Delft.

NOTE: Number of dwellings in equal regions of influence about each airport.

Furthermore, even if the hypothesis is true, it may be due to the types of safety enhancements described below.

RAND#458-3.8-0593

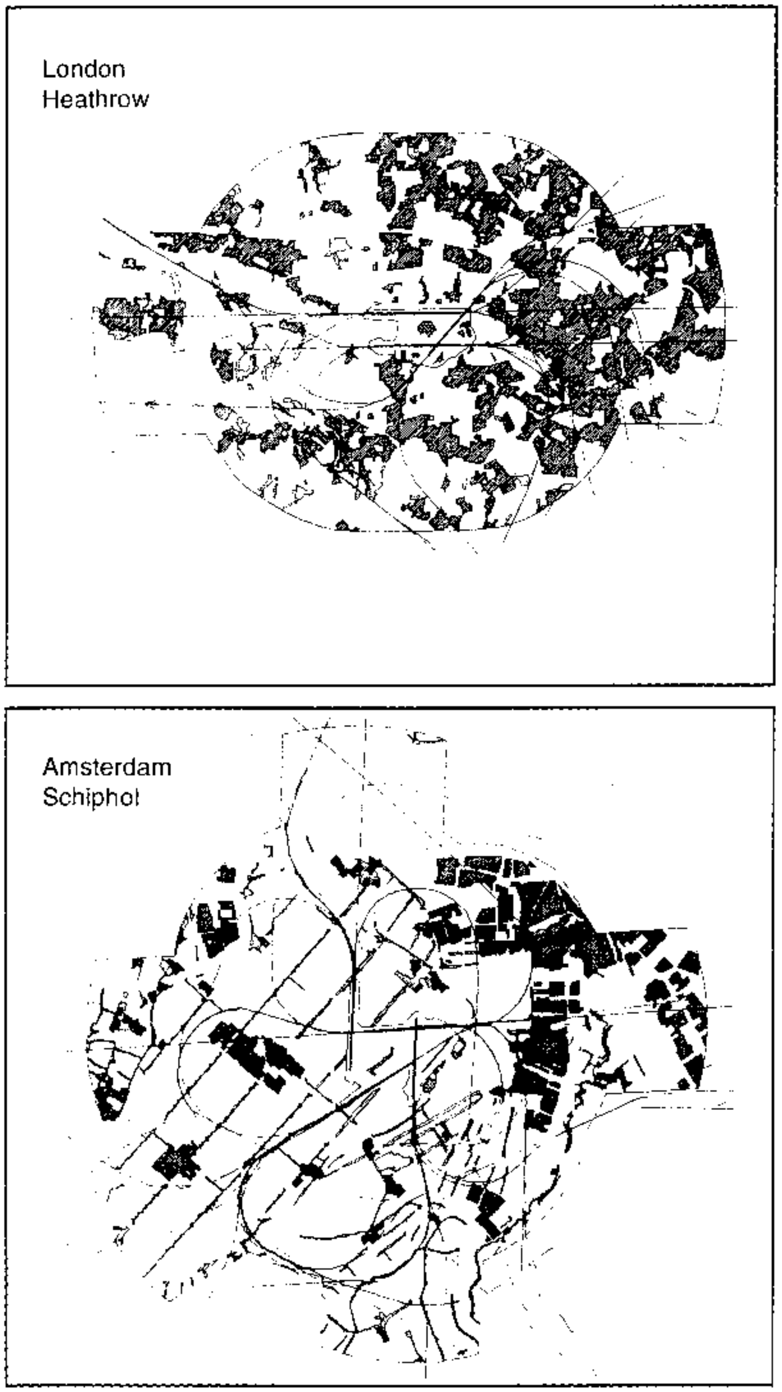

Figure 3.8—Population Distribution Around London Heathrow and Schiphol

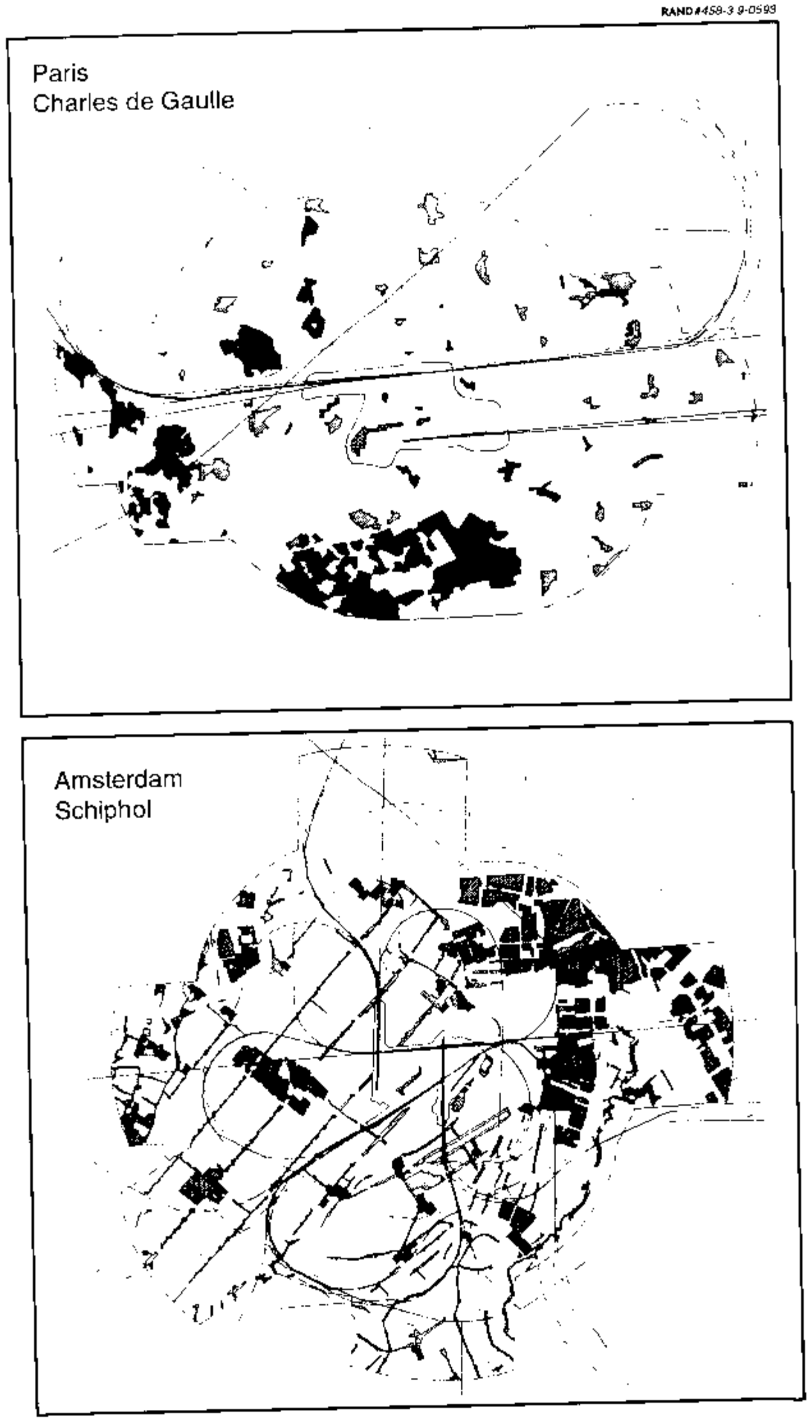

Figure 3.9—Population Distribution Around Charles de Gaulle and Schiphol

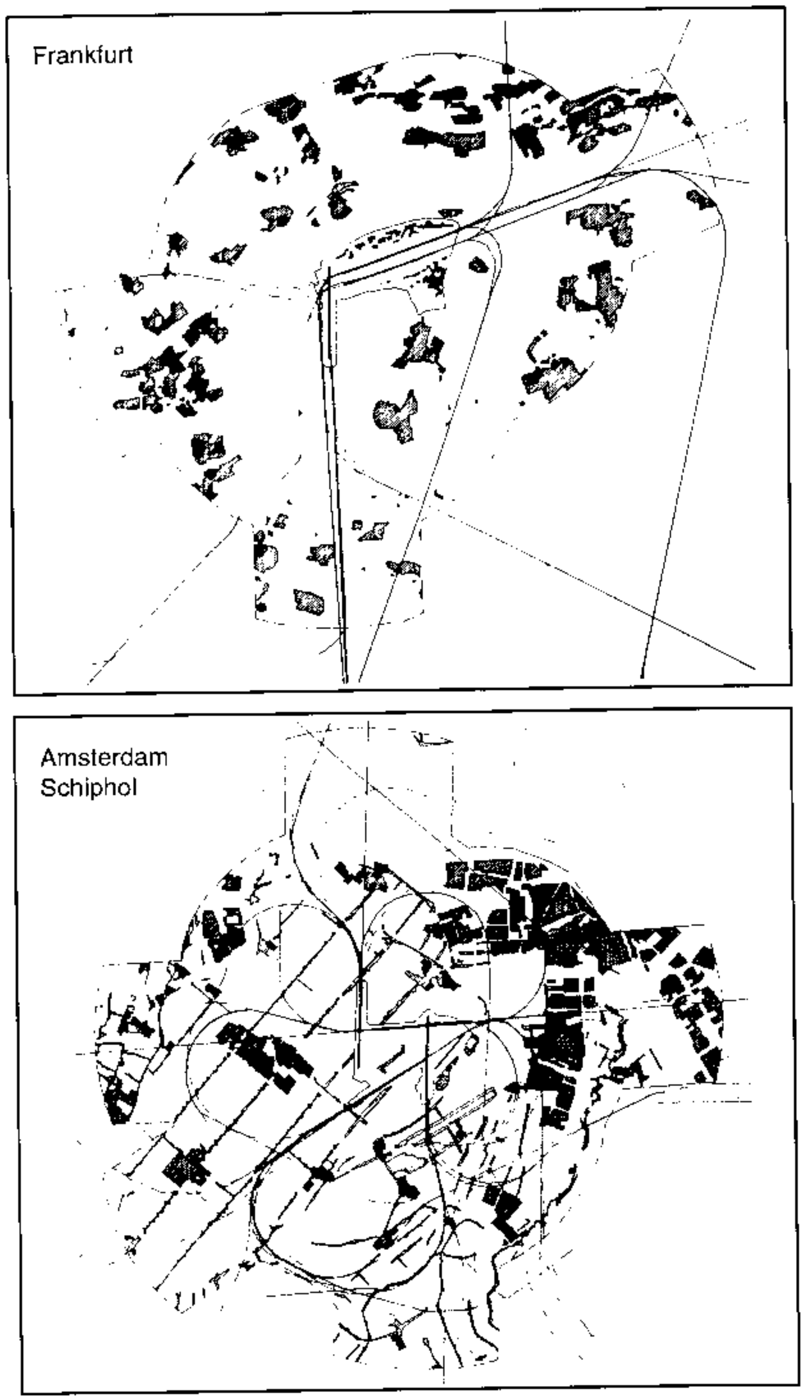

Figure 3.10—Population Distribution Around Frankfurt and Schiphol

were Orly airport in Paris, France; Frankfurt airport in Frankfurt, Germany; and Heathrow airport in London, England. The team interviewed airport personnel, air traffic control personnel, and, in some cases, civil aviation authority personnel. The discussion below is of major international airports in general and does not necessarily refer to any particular facility. The team found that the operators of all the airports visited were highly aware of safety issues and operated in accordance with internationally recognized standards. There were some variations in specific methodology for dealing with a given problem, but in general practices were similar from one place to another.

Organizational Structure

In general in Western countries, transportation matters, including oversight and regulation of aviation transportation, are handled by a Department or Ministry of Transportation. Most of these have a special aviation division (e.g., the FAA in the United States). In some countries, transportation oversight functions are kept at the national level, and others are delegated to individual states or regions, but in all cases the actual regulations are made at the national level. These agencies are responsible for the safety and, in some cases, economic regulation of aviation. This includes, but is not necessarily limited to, airport standards, aircraft airworthiness regulations, rules governing domestic airspace, air carrier certification, and certification of personnel (pilots, aircraft mechanics, air traffic controllers, etc.). Regulations are, in general, based on the ICAO Annexes, and the international standard for aviation safety in the West is consistently high.

There are different organizational structures in the various countries for airports. In some countries, some airports are owned and operated by private companies. In some, they are all publicly owned and operated. It is possible to find several different arrangements within one country. In all cases, however, airport operators are responsible for meeting nationally set standards. Other than The Netherlands, in all of the nations surveyed a formal airport certification process exists. As we will note below, The Netherlands should consider a similar licensing program for airfields used for public transport. Examples of the responsibilities of airports include maintaining the condition of the apron, taxiways, and runways; bird control; environmental issues (noise); provision of crash and rescue services; regulation of ramps and aprons; and terminal building operations.

Like airports, air traffic control organizations differ structurally from country to country. In some, they are subdivisions of the national civil aviation authority; in others they are independent organizations. In at least one country other than The Netherlands the ATC organization has been privatized, and in one case, the ATC organization is managed by the airport authority.

Operational Description

All the airports surveyed are busy international airports in large urban areas, and they are concerned with many of the same issues: safety, airport capacity, noise and other environmental impacts, and community relations with their near neighbors. Most have some kind of noise-preferential runway use program in place, where active runways are switched (weather permitting) to give nearby residents regular relief from noise. Many have night noise curfews, affecting all operations or operations of noisier aircraft. Air traffic control at many of these airports must deal with extremely complicated airspace, because of the nearby presence of other busy airports. All of them, to a greater or lesser extent, are trying to maximize efficiency in a limited amount of space. There is a limited ability for these airports to grow because they are surrounded by heavily developed and populated areas. In some cases, the airport was built in an already populated location; in others the city and its suburbs grew out to the airport site.

At most of the airports, there is movement toward automation of tasks that have traditionally been done "by hand," with the emphasis varying from place to place. Thus, at one airport, a bar-coded passenger-bag matching system is in the pilot stages. At another an intelligent security ID-reading system has been operational for some time. Yet another has automated flight progress strip-handling and automated flight data coordination between air traffic control facilities.

Inspection of Foreign Carrier Aircraft

With the exception of the United States and Canada, most countries surveyed felt that they were constrained by bilateral air service agreements and ICAO recommendations in this area. The general practice is to accept the home country's certification as proof that the carrier is operating according to international standards. The United States has instituted more stringent oversight of foreign carriers and foreign certification practices in the last two years.

Public Safety Zones

Among the countries surveyed, Great Britain had the strongest concept for safety-oriented land use zoning around an airport. Public safety zones are regulated by the Department of the Environment, with technical advice from the Civil Aviation Authority. The regulation states, "Certain safeguarded areas incorporate Public Safety Zones at the approaches to the main runways of busy aerodromes where it is Government policy that there should be no significant increase in the number of people living, working, or congregating."

Controller Training and Proficiency

In general the study team found that air traffic controllers went through a training program at an air traffic control school for a period of approximately 18 months, and then moved to on-the-job training (OJT) at a specific airport. OJT generally lasts around three years. In all cases, both the classroom and OJT training act as a rigorous screening process, which a relatively small percentage can pass. Thus, only the top-performing students and training controllers actually stay in the field. In countries where more than one air traffic control organization exists, the training may be slightly different from organization to organization, but a controller must go through OJT at the airport where he or she intends to work in all cases. In addition, once at the airport, it is common to require that controllers attain proficiency in both radar room and tower positions. Generally, the national civil aviation authority or ministry of transportation sets the certification standards.

In the area of ongoing training and proficiency monitoring, in most cases no standardized system exists for ensuring or evaluating controller proficiency. Generally, supervisors are expected to continually monitor the proficiency of controllers. In some countries, controllers must periodically renew their certification through a series of written and practical exams, but this practice is not universal. This issue is being examined by the civil aviation organization in one country, and in one other, the ATC organization was aware of the problem but felt that a legislative mandate was required before they could initiate a formal proficiency check system.

Runway Pavement

In all cases, the movement areas are patrolled several times a day by the department responsible for the maintenance of the movement areas (usually, but not always, the airport operations department). These inspections cover Foreign Object Damage (FOD), the condition of pavement and runway/taxiway lighting, and, in winter conditions, runway pavement friction testing. Additional inspections are mounted in response to pilot reports of problems.

Most major airports have a regular runway friction testing program in place as a part of ongoing pavement maintenance. Many have their own friction testing devices as a standard piece of airfield equipment. They also have regular rubber removal programs.

In Europe, it is uncommon for the airport authority to close a runway or the entire airport because of ice on the runway. In fact, in some countries the airport authority does not have the jurisdiction to close the airport or its runway; this is the responsibility of the ministry of transport or civil aviation authority. Generally in Europe, the airport does friction testing in winter conditions and then communicates the friction coefficient to ATC, which passes the information on to pilots. The decision to land is then the pilot's responsibility. Some airports have a pavement condition reporting system, consisting of sensors installed in the runways' surface. These sensors detect freezing temperatures and enable de-icing to take place before ice can form. There is some skepticism in the industry about such systems, however, as they can be difficult to maintain and can generate a high incidence of false alarms.

By contrast, in the United States it is quite common to close individual runways or an entire airport in winter conditions. At least one airport will close the active arrival runway whenever a pilot reports "nil braking" conditions to the tower. The airport then tests the friction coefficient of the pavement surface to determine whether the runway is safe for aircraft operations.

Bird Control

The methods for controlling birds at an airport are many and varied. Some airports employ only a few, while others do everything. It all depends on the seriousness of the bird problem. Whatever department is responsible for movement areas is also responsible for bird control. Methods include:

1. Locating speakers that emit random noise along the length of the runways;
2. Keeping grass at exactly eight inches in height (this is long enough to deter birds because they cannot detect predators in the grass, but it is short enough not to attract species that nest in tall grass);
3. Occasional culling of problem species;
4. Broadcasting recorded distress calls;
5. Employing noise-makers (shell crackers); and
6. Using dispersal equipment (noisemakers) located in all of the "follow me" vehicles.

Management of Aprons and Operation of Ground Vehicles

All airports recognize a need for controls on ground vehicles on the airside, particularly when they are crossing active runways. All personnel who will operate vehicles on the apron must be licensed by airport operations. At some airports, vehicles that will operate on the movement areas must also be licensed by ATC. The airport authority sets the standards and makes the rules for operations on the ramp, and either the airport authority or the airlines and contractors may have their own training courses for vehicle operators. When an airline or other agent does the training, the content of the courses must usually be approved by the airport authority. At some airports, airport management has developed a policy to limit the number of handling services available to one or two. The reasoning is that the fewer the number of handling services, the easier it is to manage training, certification, and overall safety and security. One nation is about to institute a national system of training and certification of ground handlers, mandating minimum standards for all that nation's airports.

Incidents involving ramp vehicles or aircraft on the apron must usually be reported to the airport operations department, which is then empowered to take corrective action. One airport has a formal system that employees use to identify potential hazards. Any employee familiar with ramp operations can request investigation of a potential hazard. This includes recommendations to change existing procedures to increase safety.

At most airports, runway crossings by ground vehicles are permitted, but they are limited or prohibited in conditions of low visibility. When ground vehicles are on the active airfield, they must either be in direct radio contact with the tower or be led by a vehicle that is.

Aircraft De-icing

Although de-icing is the responsibility of the carrier, it is a safety issue for airports particularly with regard to risk to third parties. Ice on aircraft wings can interfere with lift enough to cause an airplane to crash, or it can be ingested by an aircraft engine, causing it to fail. In either case, the aircraft may be airborne long enough to go beyond airport boundaries. In any situation where there are aircraft queuing at the runway end for departure in winter snow and ice conditions, there is a risk of ice contamination of the wings. There are currently two classes of glycol-based de-icers available, designated as Type I and Type II fluids. Type II provides anti-icing for longer periods of time than Type I, but it is more difficult to manage the environmental effects of

Type II. This is because it is easier to decontaminate effluent and recover the glycols for reformulating into a de-icer with Type I fluids. This process is not yet cost effective with Type II fluids.

The responsibility of airports related to de-icing is in providing locations and, possibly, equipment for this activity. Remote de-icing stations are being more widely adopted by airports. One European airport has adopted mobile remote de-icing, with three or four areas near the runway end designated for de-icing, which means that Type I fluids can be used. At the same airport, on one taxiway, trials are being conducted with a gantry de-icing system. Another airport is installing mats that can collect de-icing fluid runoff at remote locations. In Europe, wherever de-icing takes place on the aprons, Type II fluid is used. By having remote de-icing stations near the runway, aircraft queue before de-icing rather than after to enter the runway. This means there is minimum delay after de-icing, ensuring that they can depart within the glycol "holdover" period even if Type I fluids are used.

Emergency Management and Preparedness

Several of the airports visited have extensive emergency drills or written emergency response plans. Full-scale annual exercises are held, and regular desktop exercises are used to check the system. At one airport, for example, full-scale emergency exercises are carried out annually, and each year a different scenario is developed, using actual aircraft both on the ground and flying in the surrounding airspace. Local hospitals and emergency units are also involved in the annual exercises. In countries with a formal airport certification process, emergency procedures are mandated by the national civil aviation authority.

An emergency response plan is required for airport certification in the United States. The emergency plan is a detailed description of all procedures to be followed for emergencies of any type. Even in cases where the nature of an emergency has not been anticipated, the emergency plan can provide for lines of authority and general areas of responsibility.

Summary and Conclusions Regarding Comparisons

As stated above, airport safety in industrialized nations is at a consistently high level. In most cases, where differences exist from one airport to another, they are differences in specific technique, not in safety oversight as a whole. In these cases, one technique is not better than another, it has simply been found to work well where it has been employed. In some instances, however, a country or an individual airport has instituted procedures that could be usefully employed at Schiphol. These will be discussed further below.

KEY ISSUES IDENTIFIED IN THE SAFETY SURVEY AND A DISCUSSION OF POSSIBLE SOLUTIONS

In follow-up surveys, the various stakeholders were encouraged to identify possible safety issues. This section describes these issues and suggests possible safety improvements. We do not attempt here to evaluate the relative importance of these issues, however; the relatively lengthy discussion of "risky" carriers below may give an impression that this is a very serious problem. But, the limited use of Schiphol by such airlines means it is of lesser importance.

Tensions Between Safety, Environment, and Economic Decisions

There was some concern expressed about the adequacy of the balance between safety, environment, and economics at Schiphol. In the interviews, several organizations expressed their concern about the political decisionmaking process with respect to the position and weighing of safety issues. It was felt that in policy decisions, safety has been outweighed several times by environmental and economic issues, causing potentially hazardous situations. They felt that at times professional judgment was overruled by political decisionmaking, causing serious feelings of disagreement and stress. This tension is common to all areas of risk. Most people are aware of, for example, the conflict between environmental groups and advocates of nuclear power generation, the debate between the economic considerations of such generation and the potential safety risks of breakdown or leakage. The weighing of safety against environment is not an aviation-specific problem; it counts for almost every major development in The Netherlands, such as the Oostercheldewerken, the planning of high-speed trains, and the cargo railway line known as the Betuwe line.

Safety does not dominate considerations with regard to the airport. Nor should it: If air safety were the sole consideration, the airport would be shut down. Instead, there is a risk incurred from airport operations that is considered acceptable given the benefits that accrue from the airport. The safety risk is placed (and traded off against) not only airport benefits but also other negative features of the airport (e.g., environmental deterioration, noise). Also, possible measures to enhance safety are considered in terms of the political consequences, which may reach well beyond airport operations into internal and international politics. Sometimes, however, safety considerations may be overridden when they are most important.

Until the El Al crash, third-party risk was not of great concern. Over the years, because of a perception that this external risk was not significant, both locally and internationally, the environmental issues including noise, economic considerations, and political issues have been dominant. For example, there is residential noise zoning but not safety zoning. These can conflict when higher-density office buildings, not subject to noise zoning, are allowed to develop near takeoff or landing patterns and thus increase the safety risk to occupants of the offices.

The airport manager is responsible for both safety and the economic well-being of the airport. He thus faces fundamental conflict in decisions such as closing the airport for weather reasons (increasing safety at some cost to airlines) and grounding risky carriers (with the potential for political and economic repercussions). The competition between airports in Europe for market share means that there is a fundamental conflict between enforcing safety standards that go beyond an international norm and risking the loss of business. If the international standards are adequate, this is not a problem, but in some cases involving aviation safety they represent minimum standards reached by international consensus rather than higher standards that might apply in The Netherlands. Interestingly, airports do not compete openly on a safety standard. As with the airlines, the open discussion of aviation safety is avoided to prevent raising the public's latent concerns about flying in general. The Dutch Ministry of Transport manages safety through regulation and certification, but it also faces fundamental conflict in that it must also abide by environmental constraints and is responsible for the well-being of aviation in The Netherlands and ultimately for the long-term economic planning, of which the airport is a key component. Airlines and pilots are sometimes faced with the choice between taking off under conditions that affect safety such as marginal weather or aircraft condition or delaying full flights at significant cost. Passengers may be allowed to load too many bags, etc.

Several examples of possible imbalances were suggested during the safety review:

Fuel Pricing. At Schiphol, as in most airports, there is no airport monitoring of takeoff weight and aircraft are allowed to take off at maximum takeoff weight (MTOW) regardless of destination. The price of aviation fuel is low at Schiphol compared to other airports in Europe (apparently because the port of Rotterdam is a major port of entry of oil and fuel). This low price provides economic benefit to the airport in two ways—the direct profit from fuel sales and the attraction of carriers to Schiphol to obtain this cheaper fuel. However, the practice of "topping off" with fuel at Schiphol has at least one safety implication. The extra time to dump fuel may not be available in some emergencies and this increases the risk at landing or, in the case of a crash, increases the fire danger to both the occupants of the aircraft and those on the ground. Third-party risk is related directly to the size of the fuel fire footprint on the ground. It was also suggested that the maximum takeoff weight increases the risk during takeoff because problems encountered during takeoff—loss of an engine, for example—might be less easily mitigated when the aircraft is at MTOW than when it weighs less. Generally this latter hypothesis is not true because MTOW is defined with a sufficient safety margin such that takeoff problems can still be controlled. Actually, if the manufacturers of aircraft had not designed in such safety margins, then passenger aircraft would be safer operating with less than a full load of passengers and freight aircraft would be better off flying partly empty.

Noise Control. Arrival and departure routes are dictated by SIDs and STARs. These are designed to reduce controller and pilot workload and satisfy noise restrictions and consequently attempt to minimize overflight of populated areas. This is consistent with reducing the risk of crash into a populated area except for the fact the large number of relatively complicated SIDs and STARs (on the order of 40) means that Schiphol arrival and departure is more complicated than at many airports (see Figures 3.10 to 3.12), especially to pilots who land at the airport infrequently. Moreover, the maneuvering involved in the vertical and horizontal dimension of some of these routes has been said to be difficult and is performed imprecisely. If complexity is related to increased risk, this may be a case in which the attempt to avoid population overflight for noise considerations may actually increase risk.

Differential Exclusionary Zoning for Noise. Noise standards for exclusionary zoning apply only to residences. This permits businesses to locate closer to runways and flight patterns than homes. The effect of this is that during business hours, when many flight operations occur, concentrations of people near the airport are at higher risk than during the nonbusiness hours. There is some quantitative evidence for this in the results shown in Chapter Six of this report.

As stated above, the issue of balancing safety, economics, politics, and environmental concerns is common to all areas of risk and is not unique to Schiphol. A missing feature at Schiphol, however, is an integrated safety management system with a safety assurance office to review hazards and risky procedures to assure that safety considerations are not improperly or inadvertently overridden.

Control of Risky Airlines and Aircraft

It is fairly well known (and expressed to us in interviews) that some airlines and aircraft types are more risky than others. Some aircraft of airlines of some former Eastern bloc countries, especially those maintained in those countries, are considered quite risky. Some aircraft, pilots, and maintenance associated with smaller third-world countries are considered less safe than those of major Western carriers and are not believed to meet international standards. Cargo flights, generally using older aircraft and different types of pilots, are not believed to always satisfy some of the stringent safety standards for maintenance, weight limitations, and training as passenger flights. Some instances of temporary grounding of such aircraft on the basis of external ramp inspection have occurred at Schiphol. During the safety review at Schiphol, several parties indicated that the airport should be justified in posing minimum quality standards on its customers, particularly because of the huge investments involved and the airport's responsibility to the public, which is exposed to the increased risks. Consensus exists about the desire to expel customers who do not agree to meet the minimum quality standards for use of a mainport. However, there are important limitations in the control that can be exercised in this area.

One requirement of the Chicago Convention of 1944 is that member countries recognize as valid other members' airworthiness certificates and licenses, as long as the issuing country certifies that it meets international standards. Thus, if a country licenses a carrier, other countries are obligated to accept that carrier as meeting the ICAO standards for air safety. This has a number of implications for The Netherlands and Schiphol. Verifying that a carrier does not comply with standards is difficult when that carrier is not a Dutch airline. It is a breach of diplomacy to board the aircraft, and inspection is limited to checking paperwork, the quality of which depends on the carrier. Even when there is strong suspicion that a carrier is risky or external observations on the ramp indicate obvious maintenance defects, there are strong incentives against grounding or limiting that carrier's flight operations. Concern for losing reciprocal landing rights for Dutch carriers and negative diplomacy are among the largest problems. There is also concern about losing market share if the carriers perceive Schiphol as being especially restrictive. The issue of oversight of foreign carriers has arisen in the United States as well and it has adopted a more proactive approach.

In June 1991, the FAA Associate Administrator for Regulation and Certification said that the FAA intended to focus on foreign country oversight because not all foreign authorities actively monitor their carrier operations. In August 1991, FAA began assessing foreign countries to determine whether they meet international standards. Before this, the Department of Transportation (DoT), in accordance with international agreements, had relied on and accepted an applicant's home government license as evidence that the carrier could operate safely in the United States.

The FAA now assesses whether a country adheres to international standards when a new carrier from that country applies for a license to operate in the United States. Between August 1991 and the fall of 1992, the FAA visited countries in Central and South America, Africa, the Caribbean, and the Pacific Rim. It found that six of the fifteen countries visited met or exceeded international standards, but that the remaining nine countries did not. The agency found deficiencies such as no operations inspectors or airworthiness inspectors, no aviation regulations or guidance, no technical expertise to carry out a certification program, a lack of annual proficiency checks for pilots and crew, and insufficient inspector training. As a result of these assessments, the DoT did not approve any new carrier applications from countries found not to comply with international standards. Licensed carriers from these countries that were already flying into the United States were allowed to continue, however.

In accordance with the Chicago Convention, the FAA can perform routine inspections of foreign carriers that consist of examining aircraft markings, airworthiness and registration certificates, and crew member certificates. It can also review air traffic compliance, taxi and ramp procedures, enplaning/deplaning procedures, and baggage- and cargo-handling procedures. If the carrier is operating U.S.-registered aircraft, the FAA can also examine U.S. Airman Certificates, the aircraft's U.S. Airworthiness Certificate, the maintenance program, and the aircraft's Minimum Equipment List (the list of equipment that must be functioning properly before the plane can be authorized to depart). The agency has recently increased the number of these "limited inspections" of licensed carriers from countries not meeting international standards.

In a case where a serious deficiency in an aircraft is apparent from a limited inspection, such as obvious corrosion problems in an aircraft, the Chicago Convention permits comprehensive inspections of the carriers' other aircraft. In addition, under the Chicago Convention, when a foreign country does not meet international standards, other signatory nations are not obligated to accept its airworthiness certificates. Thus, for example, the FAA's findings that some countries do not meet standards would permit other signatory nations to perform more comprehensive inspections of carriers from those countries. A comprehensive inspection can include an examination of such areas as flight controls, fire protection, fuel, navigation, oxygen, and engine controls.

The General Accounting Office, a watchdog agency of the U.S. government, has recently recommended to the U.S. Secretary of Transportation further strengthening of the program to inspect foreign carriers. It interprets these recommendations to be consistent with the Chicago Convention. Specifically, the recommendations were to:

1. Require that FAA field offices perform comprehensive inspections of foreign air carriers that fly into the United States when it is found that their home governments do not comply with international standards or when the FAA becomes aware that the carrier has serious safety problems.
2. Specify the nature, frequency, and timing of these inspections and continue them until it is determined that the home government meets international standards and that the carrier is operating safely.
3. Give priority to assessing the oversight capabilities of those countries that the FAA determines have one or more carriers with serious safety problems and work with the countries to ensure that their oversight capabilities are sound.

This type of program would be more difficult for The Netherlands to initiate on its own than the United States. On the other hand, it is not likely that ICAO, with 173 members, will soon adopt stricter standards for inspection and control in this area. There are several alternative organizations or coalitions that could pursue such a program in a broader European setting and implement it in a reasonable time period. These include an association of European airports, the JAA, and the EC. We do not suggest a preference, although we expect the ease of implementation is inversely related to the number of members that must reach consensus. The Netherlands should consider sponsoring or supporting an ICAO, ECAC, or JAA initiative for the surveillance of foreign carriers on foreign flights.

The Current Distributed Nature of Safety Management Provides No Central Advocate for Safety, Especially Third-Party Risk, and No Central Review of Incidents and Hazards

The total system by which aviation safety is managed and maintained is currently informal. Despite the fact that each organization—RLD, NVLS, ATC, carriers, dispatchers, etc.—is concerned with safety, there is no integration office for safety assurance to perform central collection and review of incidents and hazards, review of interfaces, coordinated emergency exercises, etc. This is not unusual among airports, but is an important area of potential improvement. The RLD has responsibility for creating safety regulations, and enforcing them through inspection. It can examine the interfaces and cause coordination between the various parties responsible for executing safety regulations, but this is informal at present. As long as regulations are met, RLD has not required any internal form of safety monitoring management. It is recommended that consideration be given to establishing a more formal system for the integrated management of aviation safety at Schiphol wherein every operator has a clear internal safety management system to assume quality performance.

Elements of any integrated safety management system require further study, but the basic functions can be defined. We will elaborate on the nature and importance of these individual functions in more detail in this and later chapters of the report, but some of the important functions include:

1. Coordinating safety planning and training for all operating organizations.
2. Planning integrated emergency procedures planning.
3. Collecting and reviewing incident and hazard reports.
4. Monitoring the safety aspects of growth and development of the airport.
5. Acting as an advocate for safety in decisions driven by economic, environmental, and political considerations.
6. Acting as a spokesperson and information outlet for safety to the public.

Coordination requirements should be determined for all levels. The establishment of safety/quality assurance offices and the details concerning how and when those offices should coordinate is of primary importance. We also note that such an office may need an independent advisory panel of safety experts (perhaps international), independent from the airport management, to whom the significant safety issues are put. The endorsement of plans that related to the airport development by such an independent body would strengthen the management position.

More Emphasis on Integrated Planning of and Training for Emergency Procedures Is Needed

An important element of an integrated aviation safety management system should be that of emergency planning and training. An airport emergency plan, desktop exercises, and annual exercises in dealing with some emergencies are in force at Schiphol.[20] Within LVB, there is recognition of the need to expand training in emergency procedures and to involve both pilots and controllers in integrated emergency planning and training. However, formal training programs that require participation of both pilots and controllers do not exist and may be difficult to implement. This is because of the limited availability of personnel for such a program and the time and expense of involving *all* pilots, controllers, and other emergency personnel in multiple large-scale exercises, not to mention the possible disruptions in normal airport operations.

Current "full-scale" exercises are limited to airport personnel, state police, and handling personnel, and deal with emergencies on the airport surface. The manner in which an inflight emergency is handled by both the pilot and air traffic control may contribute to the effectiveness of the ground operation. While inflight, the pilot must assess an emergency and determine the best course of action necessary to ensure the safety of crew, passengers, and people on the ground. Air traffic control must be able to determine the needs of the pilot, reestablish the approach and departure sequence to accommodate the emergency, and provide the pilot with appropriate information.

Decisions such as which runway to recommend, whether to provide a discrete frequency and a separate controller to handle the emergency, and how to adjust the existing traffic flow must be made by the ATC unit. It can be argued that, because of the number of operations in Schiphol airspace, this type of an exercise system is unnecessary: There are enough actual "minor" emergencies occurring (such as low fuel and aircraft equipment problems) that such training would prove to be redundant. However, only with a formal program can LVB ensure that all of its qualified personnel receive sufficient training in this area. Moreover, only with full-scale exercises that include air traffic controllers and pilots can lessons be learned concerning the adequacy of existing training and procedures at no risk to an actual operation.

A system of training for the handling of *inflight* emergencies should be established. This should include pilots, controllers, emergency crews, and airport staff who may be involved in preparing the airport and handling the aircraft while inflight. The most important factor in this program would be allowing pilots and controllers to interface so that they can better understand each other's capabilities, needs, and limitations during emergency situations. Rather than be so ambitious as to involve all pilots, air traffic controllers, and other personnel in these exercises, the exercises could be performed with a subset of these, and then the *results* of the exercise could be used as a training aid for the remainder and to also assist in developing integrated plans and procedures.

Emergency Training for Controllers. As at most airports there is currently no *periodic* training of controllers for dealing with inflight emergencies. Controller qualification

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[20]Full-scale aerodrome emergency exercises are held at one-year intervals at Schiphol. Participation of the customers is requested and encouraged by NVLS. Desktop exercises at one-month intervals are normally held with the participation of an airline or a handling company.

and upgrade training should include aircraft emergencies and equipment malfunctions. Although every possible scenario cannot be covered, simulation of standard situations can help the controller know how to best assist the pilot in an emergency, to continue to provide services in spite of equipment loss, and to reorganize the traffic flows during such emergencies.

Simulated inflight emergency scenarios should include aircraft control problems, low fuel, medical emergencies on board the aircraft, aircraft equipment problems (e.g., loss of radio communications), and simultaneous loss of both radar target and radio communications. Simulated ATC equipment malfunctions should be based on their likelihood of occurrence (e.g., complete loss of radar or other surveillance information is so unlikely that nonradar training is considered unnecessary) and may include degradation of surveillance information; loss of primary communications; loss of NAVAIDS (including critical VORs and the ILS for the runway in use); loss of automation capabilities such as flight plan processing, metering, and spacing; and complete loss of a single operating position.

Each of these situations would require that the controller react to provide pertinent information to the appropriate personnel and agencies in a timely manner, and adjust to a change in the manner in which traffic is routinely controlled. To realistically simulate ATC system failures, Schiphol has sophisticated equipment (analogous to cockpit simulators, which are capable of mimicking any number of equipment malfunctions). For the emergency training of tower personnel, a visual simulator that can recreate the Schiphol environment is required. Such simulators do not yet exist and typically the cost is unreasonably high. ATC does have an ATC system simulator, which is a copy of the operational system, and two other basic training simulators that could be used in support of such training.

Because the equipment used and the requirements of the controller differ for each controller position, ATC emergency training at Schiphol should be incorporated into the OJT program so that it occurs near the end of training in each position. Once the trainee has learned the basics of ground control, for example, training in emergency procedures for this position could commence. This would allow the controller the opportunity to practice providing the information to the correct agencies, resolving system failure problems, and handling aircraft emergencies that would affect his operating position. Short of working actual emergency situations, simulation is the only way controllers can develop the skills and confidence necessary to perform under unusual circumstances.

Incident and Hazard Collection and Review

There is no formal process of centrally collecting, integrating, or reviewing aviation hazard and incident reports.[21] In addition to accidents, incidents and occurrences have proven a very useful source of information about the actual operation of complex systems in various branches of industry such as aviation, off-shore industries, and process industry.

At Schiphol, several independent sources of incident information are available:

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[21] NVLS does request incident reports for quality assurance and has appointed an officer to collect and analyze reports. Quarterly reports of all states of emergency are reported to RLD.

- For many years NVLS has reported every 3 months on operational aspects such as emergencies, state of readiness, exemptions, etc., to RLD.
- Since January 1992 an appointed safety advisor is responsible for the collection, analysis and evaluation of incidents.
- Since 1991 the airside unit reports monthly to the NVLS board of directors on aspects of punctuality, safety, security and environment.
- NVLS started the collection of incidents and occurrences at ramps, aprons, and runways in 1992.
- ATC has produced monthly reports over a period of several years covering all their operational activities and technical systems.
- KLM has documented reports, such as technical Quarterly Engineering Specialist Reports and Type Reviews. Since 1993, a Flight Safety Bulletin has been issued for operational feedback to flight crews.
- The Fire Service of NVLS has listed activities since 1990 covering their active participation in fire warnings. RLD has recently made the Fire Service databank for the year 1992 accessible to the public by deleting the names of the carriers involved.
- The Civil and Military Air Miss Commission supplies reports about reported air miss incidents.
- The Aviation Council has published over the years verdicts about the accidents investigated by this Council.
- The Dutch Airline Dispatchers Association (DALDA) could provide information about flight handling incidents, occurrences, and hazards but currently does not.

In a review of data collected by these sources, little overlap is noticed. This is not surprising, since every organization covers its own responsibility. Only when a more serious incident or accident occurs at a location where a common activity takes place is overlap likely. As far as could be determined in the audit, serious incidents were noticed by all sources responsible for the data collection. Underreporting is to be expected as a result of three factors. First, whenever an incident is reported to and finally analyzed by the responsible authorities, it has gone through many administrative channels and possible valuable information is lost during the processing. Second, on several occasions concerns were expressed about the production pressure that pushes the limits of reportability of incidents and the paperwork involved. Third, underreporting is caused by the fact that the Schiphol community is relatively small and complaints, incidents, and occurrences can be traced back to individuals. Repression or allocation of blame is therefore not excluded and will hamper the reporting.

Only in the cases of pilots and, to some lesser extent, air traffic controllers, is anonymous reporting possible. Dispatchers expressed their concern for the lack of such a system for flight handling operations. There is no central system through which anonymous incident reports can be channeled to the responsible organizations.

The processing of the information itself is limited. Not every organization has the expertise or the resources to elaborate on the data collected in the reporting systems. Feedback toward the pilots and controllers mainly occurs on an individual and incident-specific basis. Pattern recognition at the level of Schiphol operations is not present. Therefore, an integral picture of the safety situation at the airport is lacking. Safety parameters are hardly applied as performance indicators. The accident causation factors may be recognized but are not composed into causal chains that may lead to accidents.

Beyond the responsibility for safety that lies within each organization, an important role for an integrated aviation safety management system is that of centrally collecting, reviewing, and acting on incident and hazard reports. This should include the weighting of the data with respect to the severity of the occurrences and their potential for causing accidents. Processing should include determining how the number of incidents relates to the number of flight operations (carriers with a large number of incidents may also have a large number of operations and this may be perfectly normal). On the other hand, carriers with a larger ratio of incidents to operations relative to other carriers may be suspected of problems in safety practices. Other activities in this area include comparing these data to broader data such as worldwide incidents/accidents, determining how serious accidents from incidents were avoided, etc.

Anonymous Aviation Hazard and Incident Reporting System

Although processes exist for anonymous incident reporting for Schiphol air traffic controllers and for Dutch pilots of KLM, those systems are wholly contained within their respective organizations and the incidents dealt with internally. There is no broad, independent system for the anonymous reporting of hazards and incidents associated with aviation safety in The Netherlands. Anonymity is important because the fear of retribution prevents reporting of such incidents and hazards unless there is a system that can guarantee anonymity to the reporter. This type of system is not easy to attain because many incidents clearly point the blame at individuals and if they are witnessed by only one or a few others, it is more or less obvious who did the reporting. An important first step, however, is to provide a channel through which someone can report without fear of administrative retribution.

The establishment of a national aviation hazard reporting system that guarantees anonymity may be required.[22] This system may also offer immunity to those reporting hazards/incidents in some cases. The same system should be available to *all* aviation personnel including pilots, controllers, ramp personnel, and others. It should be operated by an independent agency and must provide a simple and easily accessible method of reporting.

In the United States, the confidential and voluntary Aviation Safety Reporting System (ASRS) was established in 1976. In this system, pilots, controllers, and others can submit accounts of safety-related aviation incidents. The success of ASRS has depended on the control of the system by a neutral third party, the National Aeronautics and Space Administration (NASA). Before the establishment of ASRS, attempts at providing voluntary incident reporting programs met with little success because po-

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[22]It can also be argued that the best type of incident reporting system lies within each operating organization, because incidents may not be reported to a central system because of the uncertainty about how that system will respond to the report relative to one's own organization. On the other hand, some form of central collection is probably also necessary to assure that serious incidents are not occurring repeatedly and are effectively dealt with.

An alternative to an anonymous reporting system is a confidential reporting system that withholds the reporter's identity but permits further information to be sought and attained.

tential reporters feared liability and disciplinary consequences. The ASRS reporting form is designed to gather the maximum amount of information without discouraging the reporters. The data are used to obtain insight into the nature of the human errors or other underlying factors in the incidents. The ASRS program is popular and over a thousand reports are filed monthly by the U.S. aviation community.

Similar "early warning" techniques to improve aviation safety using confidential reporting systems are run by neutral parties (i.e., parties independent of the aviation law-enforcing agency of the state) in Australia and the United Kingdom. The Confidential Aviation Incident Reporting (CAIR) program in Australia is controlled by the Bureau of Air Safety Investigation and in the United Kingdom the program is run by the Royal Air Force Institute of Aviation Medicine. RLD should investigate these systems as possible models of an incident reporting system for The Netherlands.

Government Certification Programs

Governmental policy in The Netherlands aims at withdrawal from interference with practical operations. The government delegates operational responsibility to the companies and privatizes a number of professional services (as is the case in mining, shipping, labor, and aviation). With respect to safety, it is argued that the operational organizations can do a better job of defining safety procedures and policies as well as maintain and monitor such procedures daily. Privatization and delegation, however, will not eliminate the final governmental responsibilities for safety. A system of certification to guarantee minimal standards with respect to a professional level and professionalism of such privatized organizations is important as is long-term monitoring and reporting to ensure that the standards are being met.

An *airport certification* process exists in all other countries visited by the study team but not in The Netherlands. It provides for an outside agency, usually the country's civil aviation authority, to review and assure quality. The airport inspection and certification program usually requires all airports to maintain an airport certification manual and an emergency plan, and some require an operations manual as well. The programs generally contain provisions for regular inspections, both scheduled and unscheduled, as well as airport self-inspection requirements. It is also common for the national CAA to provide expertise to its airports in the form of manuals based on the ICAO Annexes (e.g., Guidance Manuals in Great Britain and Advisory Circulars in the United States).

The establishment of a program, such as Federal Aviation Regulation Part 139 in the United States (described below), complete with recertification requirements, is one way to standardize the Dutch airport system. It should also increase the efficiency with which the RLD can accomplish the task of ensuring that Dutch airports meet all local and international requirements.

In the United States, FAR Part 139 requires that airports serving any air carrier passenger operation, scheduled or unscheduled, in aircraft of more than 30 seats, be certified by the FAA. Certification requires that the airport write a certification manual and submit to inspections, including unannounced inspections, by the FAA. The certification is valid until surrendered by the certificate holder or suspended or revoked by the FAA. The requirements for certification and for the contents of the certification manual will be presented in detail here as an example of a typical certification program.

To receive certification, an airport must meet and maintain specifications in a number of areas. Airport specifications and procedures pertaining to certification must be fully described in the certification manual. The manual must include operating procedures, facilities and equipment descriptions, and responsibility assignments. According to U.S. FARs, the manual is required to contain at least the following:

1. Lines of succession of airport operational responsibility.
2. Any current exemptions from the requirements of the FARs issued to the airport.
3. Any special limitations imposed by the FAA.
4. A map of features on and around the airport that are significant to emergency operations.
5. The system of runway and taxiway identification.
6. The location of obstructions required to be lighted or marked within the airport's area of authority.
7. A description of each aircraft movement area available for air carriers, along with its safety areas and each road that serves it.
8. Procedures for avoiding interruption or failure during construction work of utilities serving facilities or NAVAIDS that support air carrier operations.
9. Procedures for maintaining required paved areas and required unpaved areas, if any.
10. Procedures for maintaining runway and taxiway safety areas.
11. Procedures for maintaining required pavement marking, signage, and lighting systems on the airfield.
12. A snow and ice control plan.
13. A description of facilities, equipment, personnel, and procedures for rescue and fire-fighting functions.
14. Procedures for complying with regulations covering hazardous materials and substances.
15. A description of, and procedures for maintaining, required traffic and wind direction indicators.
16. An emergency response plan (this is usually a separate manual included as an annex to the certification manual).
17. Procedures for conducting a self-inspection program.
18. Procedures for controlling ground vehicles.
19. Procedures for removing obstructions and for marking and lighting.
20. Procedures for protecting NAVAIDS.
21. Procedures for protecting the public, including limiting access to the Air Operations Area (AOA) and protecting persons and property from jet blast.
22. A wildlife hazard management plan.

23. Procedures for reporting airport condition, such as construction under way, systems out of service, pavement irregularities, presence of snow and ice, etc.
24. Procedures for identifying and marking construction.

RLD should consider this model as well as those of other European airports in defining a process of certification for Dutch airfields.

Ongoing Controller Training and Proficiency Checks

In the area of ongoing training and proficiency monitoring, in most cases a system for ensuring or evaluating controller proficiency exists but is not always well described in the execution. Generally, supervisors continually monitor the proficiency of controllers. In some countries, controllers must periodically renew their certification through a series of written and practical exams, but this practice is not universal.

As mentioned above, LVB and RLD are currently involved in further definition of how the present process of evaluating proficiency of air traffic controllers may be administered in the new situation. A system of proficiency control exists to ensure that controllers maintain awareness of new procedures, ATC regulations, and local standard operating procedures (SOPs). For radar controllers, the simulator is also used to demonstrate skills in the handling of situations within Schiphol airspace. Written and oral examinations are beginning to be used to test basic skills such as knowledge of national/international ATC regulations and proficiency in the English language.

The LI division of RLD should monitor how well the various elements of this proficiency control system work. Local knowledge and skills, however, would be best evaluated by local personnel. The RLD should establish the requirements for an internal program that would include output designed to demonstrate the use and success of the program to the RLD. Formal internal proficiency controls can occur annually, whereas RLD evaluations of the proficiency control system could occur less frequently (e.g., every three years).

Minimum Standards for Other Operating Personnel

Dispatchers assist the pilot on the ground with slot times, load sheets, and flight plan preparations and consequently have a detailed insight into the actual aircraft configuration. Their main concern is with the fuel, weight balance, dangerous goods, and passenger loading. They are officially responsible for handling the aircraft until the pilot accepts the official load sheet and flight plan, comparable to maintenance procedures. Together with the ATC and pilot, a dispatcher is responsible for the state of the aircraft and is responsible in case of incidents associated with aircraft handling. Maintenance personnel bear responsibility for properly performing periodic and unscheduled maintenance of the aircraft. The Fire Service is responsible for the state of preparedness of elements of the emergency response to incidents and accidents. RLD should require, as part of an airport certification process, that each such operating organization provide its plan for verifying that its members satisfy standards of proficiency and safety awareness. Also, these organizations should have access to an anonymous hazard and incident report system.

Safety Concerns Associated with Growth to a Mainport

During the interviews, several parties expressed their concern that the risks at the airport will increase as a result of the increase in volume although not necessarily linearly with the growth volume. The transition to a mainport increases the complexity of the system in a number of areas. The handling of the increased volume of aircraft on the ground may not be amenable to current procedures. Weather-related problems may cause increased stacking of aircraft. Larger queues for takeoff during icy conditions may require new de-icing procedures (such as taxiway de-icing). The planned increase in traffic puts considerable pressure on airport workers to achieve the required volume. Because of the economic aspects, people may be tempted to push limits, to cut corners, and to minimize costs, thus endangering safety limits and quality standards. The requirements on punctuality may create a high workload, just to perform the tasks in time. This workload may eventually degrade professional skills, caused by insufficient training, lack of proficiency, and the lagging of paperwork and refreshment training. Increased dependence on technology such as ATM/FMS-controlled traffic flow could reduce the human skills and leads to concern about backup in case of technology failure. Control of volume-related risks such as bird strikes will become especially critical as the number of operations increases significantly.[23]

As already discussed, the SPL community can be characterized as an "ad-hocracy" in which informal relations exist in and between organizations. The creation of a mainport could introduce the need for a new type of organization with newly defined performance measures, feedback mechanisms, and combined efforts with other European mainports. Discussion is going on about the setting and enforcement of minimum quality standards, restrictions in admittance to mainports for certain types of aviation, and scaling up of coordination and cooperation beyond the level of individual organizations into a new structure (Aviation Safety Management Structure). Instead of ICAO being the prime mover for improvements, regional or locally oriented aviation organizations could emerge. They might develop into "closed" systems with local or regional control instead of the "open" systems (of complete trust in foreign licensing and control) as preferred by ICAO for a worldwide approach. It is not yet clear which role could be played by JAA or EC authorities with respect to regulations or legislation.

There are differences between developments in aviation in the United States and Europe, as well as differences between highly developed countries and third-world countries. Therefore, globally agreed ICAO recommendations do not always support the higher safety standards of more highly developed countries. The Frankfurt, London, Amsterdam, and Paris airport working group might set a trend for an approach in Western Europe in which specific requirements for mainports are developed. Mainports might thereby be inherently safer than airports. Schiphol airport is already safe compared to other major airports in the world because of such factors as favorable terrain and weather, good supporting systems, a preferential runway system that covers all wind directions, highly qualified ATC technology and personnel, and the presence of a major home carrier with high standards in its

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[23]Schiphol has an effective and what many consider to be exemplary bird control program. At the same time, bird control is especially critical at Schiphol because of its proximity to the sea and to bird migratory patterns. A review of incident reports in 1992 indicates that some bird hits or engine ingestion of birds have occurred or are suspected. As the volume of traffic increases, even more severe control of birds may be required to prevent the number of bird hits from increasing.

training, maintenance, and performance. Schiphol has even been the example for the development of other airports such as Singapore. The key point here is that there are many safety-related issues associated with growth and that the organizational structure, as it relates to safety, must adapt to the growth, anticipate problems of growth, and continually ensure that standards of safety are maintained and not unnecessarily or unreasonably subordinated to economic, political or environmental factors.

SUMMARY OF SUGGESTED SAFETY ENHANCEMENTS

At the end of each of the remaining chapters, we will present a table to summarize the enhancements and trends affecting third-party safety and its perception. They provide a framework that links the different chapters of the report with final conclusions regarding safety enhancements. They provide the reader with a means to refer back to the source (or sources) of the various options discussed. We will make no attempt to provide a relative importance of these options and trends with respect to risk until Chapter Six.

The enhancements and trends are categorized by whether they are options that are primarily management actions; regulatory or pricing actions; technical changes in aircraft, ATC, or the airport; or are considered as a normal function of growth in the future scenarios for the years 2003 and 2015. Note that some of the trends might have negative safety consequences (Table 3.3).

Table 3.3

Possible Safety Enhancements and Trends Suggested in Chapter Three

Type	Enhancements/Trends
Management actions	• Integrated safety management system/office • Integrated emergency planning/training • Safety advocacy (e.g., review safety aspects of fuel pricing policy) • Monitoring safety aspects of growth of Schiphol • Incident and hazard reporting, collection, and review • Controller training for inflight emergencies • Reducing general aviation use of Schiphol (outplacement)
Standards/regulation	• Airport certification • Controller proficiency monitoring • Anonymous hazard and incident reporting system • Identifying/controlling risky carriers
Technical/scenario	• Adding a "fifth" runway[a] • Airport growth and increased flight operations • Evolution of safer aircraft • Evolution of new ATC technology • Population and business growth near Schiphol

[a]The external risk enhancement of a new runway depends on its location, direction, and usage (operations rate, mode of use, and flight paths).

INFORMING AND LEARNING FROM THE PUBLIC

INTRODUCTION

The principal objective of this project is to use analytic tools to estimate safety hazards in terms of the likelihood that lives will be lost on the ground as a result of air crashes in the vicinity of the Schiphol airport. We estimate, to the extent possible, differences in these hazards under a variety of circumstances and the establishment of various proposed safety-enhancement measures. As this report makes clear, there is some risk to local populations around any airport. The policy questions are not whether to accept external third-party risk but whether the magnitude of this risk is acceptable, and whether measures to reduce that risk are worth their cost. Elsewhere in this report, we identify safety-enhancement measures Schiphol managers and others can take to mitigate currently identified risks and potential future risks arising from expansion of the airport. Determination of the adequacy of these measures is a political decision that must be resolved by the people and the democratic processes of The Netherlands.

SAFETY AND PUBLIC POLICY

An awareness of the centrality of the political decision process in discussing airport safety makes necessary a public communication and perception component of the project.[1] Part of our function is to help inform the debate regarding airport safety. Therefore, it is important to understand the nuances of that debate and to make certain that this study is relevant to it. Thus, one important task—reported in this chapter—is to study what people know about the safety of the Schiphol airport. This effort has two main goals: to assure that safety-related concerns of the public are addressed, and to assure that the results of this analysis—and its strengths and limitations in regard to the decisionmaking processes—will be clearly and fully set forth so as to be a useful source of information to the public.

[1]See, e.g., V. T. Covello, D. von Winterfeldt, and P. Slovic, "Risk Communication: A Review of the Literature," *Risk Abstracts*, 1986, Vol. 3, pp. 171-182; G. Cvetkovich and T. C. Earle, "Environmental Hazards and the Public," *Journal of Social Issues*, 1992, Vol. 48, No. 4, pp. 1-20; B. B. Johnson, "'The Mental Model' Meets 'The Planning Process': Wrestling with Risk Communication Research and Practice," *Risk Analysis*, 1993, Vol. 13, pp. 5-8; M. G. Morgan, B. Fischhoff, A. Bostrom, et al., "Communicating Risk to the Public," *Environmental Science and Technology*, 1992, Vol. 26, pp. 2048-2056; P. Slovic, "Informing and Educating the Public About Risk," *Risk Analysis*, 1986, Vol. 4, pp. 403-415; C.A.J. Vlek and G. Cvetkovich (eds.), *Social Decision Methodology for Technological Projects*, Kluwer Academic Publishers, Dordrecht, The Netherlands, 1989; R.A.P.M. Weterings and J.C.M. van Eijndhoven, "Informing the Public About Uncertain Risks," *Risk Analysis*, 1989, Vol. 9, pp. 473-482.

The Dutch government is perhaps more sensitive than most to issues of public safety risks, especially with regard to the environment. The Dutch parliament has accepted a policy that establishes national uniform safety standards for toxic waste emissions in a numerical form; industries emitting toxic pollutants must perform quantitative risk assessments to demonstrate that those standards are met.[2] Whether such uniform standards are appropriate, as well as whether they should be generalized to other industries, especially transportation, is the topic of ongoing debate in The Netherlands.[3]

The first step in our study of public perception was to develop an understanding of the experts' view of factors that contribute to third-party risk in the vicinity of airports.[4] Iterative discussions with multiple experts in airport safety led to the Bayes network diagram presented in Figure 4.1. This Bayes network is a convenient way to graphically present many of the factors involved in assessing airport safety.[5] Each factor identified has some causal relationship with safety, and, as shown by the multiplicity of arrows, these causes are many and are often intertwined. The arrows indicate loosely that one factor is influenced by another—that is, that the value of the factor at its head depends on the value of the factor at its tail. The factors depicted in Figure 4.1 provide one understanding of the mechanisms of possible safety-enhancement measures. For example, reducing excessive flight density might lead to better alertness on the part of air traffic controllers and hence to reducing the chance of ATC errors and possible crashes. Or, higher maintenance quality might lead to fewer aircraft failures and hence fewer crashes. The network shown in Figure 4.1 was used as an organizational tool to develop an understanding of the public's concerns regarding the operation and planned expansion of the Schiphol airport. We kept this structure in mind as we sought to understand lay views of airplane crash causality.

We performed two subtasks to help us understand the public view of airport safety. The first was a content analysis of newspaper stories regarding Schiphol airport, airport safety, and the safety of other means of transportation. The second subtask was a series of group interviews to learn about the concerns of people with different degrees of personal and economic involvement with Schiphol.

CONTENT ANALYSIS

The content analysis was based on items appearing in the Dutch press in the 12 months from January 1992 through December 1992. The goal of performing the content analysis was to assess the nature and importance of airport safety in public fora. Interestingly and not coincidentally to our conducting this study, during this time the Dutch people experienced two major air crashes (one in The Netherlands and one in Portugal of a Dutch carrier) and two train accidents.

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[2]VROM (1991), op. cit.

[3]J.C.M. van Eijndhoven and A. van Ravenzwaaij, "Optimizing Risk Analysis Relating to External Safety in The Netherlands," *Risk Analysis*, 1989, Vol. 9, pp. 495-504; Vlek (1990), op. cit.

[4]Morgan et al. (1992), op. cit.

[5]Bayes networks in general and this one in particular are neither complete nor unique but are rather heuristic devices for representing causal systems.

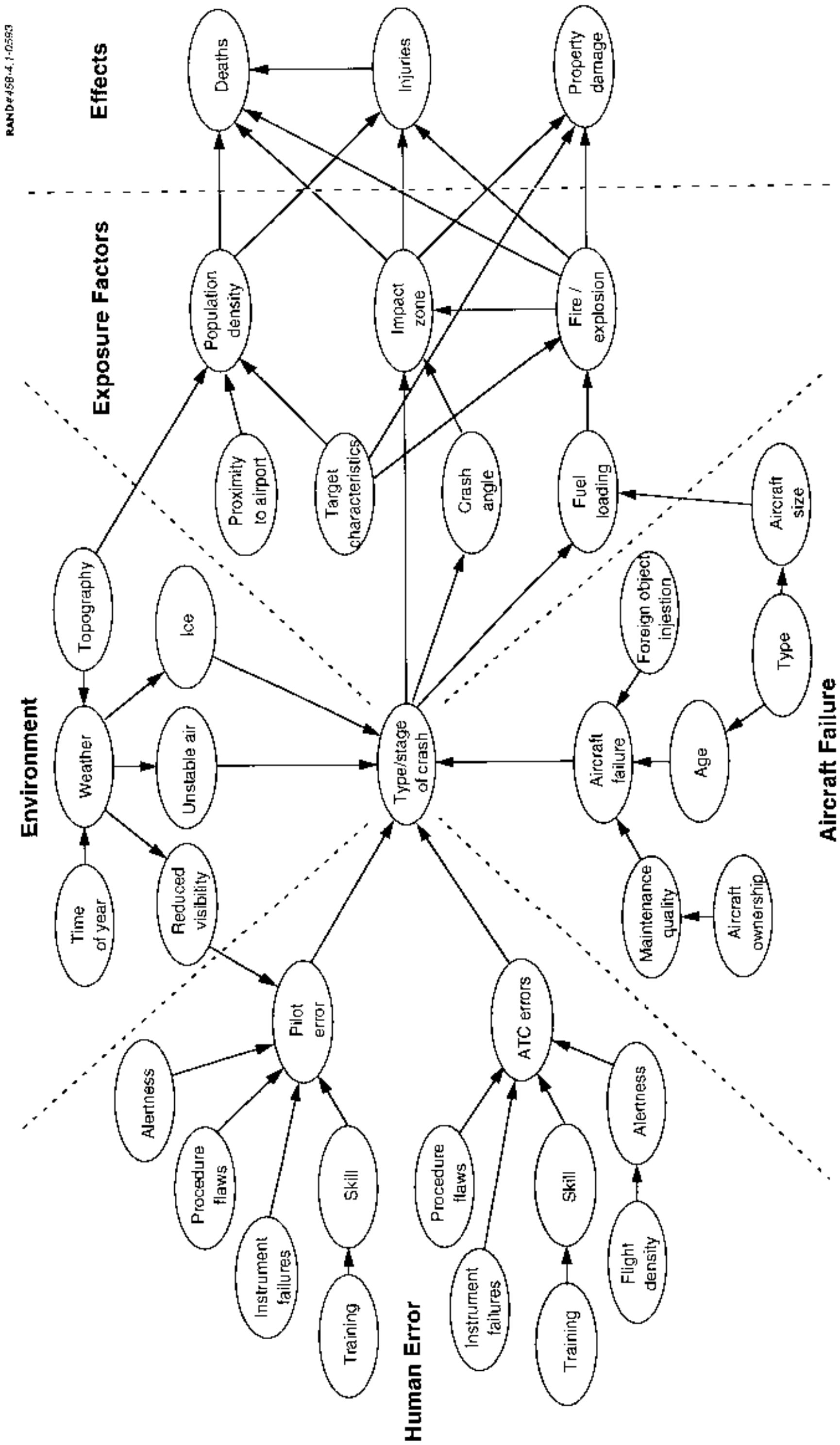

Figure 4.1—A Bayes Network for Aircraft Crashes

Content Analysis Method

We examined all articles dealing with Schiphol airport, airport safety, other transportation safety, and the development of a Dutch mainport from five "national" newspapers representing a broad political spectrum, namely *Het Financiele Dagblad, Het Parool, NRC Handelsblad, De Telegraaf,* and *De Volkskrant.* To these were added the local newspapers *Haarlems Dagblad* (from Haarlem—near the airport) and *Leidsch Dagblad* (from Leiden—a comparably sized town outside the immediate airport area). Table 4.1 shows the number of the 259 total articles that were taken from each newspaper.

An abstraction form and a coding scheme were developed to systematize the review of articles. The variables coded included:

- The date of the article. We noted in particular whether it immediately followed one of the major airplane or train accidents.
- The length of the article (short, medium, or long based on column centimeters of coverage).
- Whether photographs or graphs supplemented the text.
- Whether it was reportage, background information, or editorial opinion.

In addition, we abstracted from the articles:

- Facts and allegations regarding safety, including causes, exposure processes, reduction steps possible or taken, estimates of frequency, and mitigation measures;
- Benefits of the means of transportation (e.g., jobs, health or growth of the economy); and
- Comparative risk discussions, including mention of the national risk standards.

Results of Content Analysis

The vast majority of the newspaper articles were triggered by the crash of the El Al airplane at Bijlmer on 4 October 1992. This is shown by the number of articles published in each month, as shown in Table 4.2.

Table 4.1

Number of Articles Analyzed by Newspaper

Newspaper	Number	Percentage
Het Financiële Dagblad	10	3.9
NRC/Handelsblad	55	21.2
Het Parool	54	20.8
De Telegraaf	25	9.7
De Volkskrant	39	15.1
Haarlems Dagblad	68	26.3
Leidsch Dagblad	8	3.1

Table 4.2

Number of Newspaper Articles Analyzed by Month

Month	Number	Percentage
January	8	3.1
February	6	2.3
March	7	2.7
April	6	2.3
May	4	1.5
June	6	2.3
July	2	0.8
August	1	0.4
September	10	3.9
October	172	66.4
November	17	6.6
December	20	7.7

General Characteristics. Not all of the 172 articles in October 1992 were directly concerned about Bijlmer. Of those articles, 91 (53 percent) were about the accident; another 68 (45 percent) did not discuss the accident directly, but instead discussed air transportation safety, Schiphol airport, previous accidents, or aviation in general. Only four of the articles in October were not air-transportation-related. Into November and December, there was still a focus—much diminished but still above the base rate—on Bijlmer, until the air accident at Faro, Portugal, and the train accident at Hoofddorp (ironically, the town nearest Schiphol airport and the location of a major train car storage yard) occurred. These two events accounted for 25 of the 37 articles published in November and December 1992.

Other than in discussion of specific accidents, there was virtually no mention of likelihoods of external risk in the newspaper articles. In articles about the Bijlmer crash, there were many such references, as the uncertainty in these figures caused considerable speculation.

As might be expected, air transport dominated interest in October, with 94 percent of the articles. For all of the other months, 60 percent of the articles regarded air transportation—still the majority but considerably less than in October. Twenty-eight percent of the non-October articles were about trains, with the remainder spread among water transportation, road transportation, and transportation in general.

The general characteristics of the articles coded did not differ according to when they appeared and their subject matter. Overall, 10 percent of the articles were long, 35 percent were of medium length, and 55 percent were short. For the articles in October, these figures were 11 percent, 37 percent, and 52 percent, respectively—or virtually no difference. The type of article was similarly not affected by topic. Eleven percent of coded articles were analysis and opinion, 18 percent were background, and 71 percent were reportage; the corresponding figures for October were 9 percent, 19 percent, and 73 percent. Overall, only 14 percent of the articles were accompanied by a photograph or graph. For the articles in October, this was reduced to 8 percent, as many of the "sidebar" stories that accompanied the main story on the crash had no accompanying visual addition. Because most of the articles printed in other months were aimed at capturing reader interest rather than providing current information, there was a higher proportion of visual additions; 25 percent of these articles had graphs or photographs.

We looked for a possible overrepresentation of one segment of society in writing opinion articles (when the author was not a journalist), but found none. The opinions were authored by a wide range of people, from the Mayor of Amsterdam to general aviation pilots to spokespersons for environmental groups. No one group wrote more than four of the opinion articles.

Safety Before Bijlmermeer. Before the Bijlmer accident, there were a total of 50 articles; of these only 10 were about airport safety. The remainder were largely concerned with environmental issues, with seven articles discussing Schiphol and its proposed expansion, 15 aviation in general (possibly including Schiphol), and the remainder transportation in general. None of the articles about the expansion of Schiphol discussed safety. Instead, the environmental consequences of Schiphol expansion were paramount. There was the concern that environmental issues were being given short shrift compared to economic ones, although the articles were careful to consider both sides of the issue.

In the pre-Bijlmer articles regarding safety, the following topics were discussed:

- Understaffing of air traffic control.
- Modernization of the air traffic control system.
- Computer failures at Schiphol causing delays and danger.
- Increase in accidents from sports planes.
- The potential for human error hampering disaster planning at Schiphol.
- Human error increasing danger from Boeing aircraft.

Safety After Bijlmermeer. In general, the tone set by the newspaper articles after the Bijlmermeer disaster was negative. Journalists expressed a great deal of suspicion about unreported incidents and a possible background of safety hazards never publicly admitted. There was a great deal of speculation about information withheld regarding the accident because it would make different agencies look bad. The RLD in particular was castigated by the media.

After the crash there were 14 articles about Schiphol expansion, and all of them addressed the additional (unmeasured but significant) safety risk; the previous discussion about economic benefits was greatly reduced and the articles were more one-sided than earlier. Articles against the expansion or even advocating the reduction of traffic at Schiphol or moving the national airport elsewhere appeared. Previous accidents and reports of incidents appeared prominently.

The following topics were discussed in the post-Bijlmer articles about airport safety:

- Stories about the Bijlmer flight, what happened, and what might have happened.
- Stories highlighting the large number of third-party (ground) casualties.
- Articles about Schiphol operations affected by crash.
- Articles critical of governmental actions and statements in regard to the crash.

- History of accidents in the last five years in The Netherlands and elsewhere.
- Articles about occurrences and incidents around Schiphol.
- Articles alleging and denying safety risk of flying over populated areas.
- An investigation of takeoff and landing patterns at Schiphol.
- Stories about KLM airplanes.
- Story that inhabitants in risk areas want independent information.
- Story about a Boeing aircraft causing panic in Gelderland.
- Analytic article about tradeoffs between general well-being, safety and economic prosperity.
- Opinion piece by pilot in regard to Schiphol expansion.
- Offer by Leiden organization to independently investigate accident.
- Articles regarding kerosene tanker plans and safety hazards.
- Demand for safety standard at Schiphol.
- Story about the province of Noord Holland restricting new construction around Schiphol.

The topics emphasized by the newspapers, together with the opinions expressed in our interviews (as described immediately below), led to a set of recommendations for measures to enhance both the actual safety and public perception of safety at Schiphol. We present these measures at the end of this chapter.

USING GROUP INTERVIEWS TO UNDERSTAND PUBLIC CONCERNS

Introduction

To better understand public awareness of safety at Schiphol and public willingness to accept risks to that safety, we conducted interviews with small groups of people representing different possible interests with regard to the airport. These interviews were similar to focus groups, or gatherings of people who have some interest in common who discuss that interest in some depth.[6] Although focus groups were first used as a technique in market research, they are proving increasingly useful as a tool in policy research, especially when there is a range of public opinion with respect to the policies to be examined or when there is public uncertainty about the nature of the policies and their implications.

Although we would have preferred to conduct multiple group interviews and to reinterview groups to obtain their reactions to the conclusions of the study, the short

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[6] J. K. Hammitt, *Estimating Consumer Willingness to Pay to Reduce Food-Borne Risk*, RAND, R-3447-EPA, 1986; T. J. Hayes and C. B. Tatham, *Focus Group Interviews: A Reader*, American Marketing Association, 1989; J. W. Knodel, V. Sittitrai, and T. Brown, *Focus Group Discussions for Social Science Research: A Practical Guide With an Emphasis on the Topic of Ageing*, University of Michigan, Population Studies Center, No. 90-3, 1990; R. A. Kruger, *Focus Groups: A Practical Guide for Applied Research*, Sage Publications, Newbury Park, California, 1988; J. D. Swenson, W. F. Griswold, and P. A. Kleiber, "Focus Groups: Method of Inquiry/Intervention," *Small Group Research*, 1992, Vol. 23, No. 4, pp. 459-474.

time frame of the project made such steps impossible. What we present here are the results of what might best be considered a pilot study for a more formal survey. Nonetheless, as we will argue below, the results are informative, consistent with other sources of information, and provide important considerations to any policy regarding airport safety.

Interview Method

We describe here the groups selected for interviewing and the method of interviewing.

Groups. Three types of groups were selected to represent different degrees of economic and personal interest that people might have with regards to Schiphol airport:

- *Neighborhood group.* These people live near the airport (defined as within 10 km of the airport). They are subject to the highest external safety risk posed by the airport. For many of the members of the neighborhood group, the airport represents an intrusion into their lives; they or their families lived in the area before the airport came to dominate the region. In their eyes, the hazards to safety posed by the airports are imposed upon them rather than voluntarily incurred. The benefits this group receives from the airport, unless they are employed in airport-related jobs, may not exceed those of the Dutch general public.
- *Worker group.* These are people who work at the airport. They have an economic interest in the airport and, through their employment, may be considered to have voluntarily accepted the safety risks resulting from airport operations. We excluded from our interviews airport workers having a direct involvement in airport safety-related operations (e.g., air traffic controllers and pilots) and managers with sufficient authority to influence safety and airport expansion-related decisions, although they are technically members of this group.
- *Distant group.* These people neither live nor work near the airport. They represent the larger Dutch public that as taxpayers pay for Schiphol in return for the benefits to the nation as a whole that arise from having a national airport. This group also has the responsibility of informing their elected representatives about the acceptability of safety risks in return for the benefits of the airport.

People representative of these three groups participated in structured interviews about airport safety. Members of the neighborhood group were partially recruited by random telephone calls to people who live near the airport (four participants) and partially through volunteers from local activist organizations (*actiegroepen*) concerned about the airport (three participants). Members of the worker group were recruited by personal contacts from airport authority employees (three participants) and employees of two airlines that use the airport (five participants). The distant group (seven participants) was recruited via personal contacts from people who live and work in Utrecht, a major Dutch city 45 minutes travel distance from Schiphol that does not have an airport of its own.

We make no claim that the 22 people we interviewed are a random selection of either their identifying groups or the Dutch population as a whole. The constraints of time made it impossible for us to reach out to the communities comprising our groups, so we were forced to interview samples of individuals who happened to be available.

Nonetheless, we believe that the general opinions expressed—if not all of the specific statements—are representative of the groups the participants come from. We base this belief on the following:

- The opinions we heard were representative of and consistent with the information from the content analyses, other less-formal interviews we conducted, and our own experience with safety-related issues.
- Many of the people we interviewed explicitly stated that their opinions were shared by members of groups to which they belonged and neighborhood friends.
- Our experiences discussing Schiphol and airport safety on a less formal basis with many people and on what we have read in newspapers and interest group literature were consistent with these opinions.
- The attitudes and beliefs presented in our different sessions were similar from session to session; moreover, there was a general consensus achieved within each session.

Procedures. The bulk of our interviews were obtained in three sessions conducted by a professional group facilitator from KPMG, a large Dutch management consultant firm.[7] The distant group met at the KPMG offices in Utrecht, the neighborhood group met at the KPMG offices in Amstelveen, and the worker group met at the KLM offices in Hoofddorp.[8] Each meeting was in the evening and scheduled for two hours; in fact, the meetings lasted at least two and one-half hours. Unlike market research interviewees, participants were not paid for their attendance; we believed that payment might be perceived by some participants as an attempt to buy opinions.

Each meeting began with a brief description of the overall purpose of the research project and the specific reason for the meeting. Participants were told that they were providing information about safety at Schiphol and the relationship of that safety to other aspects of the airport. Following this general orientation, participants introduced themselves, beginning with the investigators and moving to the panelists.

The group leader then explained the tasks at hand. Figure 4.2 shows the slide used to explain the purpose of the interviews to the participants. The interviews moved from the center of the figure outwards, as indicated by the numbers. The first topic of discussion—represented by the center circle—was whether Schiphol airport was safe enough. As part of this, we asked how accidents occurred and what were the major causes of accidents. Moving outward to the second circle, we asked for positive and negative aspects of Schiphol airport apart from safety, as well as political and other barriers to safety improvement. In the third, outermost, circle, we explored peoples' perceptions of a mainport, including their understanding of what it would be, what benefits it might produce, what additional safety risks it might engender, and what would be necessary to make the safety risks of a mainport acceptable. Finally, as rep-

[7]The group facilitator was instructed to conduct the interviews in as neutral a manner as possible. He is not an expert in transportation or safety matters and, to preserve his freedom from bias, was not informed about other activities of the project.

[8]At the request of the activist organizations, some interviews were conducted with their individual representatives. Although these interviews did not follow the format of the other interviews, the content was similar.

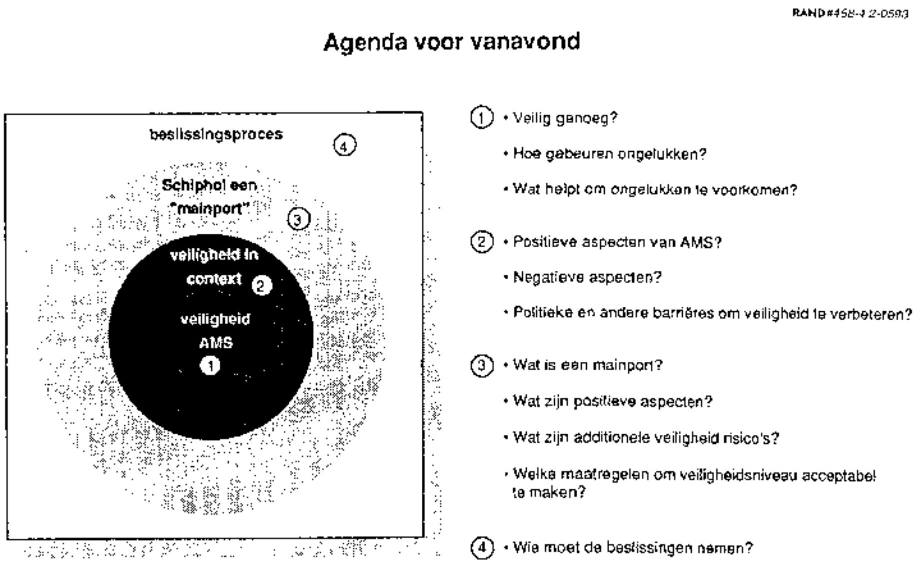

Figure 4.2—Agenda for Group Interviews

resented by the bordering square, we shifted from the substantive content of the airport to the political process and asked peoples' beliefs of the best way to come to a decision about a mainport—i.e., who should make the decision and on what basis.

To help define the context of the meetings, we displayed a number of color photographs and posters of airplanes, airport scenes, and other transportation (train and road) scenes. The photographs were placed on the wall around the meeting table. At the end of the session, participants were encouraged to examine the photographs and comment on any thoughts about safety the displays might trigger.

Results of the Interviews

Although each interview was independent of the others, common themes emerged, so that the sentiments expressed in the interviews were on the whole more similar than they were different. We found that a small number of themes dominated each of the discussions. We will orient our discussion around these themes, signaling, when they occurred, variations on these themes unique to a particular group.

Safety Is Not the Most Important Concern Regarding Schiphol. For each of the groups, safety was not the most important concern that came to mind when considering potential problems with Schiphol. Far more important were the noise associated with airport operations and environmental concerns, and these are deeply felt concerns. For example, the most vocal of the participants stated, "We are fed up with Schiphol."

The concern about noise is far from new; there is a long-standing public activist organization that addresses airport noise, while there is no corresponding organization for safety. Environmental concerns range widely. Individuals, especially in the neighborhood group, were upset by the noxious smell of kerosene in the air around the airport. Other immediate environmental problems mentioned included pollution from toxic substances associated with the airport, negative effects on local bird life, vibrations from aircraft, roof tiles blown off by vortices created by landing aircraft, interference with radio and television, and dirty laundry.

A secondary theme regarding the environment was more directly connected to the expansion of the airport. Participants from all groups considered that population growth around the airport would be an inevitable consequence of airport expansion, as expansion brought jobs and business opportunities and these in turn brought people. The additional residential and industrial growth thus engendered would itself cause all of the environmental damage associated with overurbanization.

Although all three groups were concerned about noise and the environment, the neighborhood group was more angry and more anxious about these effects, because members of the group personally experienced them. Individuals in this group believed that they suffered a disproportionate share of the negative consequences of Schiphol in its present state and would suffer an even greater share of the negative consequences of an expanded airport. They believed that they should be compensated in some way for these harms. For example, they believed that land values under takeoff and landing patterns were lower and that the owners of such properties should be paid compensation for this loss. Other suggestions included assistance in moving and compensation for physical and mental health consequences from living near the airport.

Views About Safety Are Influenced by More Important Concerns. Although noise and environmental damage were more salient concerns than safety, as concerns about the first two rose, so did concerns about safety. This association was perhaps most concisely expressed by one neighborhood participant, who noted that because of wind patterns, weeks would go by without an airplane passing over her home. Then when the wind shifted, there would be considerable noise for a few days. In the quiet periods, she tended not to think about safety, but the barrage of noise caused her to become more fearful of an accident.

Other negative effects would also be associated with safety. For example, neighborhood participants reported interference from airplane communications with their radios, televisions, and computers; in turn, they believed that the emissions from their own electronic devices might create some safety hazard for the aircraft. Others heard the noise of engines reversing thrust upon landing, assumed that this noise was related to safety, and recommended slower landing speeds for airplanes so that they would not have to reverse thrust.[9]

Schiphol Is Considered Relatively Safe. With some major exceptions, the participants, by and large, believed that Schiphol is a safe airport. People considered it safe relative to the other major European airports. The generally good weather (no northern blizzards and no tropical storms), flat terrain, quality of pilots and ground personnel of the dominant carrier KLM, the openness and multiple runways of the

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[9]This is a good example of "naive" causality. The lay person does not understand the relationship between speed and aerodynamics and the risk caused by flying too slowly.

airport, and the quality of the air traffic controllers were cited in support of this opinion.

It was noted that airplanes can get in trouble anywhere, and that there were problems with military aircraft near military airports as well as with commercial aircraft near civilian airports. One participant observed that in World War II, over 5000 aircraft crashed in The Netherlands, with remarkably few people on the ground killed.[10] A participant in the worker group stated that he can "go home with a clear conscience."

The perception of Schiphol as relatively safe arises in part because the participants attributed the causes of airplane crashes more to pilot error and aircraft malfunction than to causes for which the airport was responsible. What creates a bad impression of safety at an airport is not so much one accident, but rather subjective impressions of maintenance, a country's cultural image, the service of the major airlines who call the airport home, whether flights are on time, and communications problems. In all of these regards, Schiphol compares well to the rest of the world. Given this view, then the occurrence of an accident at any particular airport was more a matter of chance than something for which the airport should be blamed. Thus, the groups did not believe that the Bijlmermeer accident indicated that the airport was relatively less safe.

There are two important reservations to this generally optimistic picture that should be noted. First, because accidents are viewed as somewhat random with regard to airports, increasing the volume of airport operations is viewed as increasing the safety risk, even as the overall accident *rate* decreases. This means that the increase in volume of traffic as Schiphol becomes a mainport may be perceived as increasing risk, especially if any organizational and other safety-enhancing changes accompanying expansion are not made obvious to the public. Second, the attribution of accidents to causes other than the airport is not firmly fixed. If the investigation of the Bijlmer crash were to attribute responsibility to the airport or if another accident were to occur at Schiphol, then public confidence in the safety of Schiphol could suddenly evaporate.

People Believe That They Are Not Being Told the Whole Truth. That the airport is considered relatively safe is not the same as saying that the safety risk of the airport is acceptable. When we asked whether or not the safety risk of the airport was acceptable, we received some positive and some negative responses, but the consensus belief was that people were not being given enough information to make a reasoned judgment. This belief was expressed by all groups. The neighborhood group would see events themselves (e.g., a plane landing with what appeared to be an engine on fire) and would never read about the incident.[11] The worker group has an "internal telegraph" by which incidents and other safety-related matters are transmitted. And the distant group believed from friends who lived or worked near the airport that potentially negative information was being withheld from the public.

What appears to be secrecy is not viewed as a conspiracy to fool the public, but rather as defensive behavior on the part of bureaucrats and others who fear being

[10] This participant also cautioned that the population density of The Netherlands at that time was less than half its present value.

[11] We did not attempt to verify whether such incidents actually occurred.

saddled with responsibility. However, the effect of the perception of secrecy is the reverse of its intent—subjective judgments of the problem may get exaggerated as people come to believe that information is being withheld because of major problems.

There was universal confidence in the ability of the public to make a reasoned decision on acceptability. This is not to say that all those interviewed believed that incidents should automatically be published in the newspaper, but rather that all information bearing on the safety of the airport should be organized and available upon request. In that way, individuals could obtain the information relevant to their concern, and a common base of information could move a discussion on acceptability of risk to a real consideration of tradeoffs, rather than to a conjectural debate on how safe the airport is.

Some Safety Risk Is Acceptable to Have a National Airport. Everybody we interviewed saw the need for a national airport, although some regretted that it had been placed at the present site of Schiphol and others believed that relocating the airport should be seriously considered.[12] There was a consensus on the benefits of Schiphol, including the centrality of transportation to the Dutch economy ("Nederland distributieland"), the ease of accessibility of the airport, the "user-friendliness" of the airport (which participants compared to Brussels, London, and Paris), the benefits of tourism, the centrality of the airport for business meetings and professional conferences, the international reputation for quality of KLM, and the national image as represented by "The Flying Dutchman."

Moving from Schiphol's current status to become a mainport also had benefits that might be worth some additional safety risk, including the creation of jobs in The Netherlands, the snowball effect of that additional employment, and the convenience of having a transportation hub in terms of travel scheduling, comfort, and cheap charter flights. There was also some agreement on the position that as the world changes, Schiphol would also necessarily change, and that the choices were to expand to a mainport or decline to a minor airport, with a middle option not really available.

Some participants believed that some past decisions had been poor ones that could not be revisited. For example, some stated that in retrospect an airport in the Markerwaard (an area of the IJsselmeer north of Amsterdam that was considered at one time for land reclamation) should have been built instead of the expansion of Schiphol in the 1960s, but that road networks and environmental concerns now made that impossible. These participants viewed this history as an object lesson demonstrating the need for more careful planning in the future.

Some participants foresaw the need for decisions to reconcile safety-related problems that such an expansion would cause. For example, they commented that the question over whether or not to build a fifth runway was inextricably connected with whether or not to expand nearby towns. If the runway were built, then it would not be safe to permit the town to expand; if, on the other hand, town expansion was deemed more desirable, then the runway could not be built.

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[12] See, for example, P. Heijboer, "Goeree Airport International," *De Volkskrant*, Saturday 20 March 1993, p. 6 of the opinion section.

Each group foresaw that there would be limits to the additional safety risk that moving to a mainport would entail and expressed concern that Schiphol should not exceed these limits.

Decisions Regarding the Mainport Should Be Made by the Affected Parties, with Full Availability of Relevant Information. Although Schiphol as presently constituted and an expanded mainport are important to The Netherlands as a whole, all groups—including the distant group—agreed that the people in the neighborhood of the airport should have a significant voice in determining the acceptability of the external risks to safety. It was acknowledged that various air transportation industry interests—including KLM, RLD, and NVLS—should have their voice, but the groups believed strongly that no one of these interests nor all of them collectively should be permitted to completely control the decision.

All groups commented that the national government has not been solicitous of public input nor forthcoming with preliminary ideas with regard to the expansion of Schiphol and other proposed major transportation projects such as a high-speed passenger rail system and a dedicated freight rail line (Betuwe line). There is a concern that the decisions whether to proceed with these projects have already been made and that safety audits, environmental impact reports, and other such measures are just pro forma steps that will not have any influence. Some people are frustrated because they perceive governmental officials as not listening to the sincere and reasoned objections to the proposed projects. As a consequence, the public confidence in politics and politicians has decreased dramatically in the past few years.

The particular mechanism for reintroducing public input into these decisions was not particularly important to the groups; some mentioned referenda, some mentioned votes by local authorities, and some mentioned national or provincial decisions following public input. But all groups recognized both the national importance of the decision and the need to take into account in a specific manner the values and beliefs of the people who live in the neighborhood of the airport.

SPECIFIC CHANGES THAT COULD ENHANCE SAFETY

We close this chapter with a list of specific changes from the content analysis and interviews that could either enhance the safety of a present-day Schiphol or maintain and possibly improve the safety of a mainport Schiphol. These recommendations are interesting not only for their value as recommendations but also for the insights they can provide into the participants' views of what causes accidents. Such perceptions are often as important in determining airport policy as the technological truths.

A Centralized Safety Office

A repeated recommendation was for a centralized safety office at Schiphol. The belief in the efficacy of such an office arose out of the conviction that negligence, choosing expediency over prudence (e.g., "Just in Time" management), lack of responsibility, and poor communications were important predecessors to accidents, and that a responsible central office could reduce these contributory factors. For most participants, a primary function of this office would be as a clearinghouse for information regarding safety. Such an office would have the responsibility to ensure that important information regarding safety was not withheld from the public and to coordinate the various inputs from different sources (airlines, air traffic control, ground maintenance), especially regarding incidents that threaten to compromise safety. It would also have the tasks of formulating adequate policy and enabling the community to monitor and influence that policy.

Restrictions or Other Controls on Substandard Carriers

The interview participants and Dutch press view KLM as better than adequate with respect to safety but have doubts about some of the other airlines that fly passengers or cargo in and out of Schiphol. They believe that safety would be enhanced if substandard carriers were required to either come up to a minimum safety standard or be prohibited from using the airport. At a minimum, substandard carriers should be publicly identified. Participants recognized the political difficulties that such measures might create, but nonetheless believed that the measures might be necessary to achieve an acceptable balance between risk and safety.

Controls on Takeoff Weights

Neighborhood participants in particular reported seeing aircraft take off very slowly and with a great deal of wobble, and attributed this perceived unsafe action to overload. Most participants were aware that kerosene prices are significantly lower at Schiphol than at comparable European airports. They viewed this as an economic strategy to increase cargo and charter flights at Schiphol and not necessarily bad in and of itself. However, it was also viewed as an inducement for carriers—especially cargo carriers—to take off with heavier-than-safe loads. (Some participants were also concerned with maldistribution of cargo loads.) Therefore, participants advocated measures to reduce this risk, principally ensuring adherence to maximum takeoff weights.[13]

Establish Better Emergency Procedures

The public was very much concerned with improving emergency procedures, and we read or were told a number of suggestions for improving emergency procedures, including having an emergency runway, reserved radio frequencies for emergencies, prescribed fuel-dumping procedures, and better response times for on-the-ground teams such as fire brigades. The emergency runway recommendation was repeated a number of times in different guises, with the neighborhood groups advocating such a runway at a location other than Schiphol.

Employ Safety-Enhancing Procedures

Some participants advocated the elimination of general aviation and training flights from Schiphol to reduce the frequency of flights and therefore the risk. Some participants believed that the spacing of flights and the assignment of runways was not

[13]As mentioned in Chapter Three, takeoffs *at* MTOW should generally be safe because of built-in safety margins.

designed for optimal safety. Others believed that inflight routing following takeoff and before landing could be changed to better avoid crowded areas.

The Best Equipment Money Can Buy

A common recommendation in safety discussions was that the most up-to-date safety-enhancing technology should be at Schiphol, and that the cost of that technology should be borne by the users of the airport. The economic importance of the airport means that the investment in safety is worth the cost.

Training and Certification

The press and interviewees both believe that airport staff should be trained to expert status and that visiting aircrews should meet minimum training standards before being permitted to use Schiphol. Closely allied to this position was the viewpoint that automation was not a total solution—that there would always be an important human component to flying, and therefore that human expertise could not be replaced by expert systems.

The Government Has Not Dealt Well with Safety

Participants and the press were open about their disappointment in the governmental actions surrounding the Bijlmer crash. This is not to say that government actions caused the crash, but rather that governmental actions after the crash did not appear to our participants to be systematic, oriented towards minimizing the consequences, or to address the causes of the problem. Some participants expressed a slightly different viewpoint that the VROM standards for environmental hazards[14] should be adopted for the 40 km x 40 km area surrounding Schiphol; others believed instead that safety cannot be expressed in numerical terms of individual likelihoods. But most participants believed that the government should not be directly involved in crisis management.

Table 4.3 summarizes the perception of safety derived from the content analysis and interviews and discussed in this chapter.

Table 4.3

Perceptions of Safety at Schiphol

Issue	Perceptions Based on Content Analysis and Interviews
Level of concern about safety	Safety is not the most important concern regarding Schiphol. Views about safety are influenced by the more important concerns (noise and environment). Schiphol is safe by and large .
Communications	People believe that they are not being told the whole truth.
Expansion of Schiphol	Some safety risk is acceptable to have a national airport. Decisions regarding the mainport should be made by the affected parties, with full availability of relevant information.

[14]VROM (1991), op. cit.

A REVIEW OF WORLDWIDE AVIATION ACCIDENTS, CAUSES, AND POSSIBLE MITIGATING MEASURES

PURPOSE OF REVIEWING WORLDWIDE ACCIDENTS

Fortunately, the number of aircraft crashes and crash related fatalities worldwide is relatively small (fewer than a thousand passenger fatalities a year) compared to car accidents (more than 200,000 fatalities per year worldwide), drowning (tens to hundreds of thousands of fatalities per year), falls off ladders, and so on. And, aircraft accidents and accident-related fatalities at any single airport are especially infrequent. Hence, as a means of both inferring useful information about the relative importance of possible safety-enhancement measures in general, and as a way of inferring quantitative crash data specific to Schiphol, we have relied upon global aircraft crash data and customized it to Schiphol.

Global aircraft crash data over the last 20 to 30 years tells us about the cause or causes of aircraft crashes, crash rates by mode of flight and size of aircraft, impact area, and mortality rate. Using these global data and specific facts about Schiphol (such as geography, weather patterns, and types of aircraft using Schiphol), we are able to selectively pick and then apply this global information to Schiphol.

In this chapter we identify our data sources and infer information about safety enhancements across airports worldwide and discuss how these data could be generally applied to Schiphol. Then, in Chapter Six we apply our analyses specifically to Schiphol to estimate third-party risks at Schiphol and to determine how these third-party risks might be reduced as specific improvements are implemented.

SOURCES OF DATA AND ACCIDENT INFORMATION

The database is derived from multiple sources (see Appendix B for a detailed listing of our sources) including :

- Airline Pilots Association
- Airport Council International
- Air Transport Association (ATA)
- Aviation Information System Limited (AISL)
- Boeing Commercial Airplane Group
- United Kingdom Civil Aviation Authority (CAA)

- Douglas Aircraft Safety Data Office
- Dutch Aviation Authorities
- Flight Safety Foundation
- KLM pilots
- International Civil Aviation Organization (ICAO)
- Federal Aviation Administration (FAA)
- U.S. National Transportation Safety Board (NTSB)
- Schiphol Airport Authorities
- World Airline Accident Summary (WAAS)
- U.S. National Safety Council (NSC)

RELATING GLOBAL ACCIDENT DATA TO SCHIPHOL

Commercial aircraft hull loss data were examined to determine the factors that could influence third-party risk near Schiphol. The main sources for the loss data were Boeing, Douglas, and the British Civil Aviation Authority. Both aggregate statistics and individual aircraft crash characteristics were assessed and, in some cases, evaluated.

In many instances, Boeing or Douglas had already derived and included aggregate crash data in their accident documents. When this was done, we borrowed generously from them. In other instances, the data had to be assembled and then derived. The statistics found in the next subsection reflect both methods.

For this analysis, we determined that many of the worldwide aircraft hull loss accidents could have happened at Schiphol had they not happened elsewhere. Thus, safety-enhancement measures that would have mitigated these accidents worldwide would likely reduce the potential for losses at Schiphol.

We exercised care to ensure that we did not reject a crash as being relevant to Schiphol merely because the circumstances appeared to differ significantly. For example, and perhaps as the extreme case, we assessed that a crash largely caused by blowing sand (in Africa) could also have occurred at Schiphol because the inducing mechanism was the reduced visibility caused by the sand and not the sand itself. Thus, blowing sand in this instance had the same influence as fog at Schiphol. Many accidents had similar, albeit different, translations in terms of applicability at Schiphol.

Several accidents, however, would likely not have happened at Schiphol and these were omitted from further consideration. For example, one crash of a U.S. Air Force KC-135 aerial tanker was omitted because it happened on a low-level flyby during an air show and was caused by wake turbulence induced by a B-52 in formation ahead. Because air shows and formation flights are unlikely at Schiphol, this accident was thus omitted.

Although Schiphol has no nearby high terrain, crashes into high terrain were, in some cases, deemed applicable and others were omitted. This was appropriate because crashes into high terrain can be divided into two classes—those in which an airplane was off course and hit a mountain (but at a correct altitude for the course originally planned), and those in which an airplane crashed because it had incorrect altitude information (because an altimeter was incorrectly set, approach chart altitudes were incorrectly interpreted, etc.).

Of these, the latter was deemed applicable to Schiphol. The rationale for this decision was that, even though Schiphol's surrounding terrain is relatively flat, incorrect altitude information could have caused a crash. Off-course errors would likely not have occurred, however, because there is no high terrain into which to crash near Schiphol, and, thus, we did not consider this category of accident.

IMPLICATIONS OF THE GLOBAL ACCIDENT DATA FOR SAFETY

The ability to mitigate third-party risk is correlated directly to both the prevalence of a crash problem and the effectiveness of the intended safety-enhancement measure or measures that could be implemented. Although many of the problems or causes that could lead to a fatal aircraft crash persist worldwide at all airports, some factors such as local weather conditions (e.g., wind shear[1]) and local terrain (e.g., mountains), are more particular to a specific airport. In this subsection, we identify the causes of fatal accidents worldwide, identify the potential for third-party casualties and mitigating factors worldwide, and review accident trends and the implications of various factors for worldwide airports.

Causes of Accidents

The majority of worldwide, commercial jet transport accidents from 1959 through 1991 have involved multiple causes. *Flight crew error* was the most dominant cause and persisted in about 65 percent of fatal crashes (see Figure 5.1). Flight crew error was often not the single cause of an accident. A typical scenario that could lead to a fatal accident might begin with some mechanical problem on board the aircraft (e.g., an engine on fire or incorrect positioning of the flaps) and the pilot may further contribute to this problem by not making the proper response. In fatal crashes, the combination of mechanical problem and crew error often both contribute to the crash.

Of those fatal crashes where the flight crew was the primary or secondary cause, the vast majority of the flight crew errors were attributed to the captain (as depicted in Figure 5.2).

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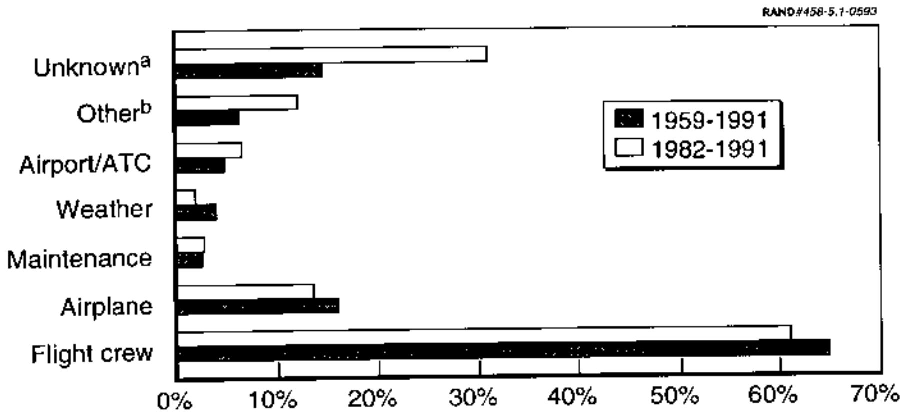
[1]Wind shear downburst is a weather phenomenon that has been identified and has received intense scrutiny over the last decade. It is a strong downdraft that extends to the ground and is normally associated with thunderstorms. Aircraft approaching the runway have been caught in this downdraft and have been catastrophically slammed to the ground. Anecdotal evidence suggests that Schiphol has largely been wind shear-free; however, Schiphol does experience thunderstorms and as a consequence wind shear could negatively affect safety.



[a]Refers to accidents of unknown cause.
[b]Refers to infrequent accidents of known cause.

NOTE: The percentages in Figure 5.1 sum to greater than 100 percent because in a few instances two different dominant causes (instead of one) were given per accident.

SOURCES: *Commercial Jet Transport Safety Statistics*, Douglas Aircraft Safety Data Office, Flight Standards and Safety Group, Long Beach, California, 1991 (Douglas Aircraft, 1991). The information is also contained in *Statistical Summary of Commercial Jet Aircraft Accidents, Worldwide Operations, 1959-1991*, Commercial Airplane Group, Boeing Aircraft, Seattle, Washington, 1991 (Boeing Aircraft, 1991); *Annual Review of Aircraft Accident Data, U.S. Air Carrier Operations, Calendar Year 1986*, National Transportation Safety Board, Washington, D.C., February 1989; and *Annual Review of Aircraft Accident Data, U.S. Air Carrier Operations, Calendar Year 1989*, National Transportation Safety Board, Washington, D.C., February 1992.

Figure 5.1—Causes of Commercial Jet Transport Accidents

The implication of this general finding to our study is that improved flight crew training and pilot training in response to emergencies could play a potentially important role in avoiding fatal aircraft crashes and third-party risk. Hence, we need to assess current training and define and evaluate other training procedures that might address and reduce the pilot and crew contribution to crash risks. Because training varies by airline, assurance must be provided that crews from all airlines of all countries have certain minimum levels of training for emergencies.

The *ground crew* and the *maintenance crew* contributed to less than two dozen fatal accidents out of a total database of 550 commercial jet aircraft accidents from the period 1959 through 1991 that we examined.[2]

Failure of the aircraft in flight because of either *mechanical problems* or *maintenance problems* also accounts for an appreciable number of fatal crashes. Of those aircraft failures, engine problems were the most common failure that led to fatal crashes. Figure 5.3 identifies engine-related problems that led to fatal accidents in more than 550 commercial jet aircraft from 1958 to 1991.

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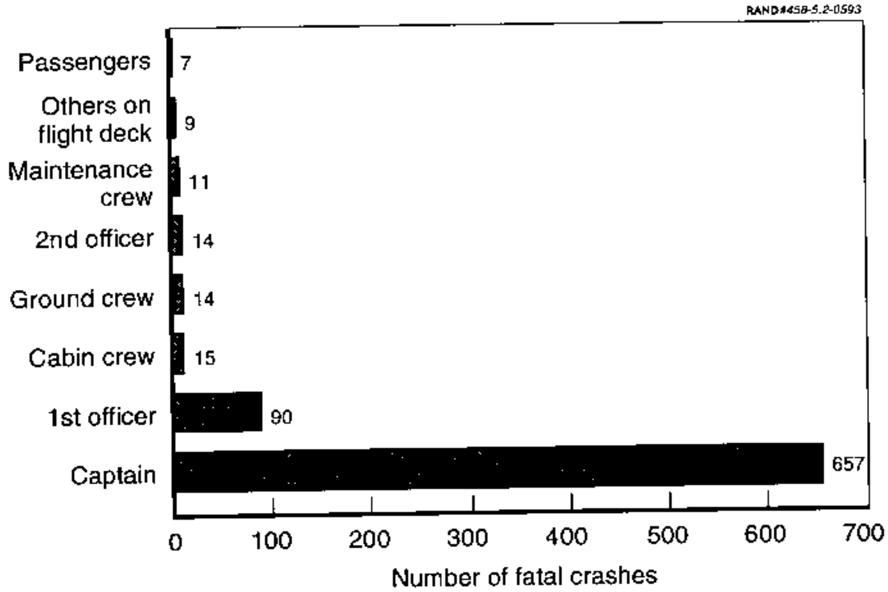
[2]Each event may involve more than one group of personnel. Hence the sum of these items may be more than the total number of accidents of this type. The information in Figure 5.2 is drawn primarily from Douglas Aircraft (1991), op. cit., and Boeing Aircraft (1991), op. cit.



SOURCES: *Commercial Jet Transport Safety Statistics*, Douglas Aircraft Safety Data Office, Flight Standards and Safety Group, Long Beach, California, 1991 (Douglas Aircraft, 1991). The information is also contained in *Statistical Summary of Commercial Jet Aircraft Accidents, Worldwide Operations, 1959-1991*, Commercial Airplane Group, Boeing Aircraft, Seattle, Washington, 1991 (Boeing Aircraft, 1991); *Annual Review of Aircraft Accident Data, U.S. Air Carrier Operations, Calendar Year 1986*, National Transportation Safety Board, Washington, D.C., February 1989; and *Annual Review of Aircraft Accident Data, U.S. Air Carrier Operations, Calendar Year 1989*, National Transportation Safety Board, Washington, D.C., February 1992.

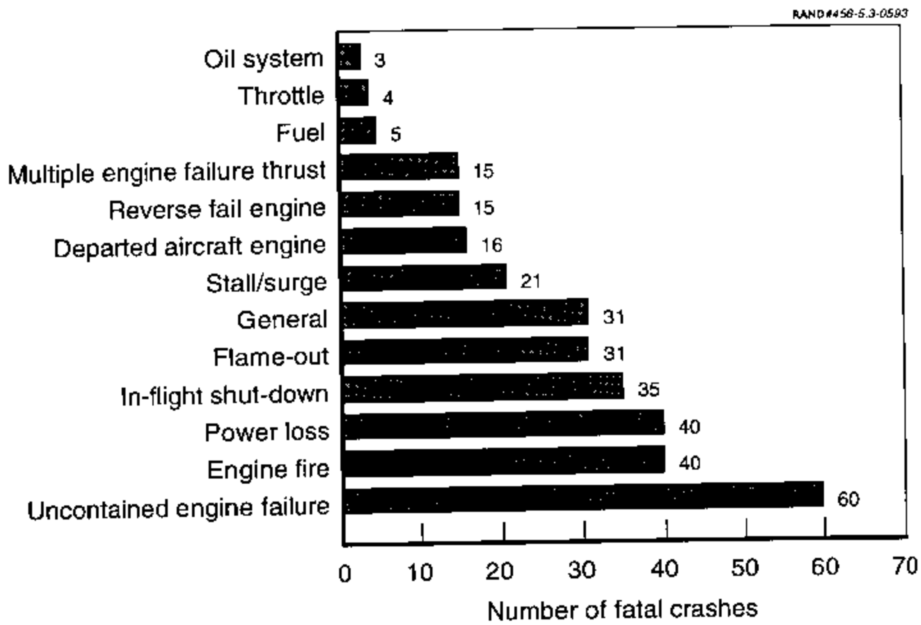
Figure 5.2—Causes of All Fatal Accidents Where Personnel Were Either the Primary or Secondary Cause

The implication for our study is that detection of mechanical or maintenance problems early and quality assurance of maintenance procedures could help assure a safer industry. Further, assurance must be provided that all aircraft meet a specified minimum standard for quality assurance of maintenance and mechanical integrity.

Weather accounts for a small percentage of all fatal crashes. And, weather patterns are specific to geographic regions. Figure 5.4 illustrates the relationship of weather-related fatal crashes by type of problem for worldwide data.

Although weather cannot be controlled, the decision to fly in particular types of weather and the ability to detect, in real time, particular weather patterns, could have a positive effect on safety.

Weather patterns at Schiphol are not typical of worldwide weather patterns. Schiphol has more foggy days—on the average—than many other airports. Yet, Schiphol is rarely closed because of bad weather. In some cases, aircraft without CAT II or CAT III landing systems will, because of fog, divert to other airports. Figure 5.5 reports on the frequency of fog (days per year at visibilities of less than 100 meters, less than 200 meters, and less than 1000 meters) at Schiphol.



SOURCES: Douglas Aircraft (1991), op. cit. See also Douglas Aircraft (1991), op. cit.; Boeing Aircraft (1991), op. cit.; NTSB (February 1989), op. cit.; and NTSB (February 1992), op. cit.

Figure 5.3—Causes of All Engine-Related Accidents

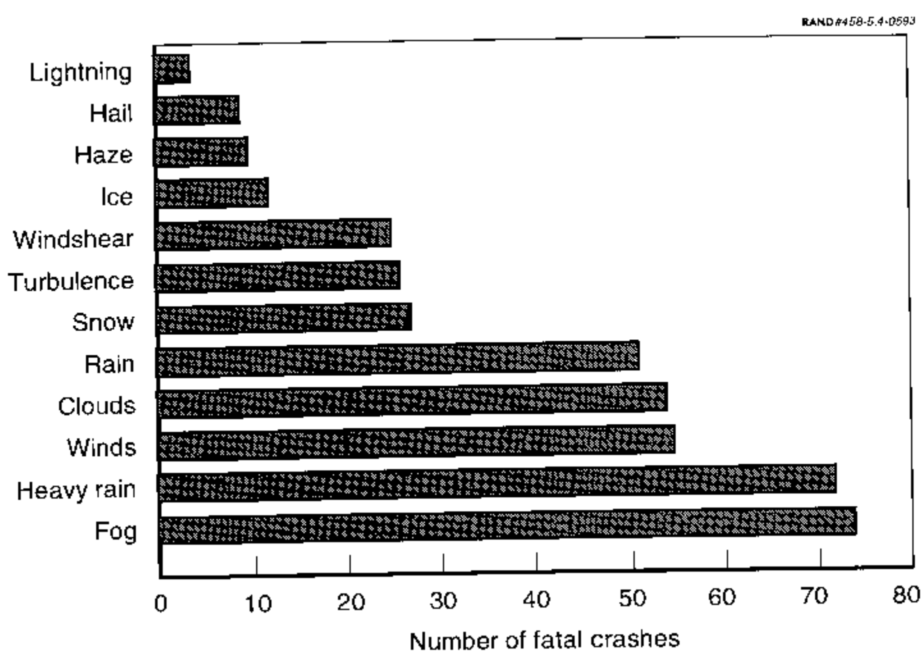
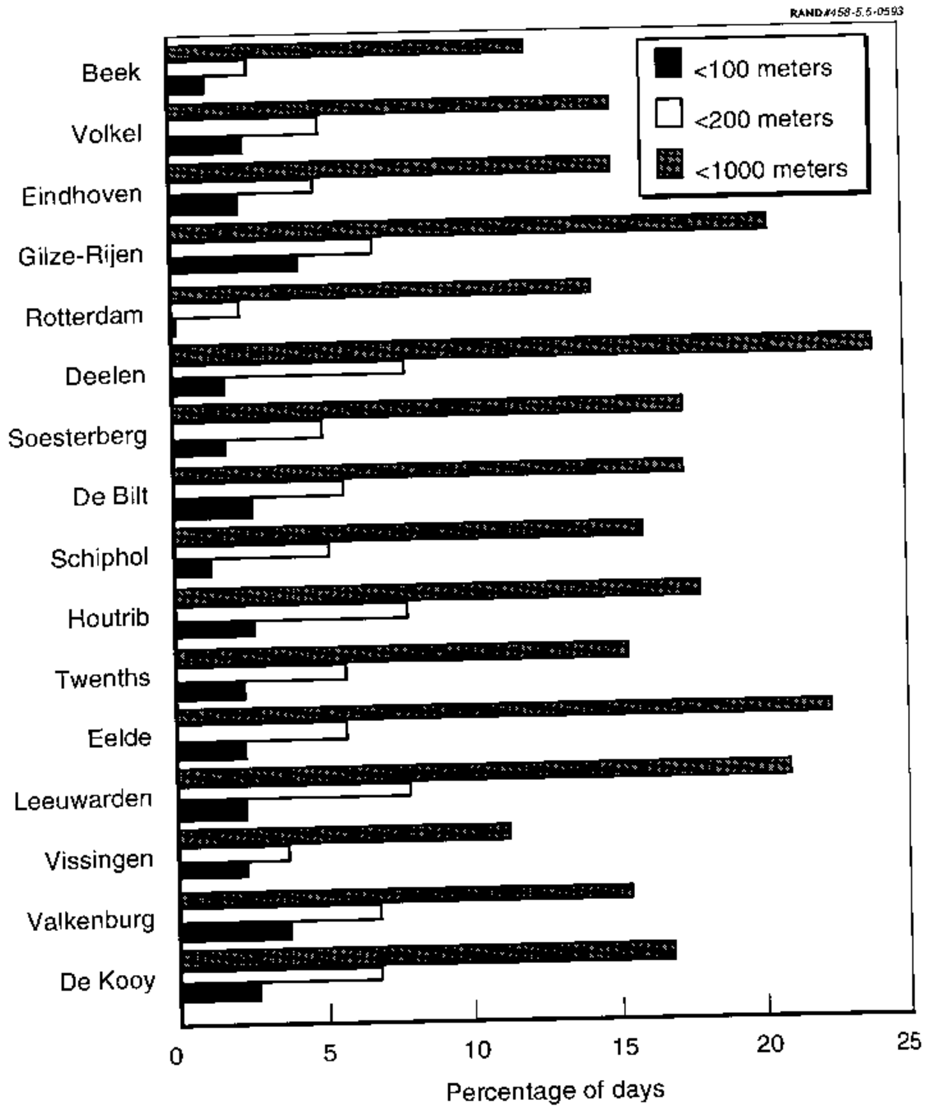


Figure 5.4—Weather as a Factor in Worldwide Commercial Jet Crashes



SOURCE: Jos Nollet, Schiphol Airport, via FAX dated April 6, 1993.

Figure 5.5—Percentage of Days at Schiphol and Elsewhere When Fog Reduces Visibility to Under 100 Meters, Under 200 Meters, and Under 1000 Meters

Worldwide *terrorism* has accounted for 33 known fatal accidents.[3] Of those 33 fatal events, several have involved loss of some of the crew and/or passengers. Of those known terrorist activities, none have caused a third-party risk to populations within a few kilometers of the departure or arrival airport. And, none of these have been known to occur at Schiphol. Figure 5.6 compares the number of fatal incidents caused by hostile activity by year from 1959 through 1991.

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[3]Douglas Aircraft (1991), op. cit.; and Boeing Aircraft (1991), op. cit.

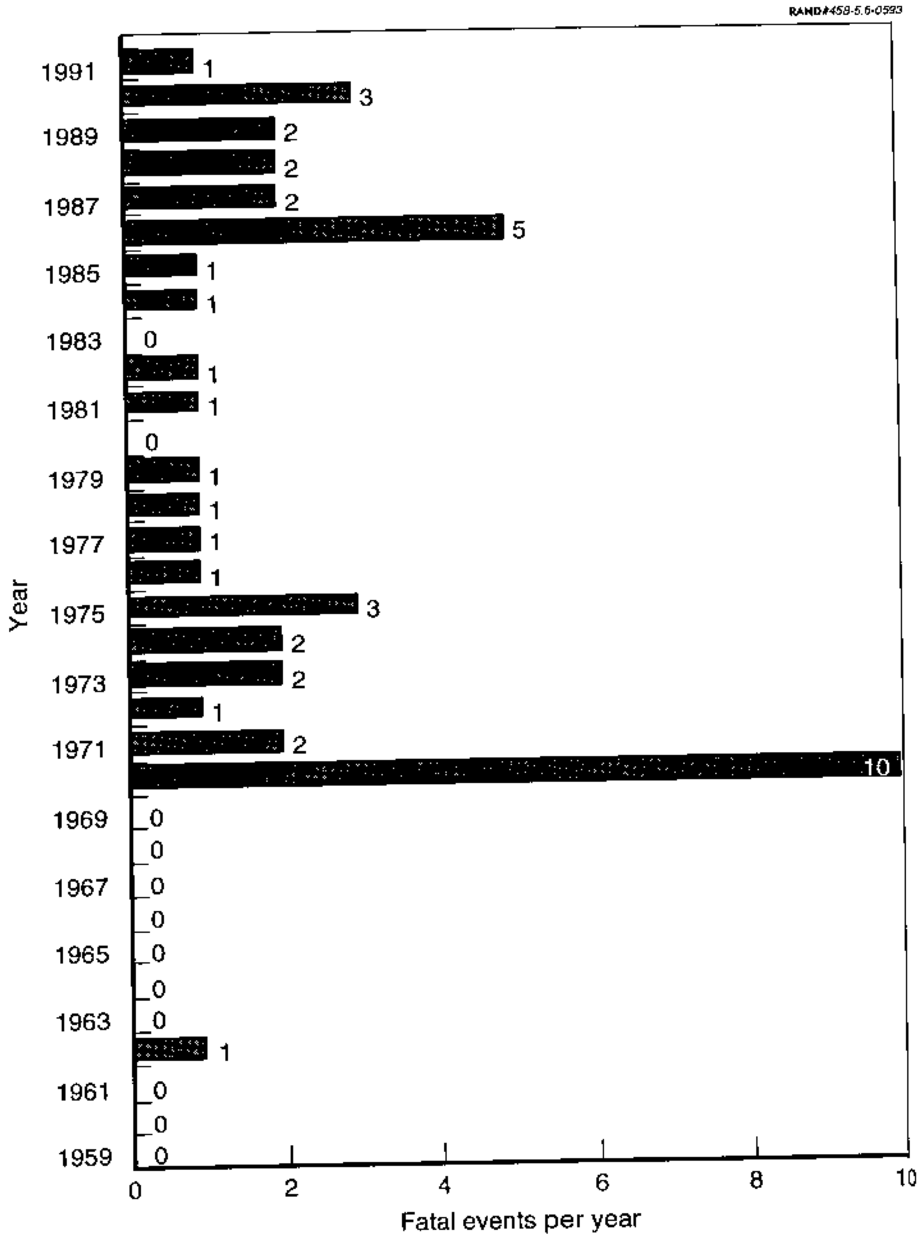

Figure 5.6—Number of Fatal Events from Known Hostile Activity Involving Free World Commercial Jet Transport Aircraft from 1959 to 1991

Means to counter the likelihood and mitigate the consequence of terrorism are treated effectively at Schiphol as discussed in Chapter Three.

The potential for *bird strikes* presents a unique problem to Schiphol. Schiphol has a significant bird population because it is along a migrating path for several bird species. Strict bird control is very important at Schiphol, especially as the number of operations increase. And, dealing with birds at Schiphol presents a challenging problem. Measures such as bird patrols to locate birds and bird calls and loud noises to frighten and divert birds away from active runways are currently in place at Schiphol and are reported as effective. More extreme measures such as shooting or poisoning birds are considered environmentally unacceptable.

Of 504 commercial jet airline fatal collision accidents reviewed from 1958 to 1991, at least six involved collisions with birds, and none were at Schiphol. Schiphol has reported a number of incidents, however, not leading to hull loss accidents resulting from suspected collisions with birds. Bird control will continue to be a high-priority safety item at Schiphol.

Not all *phases of an aircraft's flight* are equally safe.[4] An average commercial aircraft spends nearly 65 percent of its time in cruise phase, and yet less than 8 percent of all fatal accidents and less than 5 percent of all hull loss accidents happen during cruise. However, the takeoff, initial climb, approach, and touchdown phases of operation together amount to less than 20 percent of flight time and account for more than 65 percent of the fatal crashes and more than 65 percent of all hull loss crashes. About two-thirds of the fatal and hull loss accidents occur within the vicinity of the airport (see Figure 5.7).[5]

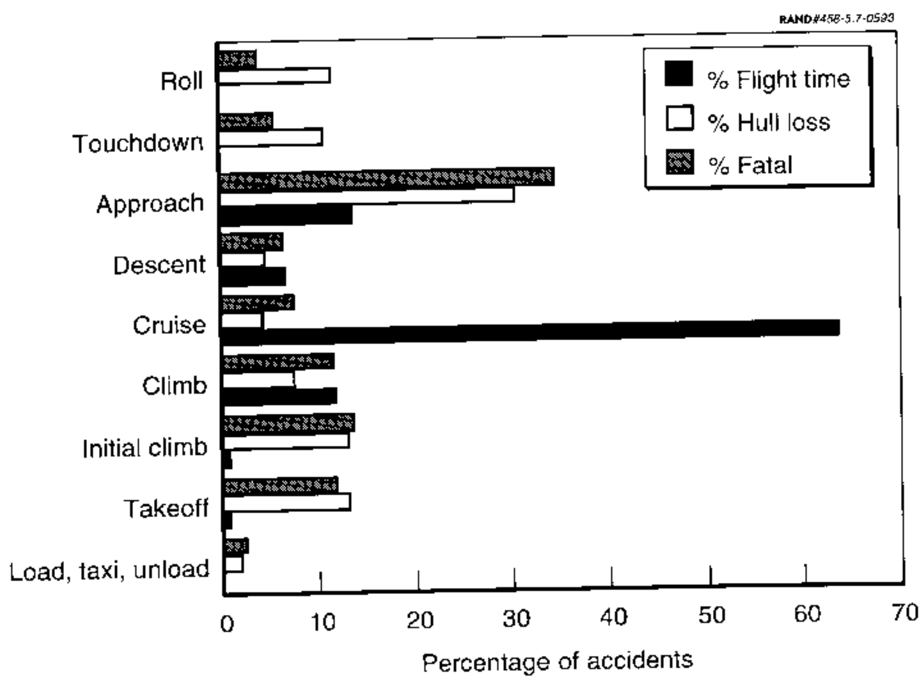

Figure 5.7—Flight Phase of Most Hull Loss Accidents

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[4]There is a problem with defining "phase of operation" during an accident. An aircraft that has just taken off, finds itself in trouble, and decides to land is basically in two phases of flight—takeoff and landing. For this discussion, an aircraft just taking off and immediately returning to land is defined as a takeoff accident (this is how takeoff and landing accidents are traditionally defined).

[5]Extracted primarily from the Boeing database and confirmed elsewhere.

The implication of this information is that safety enhancement measures more directly related to landing and takeoff have the promise of mitigating a larger number of potential accidents.

Third-Party Casualties and Mitigating Factors

Worldwide, the number of third-party fatalities (i.e., ground population fatalities outside of the airport) from commercial jet airline crashes averaged about 40 people per year from 1970 through 1992.[6] Of those 40 expected fatalities per year worldwide, most are expected within 10 kilometers of the airport and would be considered as involuntary exposures to the crash risk (see Figure 5.8). By comparison, non-pedestrian automotive fatalities would be considered voluntary risk exposures and would affect populations near and far from airports. More than 200,000 people die worldwide per year as a result of automobile crashes (about 20 percent of these are pedestrians or third-party risks).

In making these comparisons, we need to caution that not all people at third-party risk are at equivalent risk. People living closer to the airport are at greater risk than their counterparts living farther away.

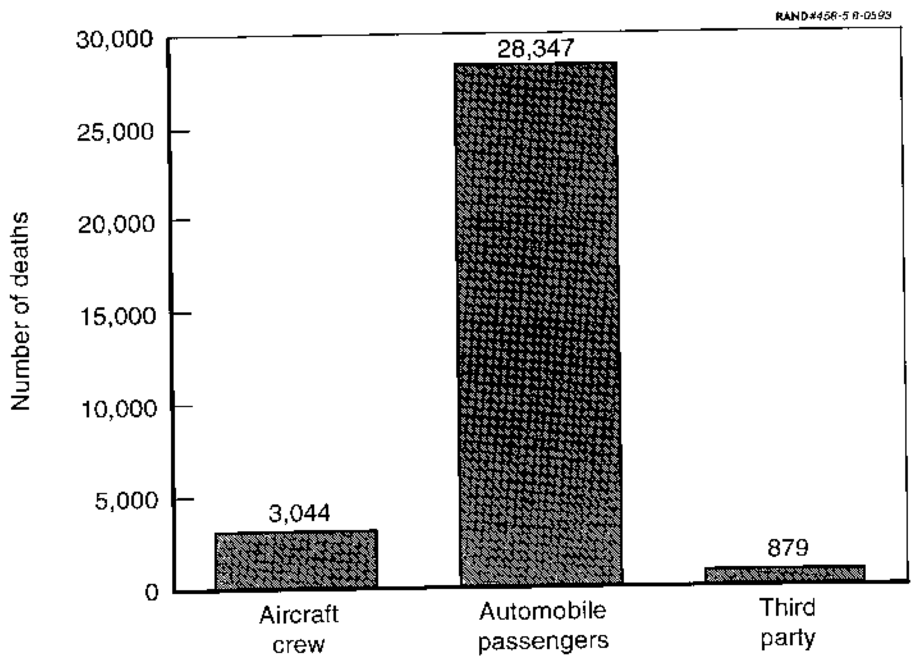

Figure 5.8—A Comparison of Crew, Passenger, and Third-Party Risks from Commercial Jets from 1970 to 1992

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[6]Third-party fatalities have been compiled from 550 commercial jet airline accidents worldwide. These data are condensed from information supplied by a database compiled and maintained by the Commercial Airline Group of Boeing Aircraft, Seattle, Washington.

Accident Trends and Implications of Various Other Factors[7]

As shown in Figure 5.9, aviation safety has increased over time. This increase results largely from improvements in aircraft capabilities and in air traffic control technologies and better understanding of human factors. We now discuss the implications of these two areas in terms of future safety.

Newer and Larger Aircraft. Over time, newer, more modern aircraft will appear in the skies, as will larger aircraft. These changes will, in turn, influence third-party safety.

As depicted in Figure 5.10, statistics suggest that after their initial, introductory period, newer aircraft have a lower accident rate than older aircraft. This lower rate happens primarily because older aircraft often lack newer, safer equipment; they are often maintained less well because they are operated by airlines that face financial constraints; and they may operate more frequently in a more hostile environment.[8]

Many of today's older aircraft will be phased out over time as they wear out or become unprofitable to keep.[9] Thus, the fleet will become relatively more sophisti-

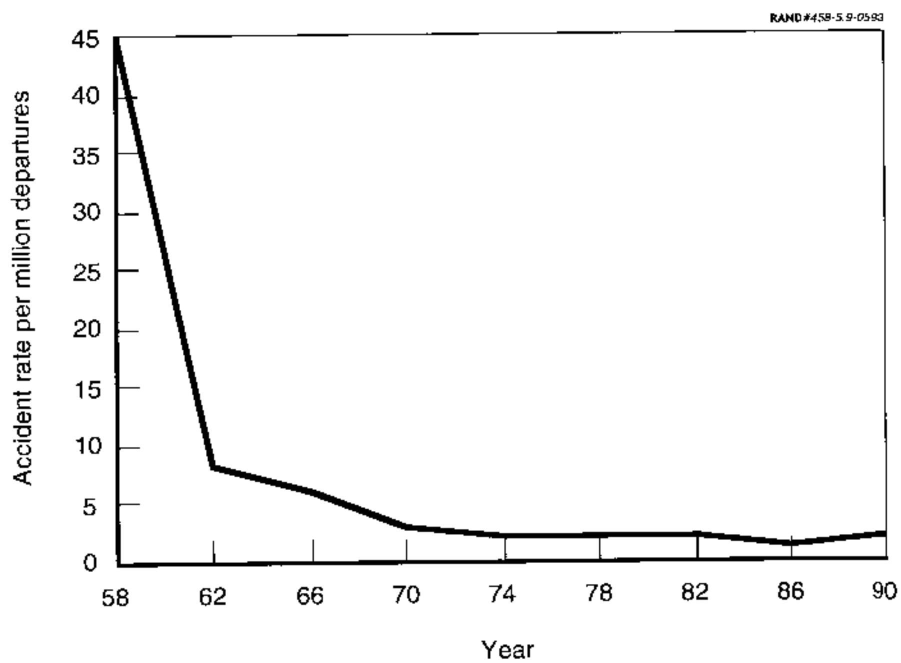

Figure 5.9—Accident Trends over Time

[7]Information contained in this section comes from largely from data and discussions with Boeing and Douglas.

[8]An example of a more hostile environment would be operating an older aircraft in a third-world country without adequate navigation and landing aids.

[9]Noise is a major factor and will prompt the phaseout of older aircraft by the year 2000 and beyond. Operators will necessarily have to pay for the substantial upgrades to quiet older aircraft (known as "Stage II" aircraft), or will have to replace them with newer aircraft to meet the quieter, Stage III noise standards to take effect in the year 2000. The list of older, Stage II aircraft includes versions of the Boeing 707, 727, 737 and 747, versions of the Douglas DC-8 and DC-9, and virtually all Eastern aircraft.

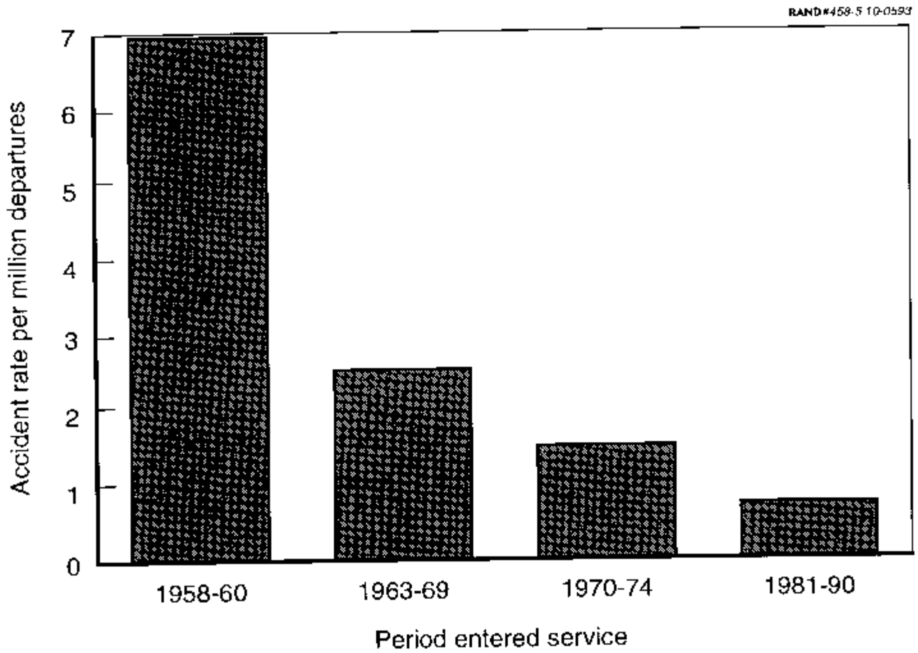

Figure 5.10—Accident Rates by Aircraft Generation (data averaged over 1959 through 1991)

cated in the future in terms of equipment. Although the mix of newer and older aircraft may not change significantly in relative terms, risk to third parties should decrease because the older aircraft in the future will have the better, safer equipment of today. Although there is no assurance that financially constrained operators will maintain these aircraft better, the fact that they will have better equipment—which can normally be expected to be operative—will mean that they will likely be safer. Summed up, as a natural consequence of evolution, aircraft should be safer with time.[10]

Also, even larger aircraft will exist in the future, some of which may carry upwards of 700 passengers.[11] This increase in passenger capacity could mean, in turn, that the number of overall takeoffs and landings will decrease (or increase at a lower rate) because fewer flights will carry more passengers.[12] Commensurately, risk to third-parties will not increase in proportion to the passengers carried. The extent to which this reduced risk component might be offset by the larger aircraft size, and hence larger, explosive fuel loads, is discussed in Chapter Six.

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[10]Because new technologies may be difficult to master by crews from less sophisticated nations, the potential exists that technological advances could increase accident rates in some instances. We doubt, however, that the overall safety trend would be reversed.

[11]These aircraft are in the preliminary design stages and therefore the exact payloads in terms of passengers are uncertain.

[12]Schiphol officials estimate that these large aircraft will constitute 5 percent of the traffic at Schiphol, or approximately 59 daily operations. See *Statistical Annual Review 1991*, Schiphol Airport Authority, pp. 26-27.

New Air Traffic Control Technologies. New technologies are also making Air Traffic Control services better, and should have an overall positive influence on safety. Third-party risks should therefore improve as these technologies are implemented in the future.

For example, newer precision landing techniques are being developed that will replace the current Instrument Landing System and improve safety. Microwave Landing Systems (MLS) and Differential Global Positioning System (Differential GPS) are two systems either employed in test configurations or planned in the future. Which is the better is yet to be determined but whichever is selected will be found at Schiphol in the future and, thus, less risk will accrue because of false ILS beams.

Many other ATC improvements are under way. Without identifying their characteristics explicitly, they include Mode S (digital) communications, Precision Monitoring Systems, integrated GPS/data link systems, and the like. All are designed to make aviation safer and, with the passage of time, should make the system even better able to cope with future problems.[13]

Third-World/East European Aircraft and Operators. Available accident data show that some third-world airlines and some airlines using East European aircraft have an accident rate at least twice that of Western airlines and Western aircraft.[14] The difference may be even higher because the accident report data from these "bad actors" may be inaccurate and incomplete.

Schiphol is already exposed to the risk imposed by some of these operators. As Schiphol grows to an even larger capacity, this risk, unless somehow offset, will also increase. But how likely is it that such offsets would occur? The future is particularly murky in this area but several rays of light do appear that may serve to reduce the accidents caused by risky airlines.

First, the United States and Canada already have efforts underway to identify and to bring pressure upon countries who have airlines in this category. The goal is to have these countries increase their certification and inspection standards such that their risky airlines correct their problems (see the discussion of the approach the United States is taking in Chapter Three).

The exposure and visibility of these activities should benefit Schiphol in the future. Simply, the activities should not only influence airlines that operate in the United States and Canada, but the exposure will also likely cause other operators, some of whom operate into Schiphol, to improve also lest they too be targeted.

Second, such risky airlines are steadily transitioning to newer, Western aircraft with safer overall operating characteristics. Thus, a byproduct of this transition will likely be increased safety.

In spite of the foregoing positive factors, the reality remains that there is no assurance that all risky airlines and countries will improve their safety records. Commensurately, it may ultimately be necessary to explicitly ban them from

[13]There is a concern that overreliance on technology can induce risk because pilots and ATC personnel may be less trained or vigilant whenever an equipment failure should occur. Or, in the case of automated equipment, occurrences that had not been foreseen could happen, thus leaving the individual otherwise unprepared and again increasing risk.

[14]This is based on our analysis of the data reported in "1992 Statistics Released on Accidents, Fatalities, and Accident Rates for U.S. Aviation," *Flight Safety Digest*, February 1993, pp. 9-12.

Schiphol until their records improve. Before this could be done, however, it would be necessary to establish procedures and methods to collect data that conclusively proved that an airline was operating dangerously. To do otherwise could expose Schiphol and Dutch authorities to international repercussions. A study of the appropriate procedures and methods that might be employed falls beyond the scope of this study. Some interesting methods would include reviews of incident reports across airports to identify risky airlines and the use of surface radars and to identify and record unusual deviations from glide path and course. Another approach would require all operators to declare operating minima for their fleets and to inform airlines and their national authorities of any "infringements;" repeated infringements would result in the operator being banned.

General Aviation at an Airport. General aviation aircraft are those aircraft that, as a rough measure, do not engage in operations for hire. This category generally includes private and corporate aircraft.[15]

General aviation aircraft have an accident rate as much as 20 times higher (in the United States) than for commercial operations.[16] Therefore, even though their activity is relatively small at Schiphol, their risk influence is probably not insignificant.

Although it is conceivably possible to reduce the accident rates for general aviation by tightening licensing and maintenance standards to those of commercial operations, this option appears but marginally palatable. The cost would not only be excessively high to general aviation operators, so also would be the perceptions of intrusions into accepted, personal freedoms. Although general aviation flyers crash more, the results are usually less spectacular and the second- and third-party consequences less severe than when a commercial aircraft crashes.

Schiphol's most obvious solution to reducing its exposure to general aviation is to create incentives for these operations to move elsewhere.[17] A combination of landing fee increases and the construction of alternative facilities could serve well in this respect. We understand Schiphol authorities are implementing both of these.

SAFETY ENHANCEMENTS IMPLIED BY WORLDWIDE DATA

The preceding subsections of this chapter reviewed worldwide accident data, addressed the implications of these data relative to Schiphol, and identified the trends and relative importance of various causes of aircraft accidents. These have implications for the relative benefits of various types of safety-enhancement measures. For example, accidents during the approach and landing phase of flight have accounted for 40-50 percent of the hull loss accidents, thus safety enhancements that reduce the accident rate during this part of the flight profile should carry more weight. Aircrew error has been implicated in 60-70 percent of accidents, indicating that this is also an important cause to mitigate. On the other hand, airports and air traffic control were listed as causes in only about 5 percent of the accidents. Thus, safety enhancements associated with the airport or ATC must indirectly reduce risks resulting from other

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[15]The definition of general aviation aircraft differs between countries and thus a more generic, inexact definition is used here to compensate for these differences.

[16]*Flight Safety Digest*, February 1993, pp. 9-12. Although we did not have European statistics on general aviation, there are some arguments that it is safer in Western Europe because of stricter controls. However, in the United Kingdom, the accident rate is as high or higher than in the United States.

[17]This does not necessarily reduce the risk; it transfers the risk away from Schiphol to elsewhere.

predominant causes (controlling the users of the airport, reducing the chance of aircrew error by providing landing aids, etc.).

Although the accident statistics suggest that accident rate is important, this is not the complete story because the predicted frequency of accidents at an airport is also based on the volume of use. Thus, even though general aviation has a significantly higher historical crash rate, if the number of general aviation operations at an airport is small then the expected risk is low. A similar argument applies to "risky" carriers in which the volume is small.

It should also be noted that many aspects of the worldwide accident data may not be applicable to a particular airport such as Schiphol, or to a particular region such as Western Europe. We have already noted that the accident rate for general aviation, drawn from U.S. statistics, may not be as high in Western Europe because of generally stricter controls. Certain weather-related accidents in the database are not likely to have occurred at Schiphol, etc. Thus, for these reasons also, the relative importance of various measures can be overemphasized by looking at worldwide accident data.[18]

In the remainder of this chapter we describe a number of safety-enhancement measures categorized by the various causal factors. We make no attempt to present an exhaustive list; rather, we mention only some of the possibilities in each of a number of areas. In some cases, the costs of such enhancements probably outweigh the benefits. In other cases the possible enhancements require considerable additional research and may not be available until long into the future, if ever. Many possible enhancements have known or unknown side effects that must be considered and mitigated before adoption. And some of the enhancements we mention are already available at Schiphol or on most airlines operating at Schiphol but are listed for completeness.

Finally, a note of caution in assessing the possible cumulative effects of enhancements. This discussion addresses the safety contribution of the measures on an individual basis. These assessments are made as if the influence of an individual measure were totally dissociated from the influence of any other enhancement or combination thereof. Because of this dissociation, and because no one individual measure had an influence that applied across each of the accidents we assessed, the results associated with these individual enhancements may differ from particular aggregated packages of measures such as those discussed in Chapter Six.

Notwithstanding this caveat, it is nonetheless useful to look at individual measures in terms of their safety contributions and in terms of the insights this glimpse provides. In fact, it is from these insights that one can assemble coherent strategies. In examining these measures, we should also be mindful of the fact that, although many of them could be quantitatively assessed in terms of their influence on third-party safety, many others can be only qualitatively assessed (such as the proposed changes in safety management suggested in Chapter Three).

Listed below are measures within each of eight categories. These categories generally correspond to the major causes of accidents as depicted earlier in this chapter. The measures are not provided here as recommendations for change at Schiphol;

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[18]On the other hand, it would not be correct to consider only the accidents that actually occurred in Western Europe, or just at Schiphol. The statistics drawn from such a limited sample would be even more misleading regarding frequency and causes.

rather, they provide insights into the possibilities (and lack thereof) for mitigating these major causes.

Measures to Reduce Crew Error

Crew error is a major cause of crashes. Measures that would mitigate the human element would therefore likely have a substantial payoff. We look at a few of these.

Cockpit Resource Management. Cockpit Resource Management (CRM) programs attempt to eliminate the consequences of individual pilot errors by training cockpit crews to work together as a team focused upon accident prevention rather than as an assemblage of individual participants. Under CRM, crews are trained and evaluated as integrated entities; in fact, under some CRM programs, if one crew member fails to pass a check flight, the entire crew fails.

Many of the sources we interviewed believe that CRM will have a positive influence on safety. We agree. Our assessment revealed that CRM programs would have reduced the likelihood of 43 percent of the accidents we examined.[19]

CRM has both pros and cons. In respect to the former, it does appear to enhance safety through increased participation and teamwork in the cockpit. On the other hand, CRM could diffuse perceptions of responsibility and authority in the cockpit if safety is compromised; i.e., a committee cannot fly an airplane.

CRM is already practiced by Dutch airlines. Therefore, this measure is applicable to Schiphol mainly in the sense that authorities there encourage CRM programs on an international basis. If practiced by all carriers using Schiphol, it could reduce third-party risk. It would be relatively easy for the government to make CRM mandatory for all Dutch airlines and to support an ICAO initiative that makes this a required part of professional crew training.

Encourage Increased International Standards. Under this measure, international organizations would be lobbied to bring pilots and maintenance personnel of all cul-

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[19]In what appears to be a unique approach, we evaluated 114 individual aircraft hull losses to assess whether or not the Safety Enhancement Measures (SEMs) identified in this study—had they been implemented at the time of each accident—would have mitigated, or averted, each accident. This helped us to identify the effectiveness of these SEMs, both individually and in packages.

The 114 individual cases represented losses that occurred from 1987 through 1991 and that were judged applicable to Schiphol. This five-year period was chosen because it was both a recent period for which adequate, published data were available and a period in which the overall loss rates were reasonably constant.

Basically, three members of the RAND staff (two pilots and a nonpilot, the latter with an extensive background in aviation risk assessment) evaluated the 114 accidents in terms of their causes and SEM effects. A larger group would have provided better results in a statistical sense, but time and resources constrained the effort. The group members generally agreed in their individual, independent assessments, and therefore we felt that this evaluation contributes significantly in terms of the insights provided if not in a true statistical sense.

Each of the individual 114 hull loss accidents was examined by the three-man group and evaluated as to whether or not each SEM, if in place, would have mitigated the accident. A score was assigned to each accident and SEM and reflected the assessed likelihood that the accident would not have occurred had that SEM been in place. In other words, the assessment rated the safety-enhancement likelihood. In this manner, a somewhat-more-than-subjective assessment was derived relative to the accident risk reduction that might occur were that measure adopted.

In a second session, this team also performed a similar evaluation of the SEMs relative to the accidents, but did so in respect to some aggregate strategies addressed in Chapter Six.

tures and nations to an increased awareness in respect to aviation safety. This, it is felt, would remove a lingering barrier to aviation safety. The proposal would incorporate measures to identify "bad actors" and encourage international bodies (i.e., ICAO) to address the problem.

The negative effect that might result from this could be in the form of reprisals against Dutch airlines should Schiphol and Dutch authorities pursue this too aggressively without international support of some type.

Exterior Viewing Systems in the Cockpit. Accidents could have been avoided had pilots been able to observe the external configuration of their aircraft. For example, engines have been physically lost from aircraft without explicit knowledge by the pilot. Rather, the crew believed an engine failure had occurred and took actions upon that belief and, in doing so, may have caused a crash.

This measure (affecting 9 percent of the accidents examined) would reduce the potential for such an accident by providing the crew with an external image of the aircraft on a monitor in the cockpit. This imagery could be obtained from either an imaging infrared device or a television camera mounted on wing tips looking inward or toward the tail. Because of its ability to detect hot brakes, compartment "hot spots," etc., in both day and night, the infrared system was identified as better than a television system. It could potentially reduce takeoff/landing *and* icing accidents.

Several organizations, including British Airways, are experimenting with exterior viewing systems. Thus, the full viability and payoff are yet uncertain. If viable, the contribution to safety could be positive. Costs to carriers, on the other hand, could be high.

Develop an Intelligent System to Monitor Aircraft Flight Phase Configuration. This would require the development of "smart aircraft" in the sense that GPS, digital maps, etc., would be employed to let an aircraft "know" where it was and what it should be doing. Such, for example, would reduce the likelihood of flap-up takeoffs, because the aircraft would know it was on an active runway.

Approximately 12 percent of the accidents evaluated would have been influenced had this capability been available at the time. The negative aspects reside in the likelihood that no one software program could adequately encompass all of the variables in aviation. Thus, the problem with false positives and false negatives again arises.

This measure, recognizably, is one at the far reaches of technology. There is no program underway to provide this capability on aircraft.

Preventing Landing Accidents

Landing accidents, as shown earlier, constitute as many as half of all hull losses. The following are measures that might mitigate these.

Mandate Coupled Approaches. Approximately 26 percent of the accidents we assessed happened because the aircraft landed short of the runway, long on the runway, or on the wrong runway. This measure would eliminate many such accidents by requiring all landing approaches be coupled, or automated, into the autopilot. Such is well within the capacity of modern technology and is used routinely when visibility is restricted.

The positive effects of this measure, and especially because of the populated areas near Schiphol, are obvious. Schiphol presently does not mandate coupled approaches and there are no plans to require them.

This measure has, however, an important negative side-effect, namely, that pilots might become less proficient in manual landings. As such, safety could be jeopardized whenever a system failure occurred that would require a manual landing. Thus, before mandated coupled landings could be required it would be necessary to assure that pilots maintained proficiency in manual landings by some means—such as extra training flights and simulators.

Implement Low-Altitude Warning System in ATC Computers. Approximately 13 percent of the accidents assessed might have been averted had this measure been in place. In this case, a ground radar system is equipped to identify when an airplane is flying too low in any one area. The concept is that the radar controller, once alerted by automated software, would warn a pilot of a low-altitude transgression before the situation became dire.

The potential for false alarms poses a real, negative ingredient in regard to this measure, because frequent false alarms lead to a tendency to ignore the warning. Ideally, technologies will advance such that the potential for false alarms becomes minuscule.

Schiphol air traffic control currently has no low-altitude warning system installed in its traffic control radars. If installed, and if the false alarm problem were conquered, the effect would be to lower the potential for crashes along the approach paths.

Encourage Ground Proximity Warning Systems Use or Improvement. In this assessment of accident data we judged that approximately 10 percent of the accidents assessed might have been averted if in-cockpit Ground Proximity Warning Systems (GPWS) had been in use, or not ignored. GPWS is an altitude and aircraft vector sensing system that attempts to warn that an aircraft is about to crash into terrain. In that case, it provides warnings to the cockpit.

Although GPWS can avert crashes, one persistent problem with it has been a high false alarm rate. These, in turn, have desensitized pilots to its warnings and may have caused crashes as a result. Crashes into terrain have occurred because pilots, responding to the negative influences of false alarms, simply did not activate their GPWS system. Later versions of GPWS, however, have much lower false alarm rates and are considered effective "preventers" of accidents.

GPWS is used by Dutch airlines. It is also mandatory on international commercial flights and therefore such aircraft visiting Schiphol should have it. However, enforcement of mandatory *use* of it is likely to be difficult. The Netherlands should support the earliest possible introduction of latest-generation GPWS in all classes of aircraft through its participation in ICAO and the JAA.

Improvements for Low-Visibility Operations

A contributing factor in many of the crashes examined was the influence of low visibility during landing. Fog and heavy rain have been a primary weather contributor to worldwide accidents.

Because they could not see their path forward, pilots have landed both short and long of the runway, have landed on the wrong runway, and have hit vehicles on the runway. In the distant future, low-visibility radar and infrared imagery may be used to help the pilot "see" the runway during low-visibility approaches and taxiing, but there are no foreseeable plans to install such technology on commercial airlines. At Schiphol the landing aids are judged by some to be so good that instrument landings (which are needed in low visibility conditions) are considered safer than visual landings, so it is not obvious that improvements for non-CTA landings will improve safety.

Preventing Maintenance-Related Accidents

Approximately 15 percent of all hull losses have occurred because of aircraft failures or maintenance deficiencies. These measures address these problems.

Technologies to Contain Catastrophic Engine Failures. Uncontained engine failure is the leading cause of mechanical failures causing crashes. There is continued research to limit the secondary effects of catastrophic jet engine failures. Such failures, when they occur, are often explosive and emit a large volume of high-velocity fragments.

We determined that approximately 5 percent of the accidents examined would have been mitigated by success in this area. The negative aspects are the significant weight increase that would likely be needed to effectively encase an engine. Also, no one, universal shroud has been found that could contain all different types of engine failures. Technologies of this nature have been sought but none have been successful.

Increased International Standards for Maintenance. The earlier discussions about increasing the awareness and concern for safety of pilots and aircrews of all cultures and nations applies as well to maintenance standards for all operations.

Removing High-Risk Aircraft

Two categories of aircraft pose the highest risk to third parties near Schiphol, general aviation and risky carriers. Thus two measures are to address the removal of these aircraft from operations at Schiphol. However, these are discussed elsewhere and will not be repeated here.

Noisier aircraft tend to be older aircraft and, as identified in Figure 5.10, these aircraft are as much as four times riskier than the latest generation transports. Prohibiting noisy aircraft would thus increase safety. The plan within Europe to ban noisy aircraft would remove them from Schiphol by the year 2003 or earlier.

Mitigating Emergencies

Even if all of the foregoing measures were implemented, it is likely that airborne emergencies would continue to occur. These measures might be undertaken to reduce the consequences of emergencies.

Develop an Integrated Action Program for Emergencies. Within this measure, airport authorities would develop programs to train controllers, flight crews, and airport personnel in an integrated response to emergency situations. Simulated emergency scenarios would be used to identify procedural problems and to establish revised practices.

This does not currently exist at Schiphol.

Develop Alternative Landing Locations for Distressed Aircraft. It has been suggested that airports establish procedures to divert distressed aircraft—with the pilot's concurrence—to specially prepared airdromes in less-populated areas when feasible, and when the situation permits. Facilities would be provided at these airdromes to accommodate passenger needs and medical problems. This would not be a mandatory procedure but, rather, an optional one.

The negative aspects of this measure appear to outweigh any benefits. These include:

- Aircraft might crash after having overflown viable landing sites en route to the diversion airdrome.
- Passenger handling could become awkward, especially for large aircraft.
- Risk will be shifted to the populace near the alternative landing site.
- Considerable expense would be involved in maintaining full facilities and a 24-hour emergency response capability on a continual basis.

It is likely that in most cases the airport of preference is the primary and not the alternative airport. Schiphol has the best emergency facilities of airports in The Netherlands.

Eliminating Wildlife Effects

A number of aviation accidents have occurred because an airliner has collided with wildlife. Birds constitute the most common source of collisions and the only serious wildlife concern at Schiphol.

Approximately 2 percent of the accidents examined would have been averted by methods of bird control. Currently, Schiphol has an exemplary program of bird control as discussed in Chapter Three. As traffic volume increases at Schiphol, however, it will be important to continuously review the effectiveness of this program because the large bird population could increase the frequency of bird strikes.

Reducing Crash Footprint and Mortality

One way to reduce third-party risk is to minimize the number of people *actually* exposed to crashes. This could be accomplished by either employing barriers (such as trees) between the path of a crashing aircraft and each structure containing a high density of people in a high risk area or by enforcing population-free zones or safety zones in areas subject to high crash likelihoods.

Barriers. To estimate the effect of employing zone barriers for high-risk population zones, the technique is to first identify the high-risk zones. For this discussion, they are defined as those zones that place populations at fatal risk with probabilities greater than one in 10,000 per year. The purpose of a barrier is to minimize the skid area resulting from a crash in front of a structure. Common barriers might be trees.

The total impact area is made up of three components: the skid area, the base area, and the shadow area. Eliminating or reducing the size of the skid area could reduce the impact area (and consequently the expected number of fatalities in the areas impacted) by up to 30 percent.[20] The effect of this result is very airport-specific.

The use of barriers is not without some costs and some difficulties. Even if trees are used, the cost of purchasing, transporting, planting, and maintaining the trees must be considered. Often a larger cost is the opportunity cost for the land being displaced by trees, and land area may not always be suitable for tree planting.

Many, if not essentially all, high-risk population zones around Schiphol are already shielded by other buildings and large structures. The addition of new barriers such as trees may not provide substantial reductions in impact areas due to reduced skid areas. As such, each individual high-risk population zone must be assessed carefully as to the relative risks and benefits of adding a barrier.

Other barriers such as stone walls may be far less attractive and far more obtrusive than trees.

Public Zoning Restrictions. A public safety zone is defined as a geographic region (typically at the end of each runway) where people are not permitted to live or work. Public safety zones reduce risks more than barriers for any specific area, but public safety zones would be more difficult to implement than barriers, since these zones would require that people move from designated areas. Again, the effect is very airport-specific.

Restricting the construction of new buildings but permitting existing buildings to stand reduces the risk less than moving everybody out. Additional population could be restricted from moving into the high-risk zones. Those who already live there would not required to move, however. Again, this is very airport-specific.

Airport Public Safety Zones (PSZ) are part of British zoning regulations at present. PSZs are areas near the airport property (typically at runway ends) that are used to limit or eliminate population density for reasons of safety. The British define their zones as 1372 meters long and from about 150 to 694 meters wide.

Figure 5.11 represents the superposition of two plots. One plot (the trapezoid area) is the British PSZ. The second plot (drawn to scale) is the distribution of a total of 24 landing (L) and takeoff (T) accident crash sites within 8 kilometers relative to the end of the runway (also shown in the figure). The 24 landing and takeoff accident sites

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[20]For detailed discussions of how the skid area is reduced by the use of barriers see Solomon et al. (1974), op. cit.; Solomon (1975), op. cit.; Kenneth A. Solomon, "Analyses of Ground Hazards Due to Aircraft and Missiles," *Journal of Hazard Prevention*, Vol. 12, No. 4, March/April 1975; and Kenneth A. Solomon, *Ground Risks Associated with Aircraft Crashes*, RAND, P-7459, November 1987.

For a discussion of how mortality rates are related to structural damage after impact, see I. B. Wall and R. C. Augenstein, "Probabilistic Assessment of Aircraft Hazards to Nuclear Power Plants," *Trans. of the American Nuclear Society*, Vol. 13, 1970, pp. 217; C. V. Chelapati and R. P. Kennedy, "Probabilistic Assessments of Aircraft Hazard for Nuclear Power Plants," *Nuclear Engineering and Design*, Vol. 19, 1972, pp. 333-364; and R. P. Kennedy, *Effects of Aircraft Crashes on Concrete Buildings*, Holmes and Narver Study, Los Angeles, California, July 1966.

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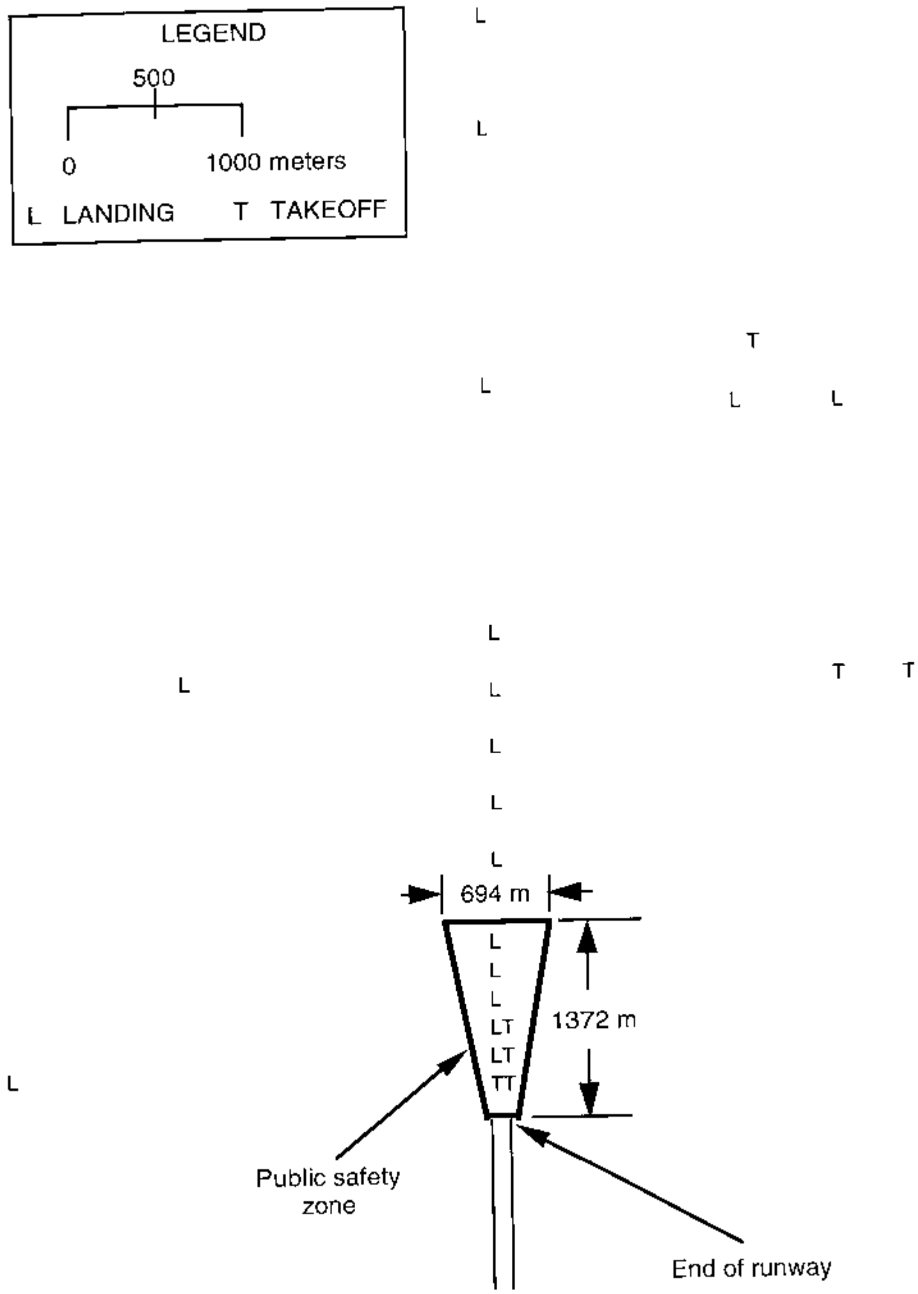


Figure 5.11—Crash Sites Within 8 Kilometers of the Runway

are plotted on the basis of reviewing the crash locations of accidents in the vicinity of worldwide airports and plotting these locations on a single grid.[21]

Several worthwhile observations can be made from this figure. First, of the 24 crash sites within 8 kilometers of the runway, nine are within the defined public safety zone. Assuming these crash sites are representative of a larger number of crashes within about 8 kilometers of the runway, the safety zone concept as defined by the British study appears to eliminate about one-third of the crashes over population. Second, of the remaining 15 crash sites, eight (or about another one-third) are along the flight path (as defined by an extension of the runway) and within 8 kilometers of the runway. This density of crashes along the flight path supports the argument for either extending the safety zone or implementing barriers (such as trees) to be placed on the sides of the structure to be protected depending on whether the runway is used for landing or takeoff or both. The actual decision to extend the safety zone or to implement barriers is a decision based on very specific risk and benefit considerations about each individual site being considered. Such a very detailed assessment has not been made in this study.

SUMMARY

Table 5.1 summarizes the causes and rates of historical hull loss accidents. It is meant to remind the reader of the relative significance of various causes of accidents and the phases of flight in which they occur. Other factors also affect the third-party risk and are not represented in the Table 5.1 and higher rates of accidents do not necessarily cause a proportional increase in computed risk because frequency of flight operations, etc., also enter the equation. A more complete perspective will be achieved as we apply the quantitative assessment model in the next chapter.

Table 5.1

Aviation Accident Causes and Relative Frequencies

	Percentage of Historical Accidents
Accident causes[a]	
Flight crew error	60
Aircraft and maintenance	18
Engine failure	10
Airport/ATC	7
Terrorism	6
Weather	4
Birds	1
Phase of flight	
Final approach and landing	41.1
Takeoff and initial climb	28.7
Taxi, load, and unload	3.4
Descent, cruise, and climb	26.8

[a]Not additive. Not all causes are listed and some causes overlap.

[21]Our assessment identified 53 crash locations within 25 kilometers from the end of the runway. Of those 53 crash locations, 24 are located within 8 kilometers of the end of the runway.

The end of the runway is defined as the point where all aircraft that crash on takeoff depart the runway and where all aircraft that crash on landing were likely to have landed on the runway.

Figure 5.11 represents the superposition of 24 aircraft crashes onto a single grid where the reference point is the end of the runway.

Chapter Six

QUANTITATIVE EVALUATION OF SAFETY AND SAFETY-ENHANCEMENT MEASURES AT SCHIPHOL

In the first part of this chapter we discuss the role of quantitative analyses in this study and in the second part we describe briefly the methodology and database used. A more detailed discussion of the methodology and database are deferred to Appendixes A and B, respectively. We then describe the major trends and changes anticipated at Schiphol and discuss how these may impact the assessment of third-party risk in 2003 and 2015. In the fourth part we discuss and quantify the baseline risk for the current situation and for the years 2003 and 2015. Both group and individual risk are described along with the extent to which uncertainty affects the results. The influence of the probability distribution of the accident crash sites on the ground, on the quantitative findings, and on the placement of SIDs and STARs is described.

Finally, we consider the effect of implementing several safety-enhancement measures on third-party risk. Although this study considered a large set of safety-enhancement measures, a much smaller set can be quantified in terms of how their implementation may influence third-party safety. This chapter focuses on only those that can be quantified.

THE ROLE OF THE QUANTITATIVE ANALYSIS

Third-party risk estimates are influenced by a variety of factors such as aircraft type and related crash rate, whether the aircraft is landing or taking off, whether the aircraft operation is occurring during business or nonbusiness hours, and so on. For example, we can estimate which types of aircraft contribute most to third-party risk. Or, we can compare the relative risks during business and nonbusiness hours. If the relative risk is higher during business hours, for instance, it may be because more people are working near the airport (in which case it is important to consider exclusionary safety zoning to incorporate businesses as well as residences) or it may be because of a disproportionate number of flights during those hours. We can determine if particular arrival and departure routes contribute disproportionately to risk. If so, it might be possible to consider redesigning those particular routes to avoid overflight of certain populated areas. We can estimate whether particular elements of the population are subject to more risk than others.

A second set of issues involves future operations at the airport. A simple straight-line extrapolation of airport operations growth onto the estimate of third-party risk suggests that the risk would increase in proportion to the operations. However, because the nature of the airline fleet will change in the future—more larger and probably safer aircraft—it is possible that the risk projection could actually be smaller, or at least less than proportionally as large. Furthermore, the addition of a new runway and certain planned mitigation measures (removing most of general aviation from Schiphol, for example) should reduce the risk still further. Because these features can be represented in a quantitative risk model we can estimate their effects on third-party risk.

Quantitative risk assessment also puts various options and risks in perspective. Although some flight operations may have a significantly higher crash probability (helicopter flights, for example), if they represent only a small number of operations, then the overall risk to third parties from these operations is not high.[1]

Finally, we would like to compare various safety-enhancement measures in terms of their effect on risk mitigation. For example, if exclusionary safety zoning is used, what is the fractional reduction in third-party risk? If there are certain advances in ATC technology, how might they affect the probability of crash used in the study and what is the consequent reduction in third-party risk?

Our analysis, as in the case of virtually any quantitative risk analyses including any airport safety study, faces an array of limitations and uncertainties. In the appendixes, we discuss these problems, which include uncertainties in the data, the nonquantitative nature of many safety enhancement measures, and the limitations of our own method and model. Although we do not believe these limitations invalidate the general conclusions of the quantitative analysis, one should be aware that the results are surrounded with considerable caveats and uncertainties and the numbers should not be taken as absolute and definitive. The quantitative results are best used in a relative manner for detecting safety trends over time and evaluating changes resulting from safety-enhancement measures. Note that all of the issues discussed above can be addressed in a *comparative assessment* of risk.

Because of the large uncertainties surrounding some of the input data and as a result of the normal statistical variance of low-probability events, it is important whether or not a particular trend is large relative to the uncertainty. In a comparison of cases with only one or a few input factors changed, a small effect can still be significant, as long as the uncertainties in other factors affect both cases in the same way. In the appendixes we discuss the uncertainties in both accident and operational data.

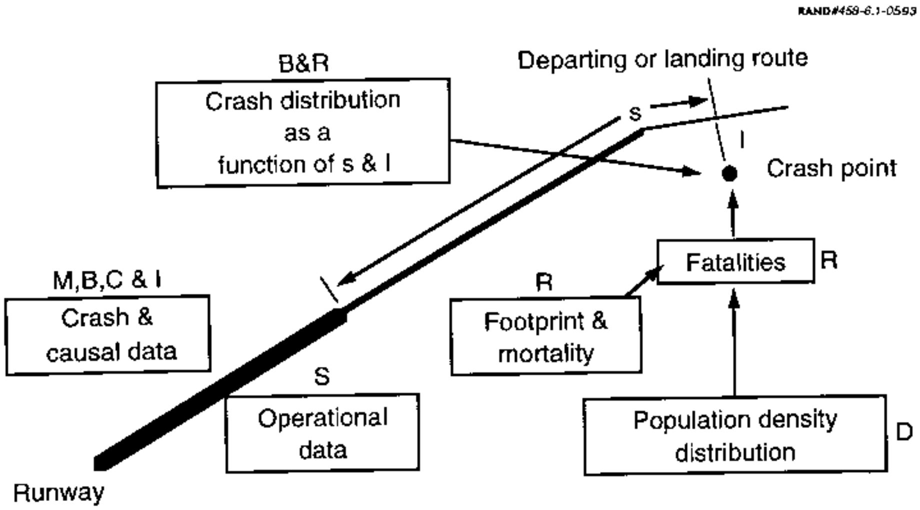
BRIEF DESCRIPTION OF DATA

Although Appendixes A and B describe the approach, model, and data in detail, this chapter discusses only some key elements. Figure 6.1 illustrates schematically the data elements and data sources.

Approach

To estimate the third-party risk for a given year, we considered the total number of aircraft movements at Schiphol in that year. We then classified the movements by

[1]This does not imply, however, that "dangerous" operations can be accepted if they are sufficiently infrequent. The public has a right to expect a reasonable minimum level of safety for *any* flight.



B=Boeing Commercial Airplane Group, C=Civil Aviation Authority, D=Dutch Government, I=International Civil Aviation Organization, M=Douglas Aircraft Company, R=RAND, S=Schiphol Airport Management

Figure 6.1—Schematic of Data and Data Sources for Risk Estimation

aircraft type,[2] flight mode (takeoff or landing), runway used, SID or STAR, and business or nonbusiness hours. These operational data were provided to us by the Schiphol airport management.

We next assembled the global hull loss accident rates during 1987-1991 for the types of aircraft used at Schiphol.[3] Hull loss data were used because they are most relevant to the third-party external safety calculations. Only a negligible number of accidents have caused third-party fatalities outside the airport but have not resulted in hull losses.[4] The sources of crash and causal data are Douglas Aircraft Company, Boeing Commercial Airplane Group, the Civil Aviation Authority of the United Kingdom, and the United Nations' International Civil Aviation Organization (ICAO). The accident rates have been adjusted downward by a Schiphol applicability factor derived by examining one historic accident at a time and asking the question: Could the accident have occurred in the current Schiphol environment? We removed, for example, some accidents in which aircraft struck mountains. On the other hand, although there are no mountains in the Schiphol environment, it was necessary to keep those

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[2]Although we have accident data on many types of aircraft and our model can handle the same, we have grouped the aircraft into three types by size—large, medium, and small—and performed the quantitative analysis on these three types. The aircraft-type mix at Schiphol by 2015 or 22 years into the future is not known with great precision, and therefore it would be misleading to disaggregate the data into more aircraft types. Also, because of the small numbers of crash events by aircraft type, it is better from a statistical point of view not to disaggregate the data too much.

[3]Although we have a database of hull loss accidents dating back to 1970, we lack the operational data by aircraft types going back that far. Thus, we used data primarily from the period January 1, 1987, to December 31, 1991.

[4]One could envision various possibilities. For example, a cargo door falling off a flying aircraft could kill a person on the ground, but the aircraft lands safely. Such events are so rare that they are insignificant for this study.

accidents that might have occurred even if the mountain were not there.[5] We have also discarded a few accidents that were related to civil war and other factors that are clearly inapplicable to Schiphol. Further adjustments were made for the third-party external safety calculation, because some accidents occurred inside airports or far from the airport (during cruise) and should be excluded for this calculation.[6] We then calculated the expected number of crashes that could contribute to third-party external risk by multiplying the number of movements by the adjusted accident rate for each particular type of aircraft.

Given the expected number of hull loss crashes, we then represented the distribution of crashes as a function of the longitudinal distance along the intended flight path(s) and the lateral distance from it using crash data defining the x and y location of crashes relative to runway.[7] We next estimated the footprint and mortality factor for each particular type of aircraft. The assumptions and data used in these are discussed in Appendix B. Finally, Advanced Decision Systems at Delft processed the Dutch census and other population data for use in noise abatement analysis, and made that data available to us for our estimation of individual and group risk. This population distribution data included variations by business and nonbusiness hours. We defined business hours as 8 am to 6 pm during weekdays and the rest of the time as nonbusiness.

The risk-estimation model permits, for policy analysis purposes, the determination of risk differentiated by scenario year, aircraft type, time of day, phase of flight, particular flight paths, and size of footprint. Figure 6.2 illustrates this differentiation of the data.

Key Operational Data

Below, we will show some of the most important operational data for the study at Schiphol. A more complete discussion of the data can be found in Appendix B.

In Table 6.1, passenger aircraft sizes are classified by seat capacity.[8] For air freight aircraft the number of seats is not relevant, and we used the maximum takeoff weight (MTOW). The MTOW ranges are chosen in such a way that if these ranges were used to classify passenger aircraft the results would roughly correspond to those by seat

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[5]We will use an applicability factor of .86. If no downward adjustment were made, the individual and group risks calculated in this section for Schiphol would have been higher by 16 percent (i.e., 1/0.86).

[6]Our approach uses the fact that only a portion of accidents occurred outside but near the airport, and we are using the historic data to determine that portion.

[7]Unfortunately, data regarding intended flight path are not readily available, so it was necessary to approximate the s and l distribution. We used Boeing data to determine a distribution as a function of distance along the runway centerline (x) and the lateral deviation from it (y). This x/y distribution was used as if it were a s/l distribution. This involves the "bending" of the x/y distribution along SIDs. For a more detailed description, see the discussion of this distribution in the appendixes.

[8]Others have done this as well. See, for example, Smith (1990), op. cit., p. 11.

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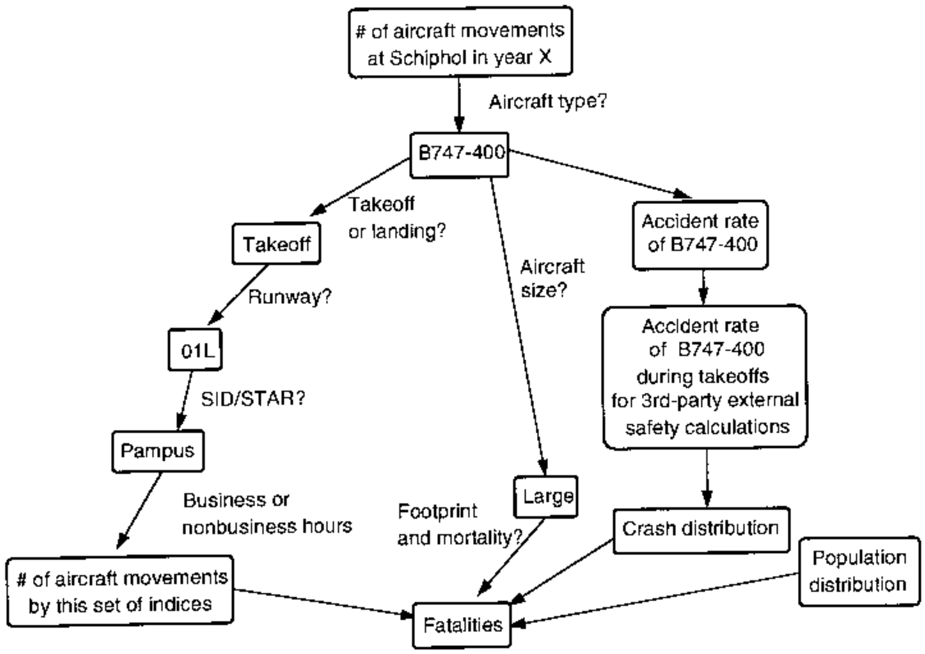

Figure 6.2—Differentiation of Data for Risk Estimation

Table 6.1

Aircraft Categorization into Three Sizes

Aircraft Size	Passenger Aircraft by Seat Capacity	Freighters by MTOW (1000 kg)
Small	<70	<27
Medium	70-180	27–05
Large	>180	>105

capacity. The seat classification is also needed, because future fleet composition data at Schiphol are given by that classification alone. In Appendix B we show the sizes of the aircraft types serviced by Schiphol and the aircraft movements in 1991. These data were used to calculate the weighted average of accident rates for large, medium, and small aircraft operating at Schiphol.

The aggregated current and projected fleet composition and aircraft movements at Schiphol are shown in Table 6.2. The future composition is based on four assumptions: (1) that 10 percent of the 50 million passengers in 2015 will be served by high-speed trains; (2) that 95 percent of general aviation will be diverted to a nearby airport; (3) that the trend of an increasing proportion of large and medium aircraft in

Table 6.2

Current and Projected Aircraft Movements at Schiphol by Aggregate Aircraft Types

	Current		2003		2015	
Size	Percent	Move-ments	Percent	Move-ments	Percent	Move-ments
Large	20.5	50,416	30.4	97,377	33.6	145,320
Medium	43.8	107,988	54.3	173,614	53.1	229,658
Small	35.8	88,181	15.3	49,009	13.3	57,523
Total	100.1	246,585	100.0	320,000	100.0	432,500

SOURCE: Current figures are given in or derived from Schiphol Airport Authority, *Statistical Annual Review 1991*, pp. 26–27 and 34–38. Future figures are provided by Schiphol management.

the fleet will continue; and (4) that the average load factor will increase.[9] In other words, although the number of air passengers will increase from 16.5 million now to 45 million in 2015 (or by a factor of 2.7), the number of air movements will increase by only 1.8. One cannot, however, conclude that the group risk will increase by either 2.7 or 1.8, because the fleet composition and other factors will also change over time.

Tables in Appendix B illustrate the distributions of takeoffs and landings by runway and aircraft size. Runway 04/22 is a short runway and suitable for use only by small aircraft, and the same constraint will apply for the years 2003 and 2015. The data for the current situation were obtained from a previous report of risk at Schiphol, modified by the use of runway 04/22 by some small aircraft.[10] The 2015 data was provided by the Schiphol management. We analyze two cases for 2003—a four-runway case (Case 2003.4) similar to the current situation at Schiphol, assumed to have the same distribution of flights as now, and a five-runway case (Case 2003.5), which uses the 2015 distribution.[11]

Given that a particular runway will be used by an aircraft of specific size, one still needs to know the distribution among various SIDs for takeoffs. Tables in Appendix B give this information. The distributions among routes were derived to meet two conditions: (1) the number of aircraft movements from all runways to the same SID destination agrees with the number determined by noise abatement considerations, and (2) the distribution of aircraft movements among runways over a year is achievable under the weather conditions at Schiphol.[12] As to landings, we used a straight approach to the runway from 12 km out and did not include any curved landing ap-

[9]General aviation is classified as "non-commercial flight" by the Schiphol airport management. It consists of training, business, private, police, test, government, and other noncommercial flights, but does not include commercial flights such as taxi or commuter flights (Schiphol Airport Authority, *Statistical Annual Review 1991*, p. 27). The load factor of an aircraft is defined as the fraction of the seats or capacity that is filled in a flight. The average load factor is the total number of passengers carried in a year divided by the total number of passengers that those flights can possibly carry.

[10]Smith (1991), op. cit., p. 7. The data for the year 1991 are considered to be reasonably close to representing the current situation.

[11]The current plan is to have the "fifth" runway operating by *2003*.

[12]Invoergegevens Kosten Berekening Schiphol, October 20, 1992, pp. 7-10 and 13.

Table 6.3

Distribution of Takeoffs and Landings Between Business and Nonbusiness Hours

	Takeoffs	Landings
Business hours (8 am – 6 pm weekdays	49%	46%
Nonbusiness hours (other times of the week)	51%	54%

SOURCE: Figures are derived from Schiphol Airport Authority, *Statistical Annual Review 1991*, p. 39.

proaches in the baseline cases. The distribution of takeoffs and landings between two time periods—business hours and nonbusiness hours—is shown in Table 6.3.

Accident Data for Schiphol

We began with global accident rates for various aircraft types and found that the accident rate for small aircraft is two to three times larger than that of medium and large aircraft and that for general aviation is about 20 times that for medium and large aircraft.[13] We also determined in Chapter Five that the accident rate for some risky aircraft might be 6.6 times as high as that for Western aircraft of the same size. For the quantitative analysis in this study, we used a more conservative crash rate multiplying factor of 2 for such aircraft. By weighting these rates by the current number of movements at Schiphol, we obtained the accident rates for the Schiphol fleet composition shown in Table 6.4, but these rates were derived *before applying the Schiphol applicability factor*. Table 6.5 shows that the weighted overall accident rates, before adjustment by this factor, are 4.5, 1.8 and 1.8 per million departures for the current year, 2003, and 2015, respectively. The lower future rates are due mostly to the expected diversion of 95 percent of general aviation currently at Schiphol to other airports and the trend of an increasing proportion of larger, presumably safer aircraft at Schiphol.

The first adjustment of these rates is to eliminate those accidents that could not have occurred at Schiphol. As stated above, studying 114 hull loss accidents worldwide, we found that 14 percent of those should be excluded, and we arrived at an adjustment factor of 0.86. Consequently, Table 6.5 shows that the rates adjusted by this factor are 3.9, 1.5, and 1.5 per million departures for the current year, 2003, and 2015, respectively. Excluding the 67 percent of accidents that would have occurred inside the airport or far away during the crisis phase (more than 30 km),[14] we arrived at 1.3, 0.5 and 0.5 per million departures for the same three years. These were further divided into rates for takeoffs and landings based on the phase of flight distribution of accidents. For example, the number of takeoff accidents that could result in third-party external risk is 0.32 per million departures for the year 1991, while that of landing accidents is 0.95 per million departures.[15]

[13]This is based on our analysis of the data reported in *Flight Safety Digest*, February 1993, pp. 9-12.

[14]The 30 km is in agreement with the 15 nmi radius within which the landing and departing aircraft are generally considered to be under the approach control of Air Traffic Control. Moreover, the aviation population data available to us cover an area of about 50.5 km by 54 km around Schiphol. This area also corresponds to a radius of about 30 km.

[15]Throughout this chapter, component numbers sometimes do not sum exactly because of rounding.

Table 6.4

Accident Rates Before Adjustments for the Current Fleet Composition at Schiphol

Aircraft Size	Category	No. of Aircraft Movements	Accident Rates (Per Million Departures)	
				Weighted
Large	Com, non-east	48,437	2.26	
	Com, east	1,979	4.52	2.35
Medium	Com, non-east	106,767	1.08	
	Com, east	529	2.15	
	Other com	692	1.08	1.08
Small	Com, non-east	47,849	2.71	
	Com, east	16	5.41	
	Other com	13,990	2.71	
	Non-com	26,326	27.07	9.98
		246,585		4.52

NOTE: Com=Commercial, East=Eastern European countries and former Soviet Union, non-com=non-commercial or general aviation.

Table 6.5

Accident Rates for the Calculation of Third-Party External Risk at Schiphol

	Accident Rate (Per Million Departures)		
	Current	2003	2015
Hull loss accidents	4.5	1.8	1.8
Adjusted for Schiphol	3.9	1.5	1.5
Adjusted for third-party external risk	1.3	.50	.50
Takeoff accidents	.32	.13	.12
Landing accidents	.95	.38	.37

In Table 6.6, the overall accident rates for the third-party external safety calculation are compared with those used in a previous study of third-party risk at Schiphol.[16] That study, however, did not use accident rates differentiated by type of aircraft. Consequently, despite the expected changes in fleet composition at Schiphol, the same accident rate was used by that study for the current and future years. In contrast, the rates we used have depended on aircraft types, and hence, the composite accident rate changes as the fleet composition changes. Our combined takeoff and landing accident rate of 1.3 accidents per million departures for the current situation is higher than the 0.79 and 0.58 rates used in the previous study. On the other hand, the fleet mix changes for the future scenario years at Schiphol causes the composite accident rate to drop to 0.50, which is lower. We will demonstrate that the group risk will drop by a smaller but still significant amount because the operations rate, footprint, and mortality factor also affect the risk calculations. Note also that the overall rate in our study is a weighted average of rates of small, medium, and large aircraft.

[16]Edward Smith, *Risk Analysis of Aircraft Impacts at Schiphol Airport*, Technica Consulting Scientists and Engineers, May 1990.

Table 6.6

Comparison of Overall Accident Rates for the Calculation of Third-Party External Risk at Schiphol

	Accident Rate (per Million Departures)				
	RAND			Technica[a]	
	Current	2003	2015	Study	Extensions
Takeoff accidents	.32	.13	.12	.22	.21
Landing accidents	.95	.38	.37	.57	.37
Total	1.3	.50	.50	.79	.58

SOURCE: Technica study published in May 1990 (p. 15) and extensions in December 1990 (p. 6) and March 1991 (p. 3).

[a]Same rate for all periods.

These rates differ from the average and are handled separately by the risk estimation model. Coupled with different footprint and mortality factors, our results are likely to be different from those of the previous study, even if both have the same average rates.

MAJOR TRENDS AND CHANGES

Through the year 2015 a number of changes are expected to occur at Schiphol including:

- Increase in the number of passengers serviced.
- Growth in population in the region of the airport.
- Removal of most general aviation.
- Changes in fleet mix (larger, newer aircraft).
- Increases in airline passenger load factors.
- Changes in the distribution of the population in the vicinity of the airport.
- Addition of a "fifth" runway.

Each change will affect third-party risk around Schiphol. In the remainder of this chapter, we will describe the changes and then examine how they may influence third-party risk around Schiphol with and without the implementation of other safety enhancement measures.

Increased Number of Passengers

The expansion plan at Schiphol anticipates that the number of passengers to be serviced will increase from 16.5 million currently to about 30 million in 2003 and about 45 million in 2015.[17] If increases in the number of passengers were the only consid-

[17]In terms of number of flights, freight accounts for about 4 percent of the traffic now. We estimate that freight will account only for about 6-7 percent of the flights by the year 2015. (Freight volume is expected to increase from 0.6 million tonnes now to 4-4.5 tonnes in 2015.) Since the statistics for accident data are not disaggregated for passenger flights and freighter services, we have not treated them separately in the

eration regarding safety trends, then an increase in passengers by a factor of 2.7 would lead to a proportional increase in number of aircraft movements and therefore a proportional increase in group risk. However, as we will show, other changes will keep risk from rising by this same proportion.

Growth in Population

The total population within 30 km of Schiphol is expected to change only a little over the next two decades. It will grow from 1.67 million currently to an expected 1.83 million in 2015 during business hours and from an expected 1.80 million currently to about 1.93 million during nonbusiness hours. In terms of percentage, the growth is about 6.7 percent during business hours and about 3.5 percent during nonbusiness hours. Because these growth expectations are approximate and for convenience of discussion, we will describe the net (business and nonbusiness hours) growth as 5 percent during the period.[18]

Outplacement of General Aviation

In 1991, general aviation accounted for 26,326 aircraft movements and constituted 11 percent of the total aircraft movements at Schiphol. It is being considered to be mostly (we assume 95 percent), removed from Schiphol for noise abatement and other concerns by the year 2015. Because general aviation has a higher accident rate than does commercial jet aviation, its removal will have the added benefit of reducing third-party risk around Schiphol. Diverting general aviation away from Schiphol may reduce the third-party risk at Schiphol but may in fact increase it elsewhere to the diverted airports. The extent to which the decrease in third-party risk around Schiphol may be offset by the increase in third-party risk around airports that accept the diverted general aviation depends on the relative population densities around the respective airports.

Changes in Fleet Mix

As Schiphol is transformed into a mainport, it is anticipated that the fleet serviced by the airport will consist of more, larger passenger capacity aircraft with a higher load factor. The fraction of medium-capacity and large-capacity aircraft is expected to increase from 64.2 percent currently to 84.7 percent in 2003 and 86.7 percent by 2015. A fleet including more larger capacity aircraft does not necessarily lead to a reduction in group risk, however, because the effect of fewer flights could be canceled by the increased risk of greater crash damage because of the greater footprint and larger

analysis. The 45 million passengers in 2015 do not include the estimated 5 million passengers to be carried in or out of Schiphol by high-speed trains.

[18] The 5 percent growth is obtained by weighting the population growth by the flight intensities during business and nonbusiness hours. This is appropriate in the analysis of third-party risk because third-party risk is closely related to flight volume. On the other hand, a simple average will give 5.1 percent and is not significantly different from the 5 percent used here. This 5 percent figure is used only for the convenience of discussion. In all model runs, the different growth rates during business and nonbusiness hours (6.7 percent and 3.5 percent) were used. Note also that the population is projected to grow 5.5 percent by the year 2003 and then decline by 0.6 percent during the period 2003-2015. The decline may be artificial, resulting from the difficulties in projecting population change more than two decades away.

mortality rate of the larger aircraft. We will show that in the particular case of Schiphol, the two effects roughly cancel each other.[19]

Changes in Population Distribution

Third-party risk depends on the distribution of the population with respect to the distance and orientation of the runways and to the layouts of the flight paths (SIDs and STARs). Generally, if future business, school, and residential developments are located closer to the airport, third-party risk will increase. We will study the effect of changes in the population distribution and its effect on risk during business and nonbusiness hours.

Adding a "Fifth" Runway

To accommodate the above changes and trends, Schiphol is planning to add a new runway. This new runway will contribute to noise abatement and will have the added benefit of increased peak period capacity especially under restricted weather conditions.

The fifth runway will affect the third-party risk as well. Primarily, it will reduce overflights of more heavily populated areas and allow more flexibility for SID and STAR selection and optimization. We will examine how the addition of a parallel runway, 01LL/19RR, affects third-party risk.[20]

RISK ESTIMATES FOR CURRENT AND FUTURE BASELINE OPERATIONS

Third-party risk estimates need to be described with wide regions of uncertainty because these estimates depend on very low probability events such as aircraft crashes as a function of aircraft size and mode of operation. Because of the relative infrequency of aircraft crashes, the expected or mean crash rate and third-party risk estimates are relatively low but the uncertainty, expressed as a variance, of such estimates is quite high. We must continually keep this issue in mind when discussing third-party risk estimates.

We begin the quantitative analysis by defining four baseline cases: one for the current year, two for 2003 (labeled 2003.4 and 2003.5) and one for the year 2015.[21] The 1991 baseline case represents the current Schiphol operational situation. In the future year baseline cases, Schiphol's operational procedures and environment will follow those recommended in the airport expansion plan[22] and those anticipated by the airport management. Below we consider cases that differ from the baseline.

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[19]Increased load factor (for any given number of passengers carried) may also reduce third-party risk. However, when flights are very full and schedules are very tight (such as during holiday seasons), other factors that may reduce safety could come into play.

[20] A nonparallel new runway and the rotation of 01L/19R are other options. Although these options are suitable for quantitative analysis, we have not included them in this study.

[21]The baseline cases do not include safety-enhancement measures other than those discussed in the subsection on Major Trends and Changes. The 2003.4 case represents the situation in the year 2003 with the existing four runways, and 2003.5, with the additional fifth runway. (Currently, there are five runways at Schiphol, but the short runway, 04/22, is usually not counted.)

[22]See, for example, *Summary of the Draft Plan of Action Schiphol and Environs*, Ministry of Housing, Physical Planning and Environment, December 1990.

Quantitative Measures

As described in the Introduction, two popular measures of third-party risk are *group risk* and *individual risk*. Group risk measures the expected number of fatalities per year caused by aircraft crashes around the airport. Individual risk measures the probability that an individual living or working near Schiphol will be killed in a given year by an aircraft crash.

A third and slightly less aggregate measure of risk is to group individuals in different categories according to their probability of being killed in a given year and then estimate the number of people at risk in each category or interval. We use histograms to show the *number of individuals at various levels of risk*, such as the number of individuals exposed to between one in a million and one in ten million chance of mortality per year and the number of individuals exposed to between one in ten million and one in a hundred million per year and so on.

These risk measures will at times be separated into two time periods—business and nonbusiness hours—because some of the possible safety-enhancement measures to alleviate risks address these timewise differences in population.

We will examine the effect of the airport expansion on group risk first and then discuss the implications for individual risk.

Baseline Group Risk Estimates

Current Group Risk. At the current level of operations at Schiphol the combined group risk (the annual expected number of fatalities among a population of people living or working near, but outside the airport) is estimated using the risk assessment model to be 0.51 fatalities per year.[23] This expected (or mean) group risk is small compared to the uncertainty associated with it. The uncertainty of this risk, expressed as a variance, is estimated to be roughly 63, so the standard deviation is 8 or about 16 times the mean. Recall that this variance of 63 accounts for only a portion of the uncertainty in the number of fatalities.[24] The actual variance would be greater than 63. Using the expected fatalities of 0.51 and assuming a negative binomial distribution, there is a 99 percent chance of six or fewer fatalities per year.[25] The chance of any fatalities at all in any given year is 1.9 percent. Using these statistics, the probability an accident of the type in the Bijlmermeer would occur with about one chance in 300 per year or, put another way, should have an average frequency of occurrence of about once in 300 years.[26]

By contrast, in the same region around Schiphol there would be about 200 fatalities per year from car accidents. Of those, about 20 percent or 40 per year are pedestrians

[23]The possibility of a pilot avoiding ground structures or populous areas in a crash has not been modeled in this study because we have no supporting data about pilot avoidance.

[24]For example, the variance of 63 accounts for uncertainty in the location of a crash, and for the mix of flight characteristics, but it does not account for uncertainty in the number of individuals killed in a crash at a given location.

[25]We computed the probabilities of these numbers of fatalities by using the negative binomial distribution to approximate the distribution implied by our model. The negative binomial distribution form fits the historical data regarding third-party fatalities. The historical data show a smaller spread or variance than predicted by our model but this is to be expected because many of the accidents in the historical database are near airports with very small surrounding populations.

[26]For the purpose of this evaluation, we assumed the third-party external fatalities to be more than 40.

(pedestrians are at third-party risk). The mean time between pedestrian fatalities is about nine days using the above estimate.

Future Group Risk. A linear extrapolation based on the assumed 170 percent increase in passengers, a 5 percent growth in population, no changes in fleet mix, no change in aircraft accident rates, and *no safety improvements* would predict a near tripling of the group risk by the year 2015. A more realistic case is the baseline curve in Figure 6.3, which accounts for the changes and trends described in the first part of this chapter. The average group risk rises to 0.66 fatalities per year by 2003 and 0.89 by 2015.[27] Thus, with no changes other than those due to already planned actions and the expected evolution of fleet, the group risk by 2015 will be less than double, instead of triple, despite a threefold increase in annual passenger traffic.

Using the model-estimated mean value of fatalities per year of 0.89 for 2015 and again assuming a negative binomial distribution, there is a 99 percent chance of 16 or fewer fatalities per year (or a 1 percent chance of having 17 or more fatalities per year as shown in the figure). The probability of an accident on the order of the El Al crash in the Bijlmermeer is then one in 200. The chance of any fatalities at all in any given year is 2.7 percent. Thus, although the current probability of a crash with some third-party casualties is one in 35 per year (or once every 35 years) this probability decreases to one in 50 per year (or once every 50 years) by 2015. The reasons for this surprising result of reducing chance in spite of increasing traffic are the removal of most of the general aviation and the decrease in the fraction of small aircraft from 36 percent in 1991 to 13 percent in 2015 (Table 6.2). Since small aircraft, especially general aviation, have higher accident rates, the current fleet mix tends to have more accidents but fewer fatalities.

By 2015, when the group risk reaches 0.89 fatalities per year as indicated in the baseline case, the average probability of an aviation-caused, third-party fatality for any individual near Schiphol will be one in 2 million.[28] Using our other example of third-party, involuntary risk, the probability of a pedestrian fatality caused by an automobile accident in The Netherlands is very roughly one in 50,000 per year. If this countrywide auto accident statistic is applicable to the Schiphol area, a person there is about 40 times more likely to be hit and killed by a car as a pedestrian than by an airplane crash. If the Dutch government were to adopt a standard that individuals working or living within an area of say 30 km of Schiphol are to be subject to no more than an average chance of one in one million of being killed by an airplane crash,

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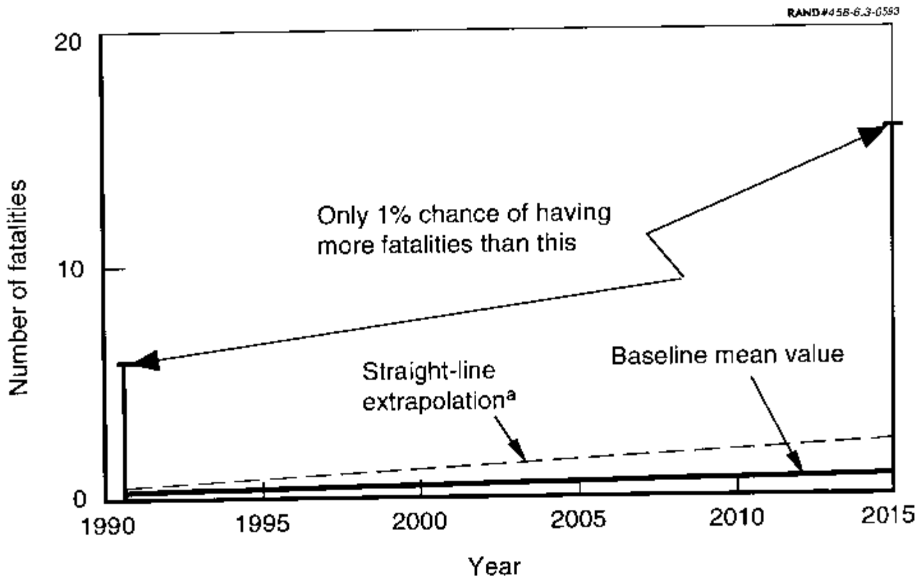
[27]The group risk for 2003.4 is 0.70 fatalities per year and that for 2003.5, 0.61. We simplify the discussion here by using the average number of 0.66 for 2003.

[28]Let the probability that an individual will be killed in a given year be p_i. The average probability is defined as the sum of p_i divided by the number of individuals living or working near Schiphol.



[a]Assumes *no safety improvements*, no fleet changes, and that risk is a linear function of number of operations.

Figure 6.3—Expected Number of Third-Party Fatalities

Schiphol operations now and in the future would both meet that standard on the average for that group. However, meeting an absolute standard of one in one million for each and every person is much more difficult, as we will show.

Table 6.7 summarizes the discussion of group risk by expressing it in various ways and comparing it with the estimate of pedestrian, third-party group risk in the same region.

Table 6.7

Baseline Group Risk Estimates

	Current	2015 Baseline
Mean or average	0.5 fatalities per year	0.9 fatalities per year
99% chance	≤6 fatalities per year	≤16 fatalities per year
Probability of any third-party fatality in a year	1/35	1/50
Mean time between accidents with any third-party fatalities	35 years	50 years
Mean time between a pedestrian fatality in the same region	9 days	Not projected
Mean time between accidents with more than 40 third-party fatalities	300 years	200 years

Baseline Individual Risk Estimates

For the convenience of discussion above, we introduced the term *risk interval.* A risk interval considers the number of people exposed to a risk (in this case the risk of fatality) and groups these people by interval on the basis of their likelihood of fatality. For example, an individual is said to be in the 10^{-8} to 10^{-7} risk interval if the risk of being killed during the year is between one in 100,000,000 and one in 10,000,000. Individuals in the 10^{-7} to 10^{-6} interval are at *higher risk* than those people in the 10^{-8} to 10^{-7} risk interval.

Because these risk intervals are defined somewhat arbitrarily (e.g., instead of defining them in intervals separated by exactly one order of magnitude we could have set them at intervals of, say, factors of 2 or 5 or 100), the number of people that fall into each interval may or may not reflect an accurate representation of the overall risk. This problem becomes especially noticeable for individuals at the very high end of a risk interval one year who, because of a minor change in the assumptions or data, just barely move into the next (more risky) interval.

Figure 6.4 shows the number of individuals in various risk intervals during business hours as predicted by our model. Figure 6.5 shows the risk-profile changes in 2003 and 2015 relative to the current situation. Currently, 362,000 people are exposed to a fatality probability of less than or equal to 10^{-8} per year.[29] There are 483,000 people in the 10^{-8} to 10^{-7} probability interval and 827,000 in the 10^{-7} to 10^{-6} interval. One hundred and thirty individuals or 0.01 percent of the population are subject to a fatality probability of greater than 10^{-6}. By 2015, using these intervals, the number of individuals at this level of exposure and with no safety enhancements could rise to several thousand. Figures 6.6 and 6.7 illustrate similar results for nonbusiness hours. However, because of the mathematical phenomenon discussed above, one *cannot* infer a significant jump in risk. Rather, the jump in individuals exposed at a higher level is best explained by the fact that those at increased risk just barely moved into the annual individual risk probability of slightly below 10^{-6} to slightly above 10^{-6}. The large jump in number of individuals is associated with the somewhat arbitrary definition of intervals rather than with a substantial change in risk. In sensitivity testing, we have found for example that changing the boundary of the risk interval from 1×10^{-6} to 2×10^{-6} changes the result in such a way that there is no significant growth in the numbers at the higher level of risk. Furthermore, very small improvements due to some of the earlier-mentioned safety enhancements or due to some of the data uncertainties would keep the individual risk from growing.

The Baseline Societal Risk

Societal risk is a measure of the likelihood of certain numbers of fatalities in accidents. This measure recognizes the higher importance placed by people on dramatic disasters with larger losses of life compared to a number of accidents with

[29]In this chapter and in Appendix B, we sometimes keep the numbers beyond their significant figures, especially during the discussion of our analysis. Otherwise, for the examination of small changes, it would be difficult for the readers to trace our calculations. On the other hand, we will try to indicate whether the results are significant or not.

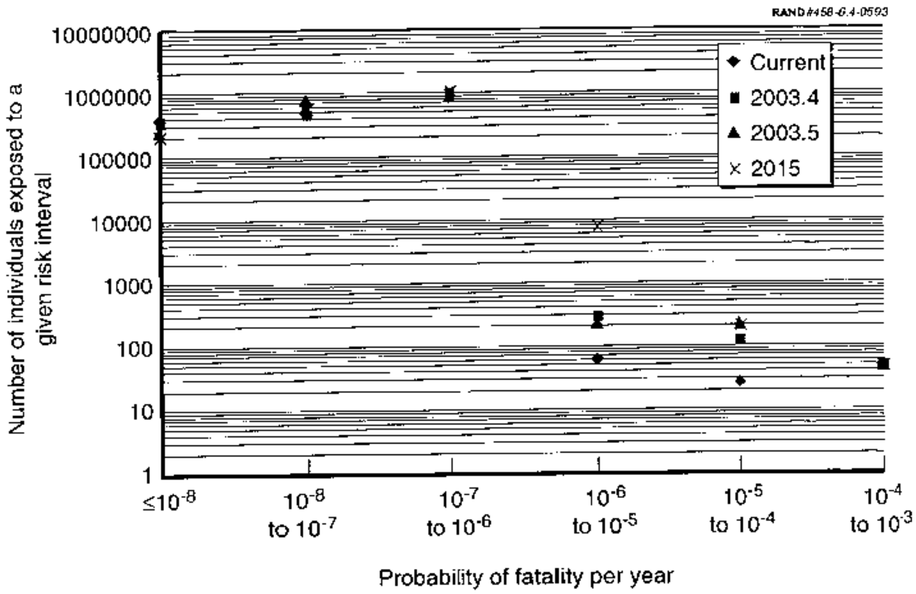


Figure 6.4—Number of Individuals Exposed to Various Risk Intervals During Business Hours

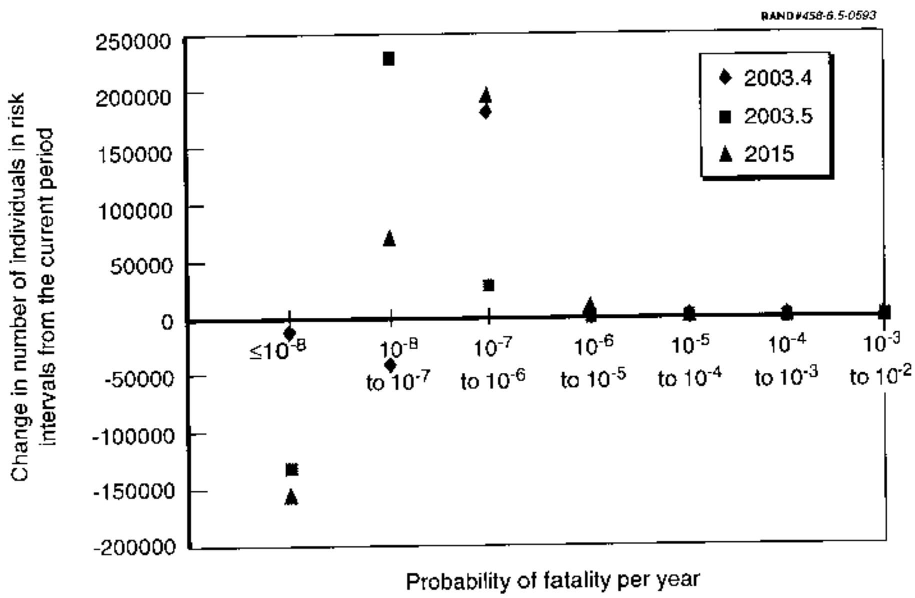


Figure 6.5—Future Changes in Number of Individuals at Various Risk Intervals During Business Hours

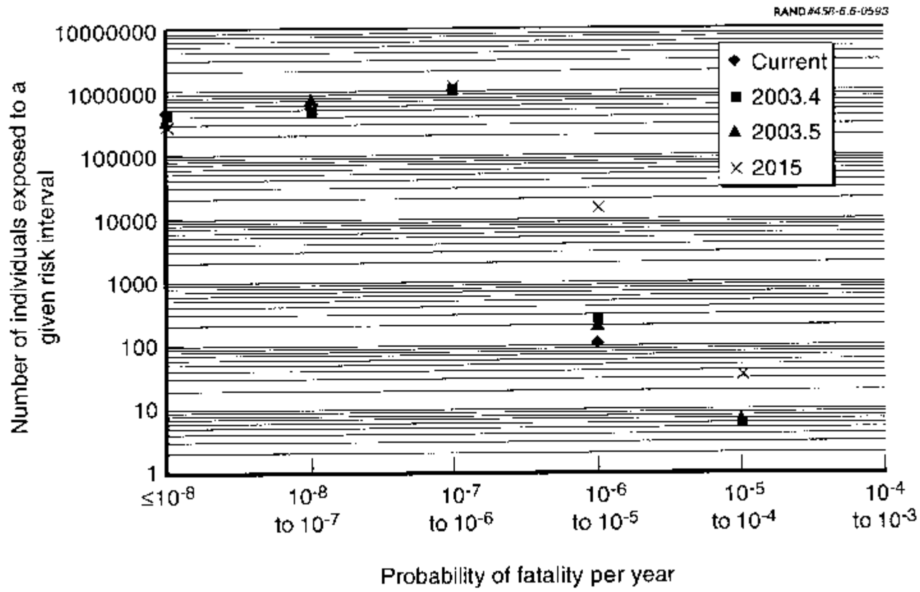


Figure 6.6—Number of Individuals Exposed to Various Risk Intervals During Nonbusiness Hours

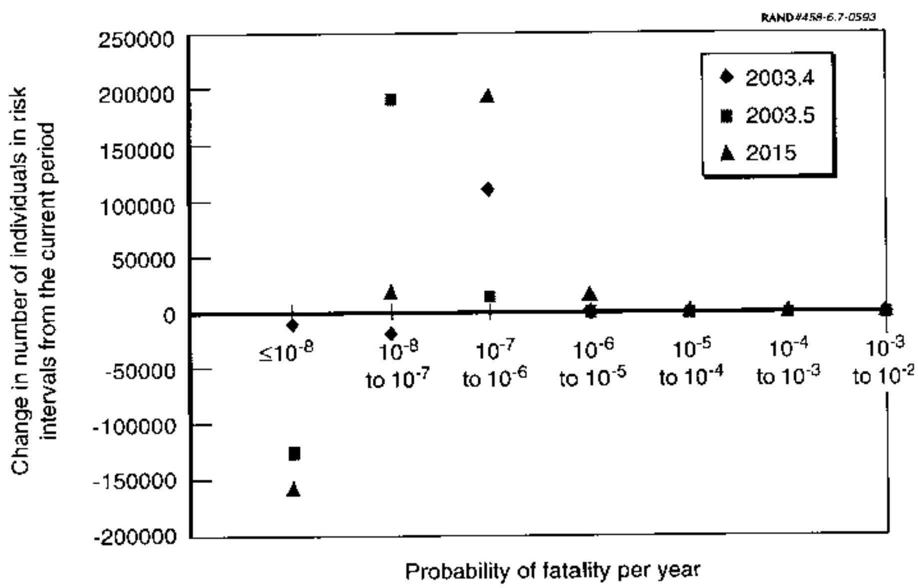


Figure 6.7—Future Changes in Number of Individuals at Various Risk Intervals During Nonbusiness Hours

fewer fatalities that may still lead to the same number of overall fatalities.[30] Figure 6.8 shows this societal risk for the current situation and for 2015. Although there is no significant growth, neither would meet the environmental plan's standard for societal risk if that standard was applied to the airport.

In fact, a *societal risk* standard also implies an individual risk standard. Using the plan's permissible group risk levels, we derived the average individual risk standard as one in one billion.[31] Thus, the plan's standard implies an acceptable individual risk level that is 1,000 times more stringent than a one in one million *individual risk* standard. This level of individual risk would be extremely difficult to satisfy near any airport in the world.

EVALUATION OF CHANGES AND TRENDS

We used a risk model above to estimate the aggregate effects of future trends and anticipated changes on third-party risk. If these trends and changes did not take place, the risk by the year 2015 would be about three-fifths higher. We will now show the contribution of each of these changes to this reduction.

Increased Number of Passengers

Absent any other changes or considerations, the anticipated 2.7-fold increase (from 1991 to 2015) in passengers serviced by Schiphol would increase the third-party fatality risk by 2.7 times. This 2.7 multiplier has been incorporated in both the extrapolation and the baseline risk shown in Figure 6.9, and thus is not a factor in explaining the difference between those two cases.

Growth in Population

Again, absent any other changes or considerations, a 5 percent growth in population around Schiphol will lead to the same 5 percent increase in group risk. Because both cases in Figure 6.9 have accounted for this growth, it is not an explanatory variable for the difference.

Removal of Most General Aviation

The base cases for the years 2003 and 2015 have already included the removal of 95 percent of the general aviation. What would be the effect on group risk by the year 2015 if general aviation continued to grow at the same rate as the overall traffic?

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[30]The 1989 Dutch National Environmental Plan also proposed a standard for group risk. In that plan, the maximum permissible risk levels for disasters from each industrial activity are as follows: one chance in 100,000 for fatalities of 10 or more; one in 10,000,000 for fatalities of 100 or more; and so on. Dutch National Environmental Policy Plan, *Premises for Risk Management*, Second Chamber of the States General Session 1988-1989, Vol. 21, 137, No. 5. These figures were quoted in the Technica study of December 1990, p. 18. Technica also shows a similar graph on p. 19.

[31]The Dutch National Environmental Plan actually specifies the entire permissible probability distribution of fatalities, the numbers "one chance in 100,000 of 10 or more fatalities" and so on being particular quantiles of that distribution. The entire distribution can be used to compute the expected number of third-party fatalities in a year, using standard statistical methods.

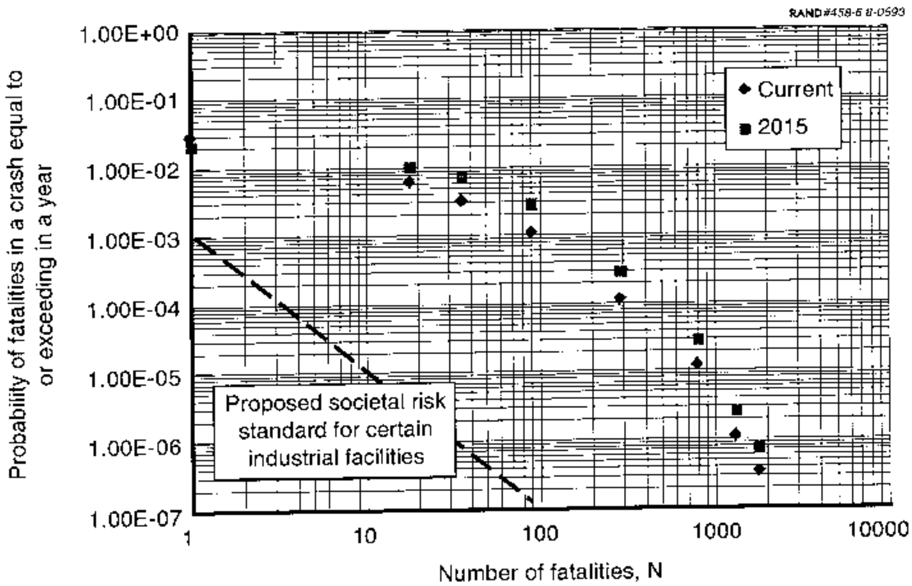

Figure 6.8—Probability of Fatalities Equal to or Exceeding N in a Year

In 1991, general aviation constituted 11 percent of the total movements at Schiphol. If it were allowed to remain at the same proportion, general aviation would account for 52,000 flights by the year 2015. Since the base case has already allowed 1,300 general aviation flights[32] there would be a net increase of 50,700 general aviation flights, bringing the total number of flights by any types of aircraft to 483,200. If Schiphol does not outplace general aviation in any way, the computed group risk would be 1.1, an increase of 25 percent from 0.89 for the 2015 base case. Although the flight volume of general aviation as a percentage of total flight traffic increases by 11 percent, the risk rises by 25 percent, because general aviation—on a per operation basis—is riskier than commercial flights.[33]

Changes in Fleet Mix

At Schiphol, there is a trend toward increasing the proportion of larger aircraft in the fleet by the year 2015. To isolate the effects of *fleet mix changes* from those stemming

[32]This is 5 percent of the 1991 general aviation traffic at Schiphol.

[33]The crash rate statistics used for general aviation reflect U.S. figures. In actuality, the makeup of Dutch general aviation is different, and possibly less risky, than the American fleet of general aviation. If this is true, then the effect of reducing general aviation flights would be smaller. On the other hand, one primary risk of general aviation is in its interface with commercial aviation—the risk of collisions—and it may therefore increase the risk of commercial aviation accidents as well.

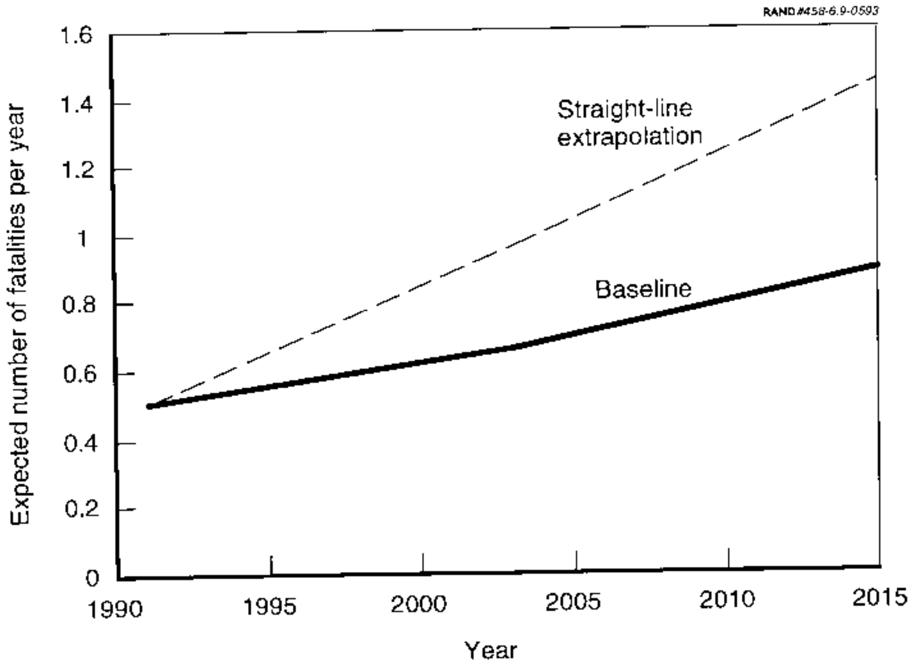

Figure 6.9—Third-Party Group Risk

from *removal of most of the general aviation*, we constructed a special computational case. This case used the same accident rates for large, medium, and small aircraft. We found that the changes in fleet mix from 1991 to 2015 do not significantly alter third-party risk. This is because the risk-reducing effects of fewer flight operations are offset by the risk increasing effects of the larger crash footprint of such aircraft.

Load Factor Increases

Increases in load factor have positive effects in two areas: profitability and safety. Based on the fleet mixes, seat capacities, numbers of passengers carried, and the numbers of aircraft movements provided by the Schiphol management, the load factor is expected to increase by 10 percent by the year 2015. This causes a proportional reduction in third-party risk below the straight-line extrapolation.

Changes in Population Distribution

Figure 6.10 shows the group risk during business hours and nonbusiness hours. The expected number of fatalities (in 1991) was estimated at about 0.23 per year during business hours and 0.27 during nonbusiness hours.[34]

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[34]This is for an area of 50.5 km by 54 km surrounding Schiphol. The population database provided to us, however, has data in only an irregular shaped region inside the rectangle. See the maps in Appendix B.

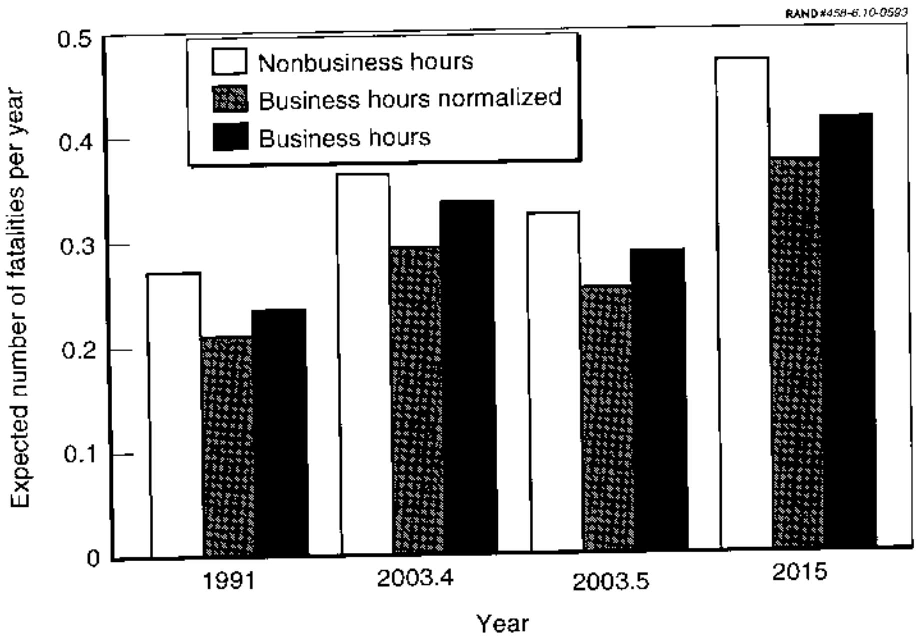

Figure 6.10—Comparison of Third-Party External Group Risk During Business and Nonbusiness Hours

The group risk during business hours was lower because of three factors, two of which made the risk lower and one that made it higher. Population in the region during business hours was only 85 percent of the nonbusiness population, and the flight volume during business hours was only 90 percent of that during nonbusiness hours. The third factor was that businesses were located in riskier areas than residences.

It also appears that there are more businesses moving into riskier areas by the year 2015, because the risk increase of 7 percent during business hours is higher than the 3 percent increase during nonbusiness hours. One may speculate that, since current noise abatement constraints apply only to residences and not to businesses, the businesses are more likely to move into the high noise (and probably lower cost) areas, which are more risky. This is a case in which the noise abatement consideration does not automatically take care of safety.

Adding the "Fifth" Parallel Runway

Other than reducing noise and adding peak capacity, does the addition of a new parallel runway reduce third-party risk? We prepared two runs—one with four runways and one with five runways.

Comparing these two cases for the year 2015, we found that the group risk without the fifth runway would be 1.03 fatalities per year, instead of 0.889 with the fifth runway. The group risk would have been 16 percent higher.[35] Thus the safety-enhancement effects of the fifth runway are significant. The key factor affecting risk in these two cases is the population near this fifth runway versus that near the other runways, especially the existing parallel runway 19R for landing and 01L for takeoffs. The traffic on 19R and 01L is expected to be reduced the most by the addition of the fifth runway. Since landing accounts for three-quarters of the accidents and the landing route 19R involves directly overflying Zwanenburg, the primary safety effect of new 19RR is that it does not overfly it or another populous area.

A Summary of Trends and Changes in Baseline

The 2015 baseline case has included the above seven potential trends and changes. Since the first two—an increase in the number of passengers and population growth—have also been incorporated into the case of straight-line extrapolation of risk, they are not needed to explain the difference between that and this baseline. Table 6.8 shows the remaining five, which explain most of the difference. The unexplained 7 percent labeled as "others" is likely due to inaccuracies in the estimation of the effects of the five changes and trends and other changes. The compound effects of these changes amount to 62 percent, which is the difference between the extrapolation and the baseline risk.

SAFETY-ENHANCEMENT MEASURES

Population Safety Zones

The following safety-enhancement measures have not been included in the baseline but can further reduce third-party risk.

A majority of the air crashes occurs on and near the runway (see the discussions in Chapter Five and the appendixes). Occupants of businesses and homes located immediately off the end of a runway are subject to an unusually high level of risk. During business hours, the two dozen or so individuals presently working or living in

Table 6.8

Effect of Trends and Changes to 2015 on Group Risk

Trend or Change	Percent Risk Reduction[a]
Reduction of general aviation	25
Fleet mix changes	0
Load factor increases	10
Changes in population distribution	−5
Additional runway	16
Others	7
Above effects compounded (to reach the risk level of the extrapolation line)	62

[a]As a percentage of baseline group risk.

[35]We have also made a pair of runs for the year 2003 with and without the fifth runway. Without the fifth runway, the risk would have been 23 percent higher. The risk increment is consistent with the results for the year 2015.

buildings less than one kilometer directly off the southwest end of runway 06 appear to be at the highest risk relative to individuals in other locations [36]

Because runway 06 is the most used runway for landings and currently accounts for a third of all landings, the individual risk for these people during business hours is about 1.9 in 10,000 per year. This level of individual risk is 1,400 times higher than the average risk for people in a 2,500 square kilometer region surrounding Schiphol. During nonbusiness hours, a few individuals remain in this area and their risk level is a factor of 500 higher than the average. A population safety zone is most feasible when the number of businesses and houses in the high-risk area is small. Although the overall group risk reduction by a safety zone at this site is only about 2 percent, public safety zoning for such high-risk areas should be strongly considered. Safety zones and the approach used by other countries are discussed in Chapter Five.

Helicopter Operations

The third-party risk associated with potential helicopter crashes is small and removing helicopter operations from Schiphol would have little effect on third-party risk. Although the crash rate for helicopters is larger than that for fixed-wing aircraft including commercial jet airlines, the limited number of helicopter operations per year (Schiphol has fewer than 2000 helicopter operations per year) combined with the reduced footprint of helicopters following a crash suggest that for the base case helicopters account for less than one half of one percent of the total third-party risk around Schiphol.[37]

Potential Growth in Air Traffic from East European Countries and Former Soviet Union

Available data do not show conclusively whether aircraft manufactured by the former Soviet Union (FSU) are riskier than aircraft manufactured in the West but concern was expressed during the safety survey about these FSU aircraft. These aircraft contributed only 2,500 or 1 percent of the total aircraft movements at Schiphol and, as long as this percentage does not increase substantially in the future, the effect of FSU aircraft on overall group risk estimates will remain small.[38]

However, the collapse of the Soviet empire has set in motion a process of convergence and integration between Western Europe and the rest of the continent. Coupled with the desire to make Schiphol a mainport, the traffic from the East European countries and FSU could rise by a much larger proportion. Also, the former Soviet republics may want airlines of their own, and young and small airlines are likely to have an uncertain safety record. This traffic could become a potential concern to Schiphol, if safety levels for these airlines do not in time converge with those in the West.

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[36]The discussion is based on the 1991 baseline run. The situation has not been corrected and still occurs in the 2003 and 2015 runs.

[37]Crash rate information for helicopters is extracted from NTSB (February 1989), op. cit. Operational information about helicopters was obtained from Wylse Brouwer and Jan Jansen, KLM ERA Helicopters, and is documented in a fax dated March 19, 1993 addressed to RAND, Santa Monica, California.

[38]Of course, the public should expect that certain minimum safety standards are adhered to regardless of the level of group risk and so truly "risky" operations must be prevented. This applies to helicopters as well.

Modifying Arrival and Departure Flight Routes to Reduce Risk

In principle, one can change runway assignments and modify SIDs and STARs to minimize arrival/departure overflights of populous areas. In practice, however, one has to consider the implication of this change on the airport's operational capacity, delays, and increased workloads to ATC and cockpit. Furthermore, if the route is too circuitous it will impose fuel and time penalties on an airline and, worse, on aircraft safety.

Using the risk model and performing sensitivity analysis with SID routing, we found that modifying SID routes will have only a small effect on third-party risk. We found that on an individual high-risk SID, we could make a maximum change of only 13 percent in the *departure* third-party group risk. This change of 13 percent will not reduce *total third-party risk* by 13 percent. Takeoff accidents account for only 25 percent of the total accidents.[39] (To get a 13 percent reduction in overall group risk for Schiphol, we would actually need to have a new set of routes that reduce risk on average 52 percent below the existing SIDs.[40])

The baseline case has already included SID reconfiguration for noise abatement, which generally has positive effects on third-party safety. The above example shows that further[41] SID redesign may reduce the overall group risk by only a few percent. There is also a danger of relying too much on populous-area avoidance as a safety enhancement measure. If the attempt results in a complicated SID structure, the errors in navigating these SIDs and the higher workload that may increase the scope for errors or delays in cockpit actions may well overwhelm the small risk reduction from SID optimization. *Simplifying SID choices and structure may well be more beneficial.*

Because landing accidents account for 75 percent of the total number of accidents, one might expect that changing the landing routes to avoid highly populated areas would yield a larger reduction in third-party risk. Currently, there is little flexibility in altering STARs, which are straight along the runway centerline and start from 12 km away. The opportunity might grow when new landing aids, such as MLS or GPS, come into service and allow curved approaches.

In Appendix A we discuss the probability distribution of crash sites used in this study. This distribution, based on historical data, is broader than that used in previous studies. This too has implications for flight path optimization for safety. Although we show similar high-risk zones near the ends of runways and extending from one to several kilometers, from those runways the remainder of the risk is spread over a broad area and route optimization outside of the high-risk region is likely to be quite difficult. Further study of historical crash location data (identifying the specific intended route of the faltering aircraft for example) might lead to tighter crash location distributions and permit more route optimization. This was not possible in the time frame of this study.

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[39]These are the crashes located outside, but near, an airport.

[40]For a 52 percent risk reduction in every SID, the group risk reduction for Schiphol would be 52 percent multiplied by 0.25, or 13 percent.

[41]This observation is reinforced by the results of another sensitivity test. In that case, we used all assumptions in the 2015 baseline, except that all SIDs from all runways were straight lines. We found that the group risk of the 2015 baseline is only 1 percent lower than the straight SID case. Thus, for the crash distribution we used, the merit of SID reconfiguration is likely to be small.

Technology-Based Safety-Enhancement Measures

Are there technological safety-enhancement measures that could further reduce risk below the baseline? In Chapter Five, we discussed a number of such safety-enhancement measures. It is possible to quantify the reduction in crash rate associated with some of these measures. Specifically, we considered the following technical measures as a group:

Technical improvements in avionics:

- Traffic Collision Avoidance Systems (TCAS); and
- Ground Proximity Warning Systems (GPWS).

Employment of new systems or procedures at Schiphol:

- ATC Computer Warning Systems; and
- Mandating coupled approaches.

Introduction of new systems in aircraft:

- External viewing systems for cockpit;
- Health monitoring systems; and
- Intelligent system to monitor aircraft flight phase configuration.

One might also anticipate further technical advances in pilot/controller communications, ice identification, and de-icing materials and coating, as well as improvements in cockpit resource management.

It is difficult to predict accurately which systems will become feasible and effective, and when, but the aerospace history indicates some continued innovation and breakthrough in both technical and related managerial systems that improve safety. Looking as far as two decades into the future, it is important to consider the possible effects of new systems on third-party safety, although these technologies are not currently at hand.[42]

We selected the sample group of technical measures indicated above and asked the question: By 2003 and 2015 if feasible and if implemented, how effective would they be? We then evaluated, subjectively, the group of improvements against the 114 commercial jet hull loss accidents worldwide during the 1987-1991 period. We then used experts to ask: Could the accident have happened at Schiphol? and, if it could: Could it be avoided if the technologies were implemented?

Because of the subjectivity involved in applying each of these measures against the 114 hull loss accidents, we were not able to arrive at definitive quantitative findings. Rather, we were able to observe some general trends. We found that by 2003, using conservative estimates, about a quarter of the accidents that were relevant to Schiphol might have been avoided if our group of safety-enhancement measures were in place and implemented. By 2015, some of the implemented measures would have even more time to have their effects felt and up to half of the accidents might

[42]It is also possible that a plateau of safety has been reached that will be difficult to improve on and that some technology might actually increase risk.

have been avoided. In other words, this group of measures might lower the baseline risk by 25 percent in 2003 and 50 percent in 2015. The implication of this is that such safety enhancement might keep the risk from rising in spite of increased future operations at Schiphol. Also, the number of individuals who have fatality risk exceeding 1 in a million may stay at the current level. Of course there are some reasons to be skeptical about such technology and its effect on safety, and the uncertainties in this type of projection are large. As new technologies are considered for Schiphol, however, this approach to evaluating their effect on external risk at Schiphol may be quite useful.

The Cumulative Effects of Changes on Group Risk

We have discussed several types of changes and possible safety enhancements at Schiphol. The first group of changes are those that are planned or will naturally occur and that we can be reasonably confident will take place. These include the likely changes in fleet mix, the plan for outplacement of general aviation, the expected growth in population, the rise in the number of passengers, and the probable addition of a new runway. We have shown the relative importance of these changes as predicted by our model and, of course, subject to the many uncertainties we have noted. The baseline group risk, after these changes, shows a modest growth from a relatively low number (relative to other third-party risks such as those of pedestrians in the same region or to first- and second-party risks due to travel in automobiles) to another larger but also relatively low number. This does not account for other suggested safety enhancements associated with the management of aviation safety and that make up the bulk of our recommendations in this report. It also does not include the possible technological enhancements to safety mentioned in this chapter and Chapter Five. Although there is considerably uncertainty on our part about the magnitude of the effect of these changes on the external risk in the vicinity of Schiphol, we certainly expect the improvement to be in the direction of reducing the risk. We have noted this in Figure 6.11.

RAND#459-6.11-0593

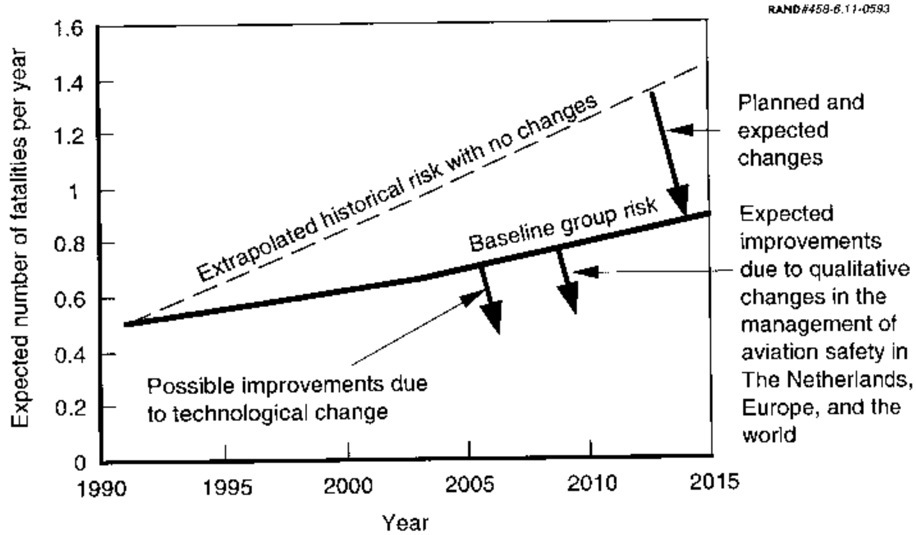

Figure 6.11—Projection of Group Risk and the Possible Effects of Changes

Chapter Seven

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Each chapter of this report, from the descriptive Chapters Two and Three to the quantitative analysis in Chapters Five and Six, has suggested or implied conclusions about the current and future safety at Schiphol airport as well as possible safety-enhancement measures. We attempt here to organize the conclusions into major themes and ultimately to suggest recommendations for the management of safety at Schiphol.

Schiphol Is a Modern, Safe Airport

Despite the tragedy of the El Al aircraft crash into the Bijlmermeer apartment complex, our safety survey, comparisons to other airports, and estimates of current third-party or external risk find Schiphol to have safety comparable to that of other modern airports in Europe and the United States. We find that safety is an important consideration for the various organizations associated with aviation management in The Netherlands and at Schiphol including the ministry (RLD), the airport (NVLS), air traffic control (LVB), and the major airline at Schiphol (KLM). The managers of these organizations are quite aware that there are economic as well as moral and societal reasons for maintaining a high standard of safety at Schiphol. Quantitative comparisons show that Schiphol's current operations and surrounding population fall within a range bounded by those at Frankfurt and London Heathrow.[1] The estimated average individual risk satisfies a standard that is under Dutch government consideration for application to airport operations, although small regions of population may exceed that standard.

Schiphol is generally perceived to be safe by the public. In our interviews of public perceptions and in the news content analysis we found that in general, third-party risk was not a strong concern of the public before the El Al crash and in the absence of a finding that gives the airport authorities blame in the accident, the public largely absolves the airport of responsibility and believes that mechanical failure or crew error in the aircraft was the primary causal factor. This analysis also indicates that *other negatives associated with the airport have been and will probably continue to be*

[1]Group risk is directly proportional to the population and the number of flight operations at an airport. With respect to the product of these two factors, Schiphol falls between Frankfurt and London Heathrow using current operations and populations. Many other factors such as flight path, distribution of population, and fleet mix affect the group risk, so this comparison is a very crude measure.

more important, including noise, environmental damage and, for some of those living near the airport, lower property values. For the limited sample of people we interviewed, as long as certain minimum standards of safety are maintained, the benefit of the airport balances the low external risk. Maintaining that perception, however, requires continued trust in the management of aviation safety and this may require qualitative changes in that management as well as more open information about incidents and safety related decisionmaking.

Safety Considerations May Change as Schiphol Evolves into a Mainport

The growth projected for 2015 (2.7 times the number of passengers and 4.5 times the freight tonnage of the current operations) will increase third-party risk simply because the number of flights will increase. However, mitigating factors such as a safer fleet of aircraft, likely adoption of technological improvements in air traffic control and aircraft avionics, a new runway, and improved international control of risky airlines should keep the external or third-party risk from growing significantly. Indeed, our quantitative analysis suggests that despite the projected growth and increased number of flights implied, the third-party risk could actually decrease as the fleet becomes safer and technological advances are implemented.[2]

However, there is also some concern that growth will increase external risks and there is a natural distrust in the hypothesis that technology will make operations and airports safer. Large changes in magnitude bring about qualitative changes that might produce unanticipated side effects from interactions of modes of transportation, taxiway and ramp traffic multiplication on the ground, increasing severity of weather-related queueing (and possible pressure to reduce safety margins), problems with volume-related incidents such as bird strikes, and risks during the airport-to-mainport transition process. There is also concern about the reduced government control implied by privatization, the effects of the EC open employment market on standards and skills, the increase in freight flights (which generally use older aircraft), and the possible use of technology to compress operations or reduce safety margins rather than to increase safety.

Thus, the evolution of Schiphol from an airport to a mainport is seen by both experts and the lay public as generating potential risks to safety, but those risks can be mitigated if the managers of aviation safety anticipate and correct problems associated with growth before they occur and if safety has an advocacy that can balance the economic, environmental, and political aspects of growth.

Schiphol Airport Safety Must Be Taken in Context

A broad array of changes on the economic, political, and environmental fronts will affect aviation safety during the next decades. The Nederland distributieland concept emphasizes the central importance of the transportation infrastructure and expansion of that infrastructure, including Schiphol airport, for long-term economic

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[2]In Chapter Five we examined the relative influence of various factors in aircraft crashes and the possible implications for third-party risk. In Chapter Six, we calculated the external risk for a small subset of the quantifiable measures. From these chapters it is possible to see what the important leverage areas are for reducing external risk.

benefit to The Netherlands. The EC is taking on a number of responsibilities that were formerly handled by member states. For example, the EC will shortly issue guidelines and regulations that will replace national legislation on many topics, not least of which is transportation. These organizational changes will take place in an environment of growth, where Eastern and Western Europe are rapidly increasing their economic interdependence.

Environmental concerns, already dictating choices of routing to satisfy noise standards, are likely to increase as concerns about growth in air traffic, new construction projects, and increasing auto and rail traffic in the vicinity of Schiphol are realized. The political, economic, and management actions to satisfy environmental concerns will not always be consistent with improvements in external safety (for example, compression of flight operations into more acceptable time periods, or more complicated departure routes to reduce noise to residences may also be more hazardous).

Changes in international aviation that will affect aviation safety include deregulation and its possible effect on airlines and their fleets, increasing flights from new states and concern for the air safety standards of those airlines, and increasing air traffic, which leads to increasing congestion and schedule pressures. At Schiphol, there will continue to be tensions between the economic importance of expansion, the environmental effects, and safety. Some risks must be taken and there will be tradeoffs between noise and economic benefits, but this will generally be acceptable if risks are well managed and the safety implications have been considered.

There are also limits to what Schiphol and the Dutch government can do themselves. There is no effective international air regulatory body to enforce the high standards of aviation safety of Western Europe in other countries. Control of other countries' risky carriers and assurance of high standards of crew training and maintenance for all airlines using Schiphol will either require difficult decisions by the government to exercise unilateral restrictions with consequent political and economic reactions or will require regional confederations such as ICAO, the EC, JAA, or even a regional airport coalition with higher standards and controls.

Safety Is an Airport-Wide Problem

Our safety survey indicates that coordination of safety is currently dealt with informally across the various operating organizations associated with aviation safety at Schiphol and within the government. An integrated safety management systems/office is needed to coordinate and assess the safety procedures of the various operational organizations at Schiphol. We have identified other possible functions of this office to include that of collecting, reviewing, and acting on incident and hazard reports. The office should coordinate emergency planning and integrated emergency exercises. It would generally act as the safety advocate to balance decisions that are made on an economic or environmental basis and that might inadvertently overlook important safety concerns. It would monitor the safety aspects of the growth of Schiphol to a mainport.

The public information aspects of safety should not be overlooked. As indicated in the study of risk perception, there are rumors about incidents and hazards at Schiphol that are not effectively dispelled or explained. There also exist misperceptions about unsafe operations because of lay observations and interpretations of situations. For example, noisy takeoffs or wobbling of wings during a landing approach are sometimes interpreted as problems. Because each organization currently deals internally with safety, there is some bureaucratic reluctance within the organizations to respond openly to inquiries from the outside. Another important function of an integrated safety assurance office would be to provide information to deal with public concerns and to act as a safety spokesman.

No "Magic Bullet" Dramatically Reduces the Quantitative Risk Estimates

Throughout the report, we have discussed possible changes that could enhance aviation safety at Schiphol as it relates to third-party risk, but many of the options are not quantifiable for risk assessment. For example, we have suggested an integrated safety management system for Schiphol and have indicated some of its desired functions. Although we believe this is an important safety-enhancement measure, its actual effects on risk are not quantifiable. We have also discussed possible enhancement measures that are more quantifiable, such as the removal of risky aircraft and the use of public safety zones. Using the quantifiable measures, we have shown that actions can be taken to reduce risk now and in the future and in fact a number of these are planned (moving most of general aviation flights to other airports, for example). We have found no "magic bullets" in the sense of measures that make dramatic changes in the quantitative estimation of external risk. This is to be expected given the safety consciousness that already exists at Schiphol. Some measures dramatically affect the risk-estimation inputs but still make only marginal changes in the individual and group risk estimates. For example, public safety zones near the runways dramatically reduce the fatality risk in those zones, but, because only a small proportion of the population lives in such areas now, the effect on group risk is not dramatic. Similarly, removal of general aviation significantly reduces the probability of crash for small aircraft at Schiphol, but because there are far fewer small aircraft operations and their crash footprint is smaller, the external risk estimates change by a much smaller amount. An important aspect of the quantitative risk-assessment model used in Chapter Six is the ability to measure enhancements in context. But, even when measures are evaluated as a group as done illustratively in Chapter Six, the effects are limited because they are not necessarily additive.

Airport Third-Party Risk Assessment Is Not a Well-Developed Science

Although the quantitative aspects of risk-assessment models are fairly well developed and have been used for other areas of risk for many years, there are components of airport third-party risk assessment that are still in a somewhat primitive stage. A key problem is that the complete data for risk estimation is either not collected or is very difficult to obtain from available sources (particularly for a short-term risk assessment). Fortunately for safety, there are few accident data points, but this also means that statistical estimates suffer from large uncertainties. For example, the paucity of accident data by aircraft type or airport means that the data across aircraft types and airports must be aggregated to have any statistical significance. Despite the fact that many aviation accidents are well documented, the specific causal chains for those accidents are frequently missing, either because they were indeterminate or because of sensitivity they have been suppressed. (Recall that under ICAO rules, the responsibility for accident investigation lies with the country in which the accident occurred, and in some countries there is little open discussion of blame.) The data regarding aviation incidents are even less complete and not systematically collected.

We have discussed in this report some of the other data difficulties that make it difficult to assess the probability of crash, the locational distributions of crashes with respect to flight paths, and the effects of crashes in an arbitrary built-up area. Judging by a review of several airport risk models,[3] there does not seem to be a consensus among the community of experts as to how to represent various aspects in the estimation of risk.

The data uncertainties can easily swamp estimates of risk and make definitive estimates difficult. There are other important uncertainties, described in the appendixes of this document, such as the fact that in many cases once the cause of an accident has been determined the aviation industry takes steps to remove it as a possible future cause, thus at the same time improving safety and reducing the prediction value of the historical crash data.

The recognition of these broad uncertainties in airport risk assessment is important both for this study and for future actions predicated on the ability to predict risk. Although we state the absolute risks from our calculations and compare the influence on this risk of various scenario changes and safety-enhancement options, we believe that these should be considered primarily in terms of the comparative assessments and possible directions of improvement. And, the variance in the results as stated in Chapter Six should be explicitly stated and considered.

The uncertainties have implications for risk standards. As stated in the introduction, risk standards make the most sense when there is an ability to reasonably predict the risk definitively. In the case of airport risk assessment, our results indicate that there is some doubt about this definitiveness. The uncertainties also make it more difficult to argue that certain possible safety enhancements are worth the costs and possible political consequences. These include the building of safety barriers, zoning, designing of flight paths to reduce risk, etc.

It is well known that the perception of risk is important and that this may swamp the quantitative considerations. For this reason we relied heavily on the safety survey, the interviews, and the content analysis to understand how external risk was perceived and how it is currently balanced against other factors. This aspect of a risk assessment, used before by RAND/EAC in The Netherlands in the case of flood risks associated with riverdikes,[4] provides an important complement to quantitative assessments and helps to address issues that cannot be addressed with quantitative risk calculations, particularly when there are large uncertainties.

We also believe that additional research at the international level is both desirable and possible to improve the state of airport risk assessment. Much more could be done in assessing the dimensions, applicability, and underlying models of the aviation accident data. We discuss some of this in the recommendations below.

RECOMMENDATIONS

Throughout the body of the report we have suggested certain safety improvement options. In this subsection we organize and repeat these recommendations.

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[3]Solomon (1975), op. cit.; Smith (1990), op. cit.

[4]Walker et al. (1993), op. cit.

Safety Management

The safety survey suggests that in accordance with the growth of Schiphol airport to a mainport, the informal nature of aviation safety management and coordination associated with Schiphol should be replaced by an integrated safety management system/office, which can perform the following functions:

- Coordinate and assess the safety procedures of the various operational organizations at Schiphol.
- Develop and coordinate airportwide emergency exercises, training and plans. This includes joint exercises with controllers and pilots involved.
- Centrally collect and review incident and hazard reports from all operating organizations at Schiphol. Develop actions and track their implementation based on the review. Collect and review incident and accident data from other sources, including U.S. and international aviation safety organizations, airlines, aircraft, and manufacturers.
- Perform ongoing reviews of operating decisions and Schiphol expansion plans as a safety advocate to balance economically, politically, and environmentally based decisions. Examples of safety issues and practices that should be reviewed by this office include:
  - — The low fuel pricing discussed in Chapter Three.
  - — The use of a single controller for both approaches and departures.
  - — The safety aspects of new SIDs and STARs.
  - — Fleet management including the outplacement of general aviation, etc.
- Provide information and act as a spokesman for safety to the public.

This integrated office should be implemented at Schiphol and consideration should be given to the establishment of an associated safety advisory panel of aviation safety experts that is independent of the airport management. The advisory panel would have no executive power but its advice would be made public.[5]

Maintaining and Enforcing High Standards

Schiphol and the Dutch organizations managing aviation safety already have high safety standards but some areas can be improved. It was observed during the safety audit that of the major European airports visited, Schiphol is only one without a formal airport or aerodrome certification process. The procedures for government certification and reexamination of air traffic controllers after privatization await acceptance by Parliament. As stated above, the government, while withdrawing in favor of decentralization and privatization, must still bear the responsibility for setting and verifying high safety standards. We have suggested that relevant certification programs be developed.

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[5]Because public perception is such an important part of risk, this structure should enhance the public confidence that airport safety is well managed.

The small size of The Netherlands and the economic and political dependence of the Dutch on the rest of Europe and the world make it difficult to enforce aviation safety standards with respect to foreign carriers, particularly when these standards exceed the *minimum* international standards (ICAO). We have discussed in Chapter Three the problem of restricting operations of suspected risky carriers, or of verifying unsafe operations of foreign aircraft and airlines. We also discussed how the United States has taken a more proactive stance in this regard. Because this is an important area of aviation safety (and will be even more important with growth and increasing flights from the new countries of Eastern Europe and the CIS), it is important that The Netherlands begin examining ways to identify risky carriers and considering the appropriate coalition within which to enforce limitations on them.

Currently, only two groups can report hazards and incidents anonymously or confidentially with respect to Schiphol and aviation safety in general. These are Dutch pilots and air traffic controllers, respectively. However, such reports are held and acted on independently by their respective organizations. There are no similar channels for other groups at Schiphol, such as the dispatchers, maintenance workers, and emergency teams. Because the lack of such a process is likely to result in some important safety-related incidents being unreported for fear of retribution, it is important that procedures be developed to permit anonymity to all possible reporters of aviation hazards and incidents and to assure that such is the case for the existing two processes.

Public safety zoning is another aspect that the government should address. Because the majority of historical aircraft crashes have occurred in a relatively tight region near the ends of runways, it is possible to create public safety zones that mitigate some of the highest individual third-party risk associated with the airport. This is currently done in the United Kingdom but in The Netherlands, only residential noise zoning limits development in these risky areas. Furthermore, because even these standards do not apply to businesses, it is possible for the business population to increase in these important areas of risk. The government should consider creating public safety zones in the regions near runway approach and departure points, as discussed in Chapter Five.

In general, the management should set "safety first" as a goal of all organizations associated with Schiphol. Although it is understood that levels of safety and risk must often be traded off against costs and other benefits, it should also be clear that safety is a first consideration and is not unnecessarily or unconsciously subordinated.

The government should also exercise caution in setting standards for external risk at Schiphol. We have noted in several places in this report some of the potential problems with standards, most notably that there are tremendous uncertainties in our ability to predict the external risks definitively. The benefits and risks associated with Schiphol are different in scale and type from those of other industrial facilities and therefore common standards that lump the airport with such facilities may not be appropriate.

Implementing Other Safety Enhancements

A number of potential safety-enhancement measures were discussed in the body of the report that have not been included in the recommendations so far. Technical measures such as the installation of GPWS in all classes of aircraft are not within the purview of the government but for such developed technology, it is possible for the RLD to advance recommendations to carriers or to propose ICAO initiatives that advance the timetable and comprehensiveness of implementation. The additional runway was shown to reduce third-party risk. This should be examined in more detail with the NLR risk model for verification. If found to be true, there is a safety incentive for this aspect of airport expansion. We have concluded through sensitivity testing with our risk model that optimization of SIDs and STARs for external risk reduction does not have high payoff once the effects of a new runway have been considered. This result depends on the model and data assumptions and should be verified by additional testing with the NLR model. If upheld, then we would recommend that the primary safety consideration of SID and STAR design be that associated with reducing complexity and workload for pilots and ATC. We also mentioned the practice of Cockpit Resource Management as a possibly important safety enhancement because of the frequency of aircrew causes in accidents. Although we are aware that KLM currently practices CRM, it is possible for the government to be more proactive by requiring all Dutch operators to practice CRM and to advance an ICAO initiative that all international carriers include CRM in aircrew training.

Informing the Public and Maintaining Trust in Safety Management

Chapter Four, which describes public perceptions about airport risk at Schiphol, indicates that there are concerns about growth, misperceptions about what constitutes risk in flight operations, and a belief that the various organizations are not telling the whole truth about some risks. Although it is not generally believed that there is a conspiracy to withhold information, it is clear that there is a perception of a bureaucracy that is not open to the public. Although there are valid concerns by the various organizations about disclosing information that cannot be judged in context, or that may lead to further misperceptions or exaggeration of risk, in Chapter Four we suggest some ways that a more open exchange might be achieved. The existing stakeholder and neighborhood groups, which meet periodically with Schiphol authorities, provide one forum for discussions of risk. An integrated safety management office described above would provide another. The important point is that the trust engendered by openness is critical to the acceptance and discussion of risks associated with expansion of the airport to a mainport.

In addition to more open communication, the public view of independence in the management of safety issues is important. If an integrated safety management system is not viewed as independent of organizational pressures on important safety matters, then the public perception of airport safety management will be tainted by skepticism. For this reason, the government should consider the use of an independent safety review panel to act in an advisory (nonbinding but public) capacity in conjunction with the proposed integrated safety management system.

Additional Research

Important research should be undertaken at the international level. There should be more definitive studies of historical crash data to understand better the causes, crash location distributions, and patterns associated with risky carriers, third-world airlines, older aircraft, the effect of airport size on safety, etc. These all have important implications for predicting risks for public safety zoning and standards, routing of arrivals and departures, limiting risky carriers or operations, and setting international standards. Research is needed on how to identify and control risky airlines, and how to collect, analyze and disseminate incident data, and international or regional databases for airport risk determination should be developed. Approaches and assumptions used in modeling airport risk should be published and debated in an open forum. It would also be useful to perform additional international airport safety comparisons to highlight alternative approaches to safety management and measure their effectiveness. The Netherlands could advance an EC initiative to perform this type of research for the enhancement of European aviation safety.

DESCRIPTION OF THE RISK-ASSESSMENT MODEL

INTRODUCTION

In this appendix, we overview the methodology used for estimating risk to third parties in the vicinity of Schiphol airport. The model is designed to be a useful policy-analysis tool and is general in nature. However, it has been developed and implemented with specific consideration for the character and quantity of data available for our analysis. The aim here is to present the modeling approach itself, along with descriptions of the risk measures obtained by our implementation of the model. Appendix B discusses the data used in our study.

Our model uses standard probabilistic concepts for estimating risk levels for individuals and groups near the airport. Estimates are computed for the likelihood of the crash of a specific flight, a probability distribution for the location of the crash, and the number of third-party fatalities resulting from the crash. To evaluate alternative policies, however, the model also pays specific attention to certain characteristics of each flight—both when interpreting historical data for estimating crash probabilities and when applying these probabilities to anticipated future flight operations at Schiphol. In particular, each flight is characterized by its aircraft type, mode of operation, time of day, assigned runway, and scheduled flight path (SID or STAR) within the airport study area. The occurrence of crash-related events is then conditioned upon these flight attributes in our analysis. Since the overall mix of flights with various characteristics is influenced by Schiphol policies and other factors, this conditioning approach allows us to examine the relative effects of specific scenarios on the safeness of the airport environs.

This appendix is divided into three parts. First, we describe the stochastic model of flight crash behavior. We then discuss sources and treatment of uncertainty in the model—introduced both by the stochastic variation inherent in the model and by the use of very limited data, as brought about by the fortunate rarity of airplane crashes. Finally, we describe how third-party risks are estimated and explain the model output measures.

RISK-ASSESSMENT MODEL

An individual flight is characterized by its aircraft type, mode, and time of day, as well as by the runway used and intended route. The model allows any definition of groups of aircraft types, modes, and times of day. However, for specificity, we include in parentheses below the sets of each used in our experiments. Runway and route descriptions and usage patterns are also model inputs of the user's choosing.

Further details regarding the definition of the attribute sets, along with runway and route descriptions, are given in Appendix B.

Let an individual flight be designated by amt, where

$$a \in A \equiv \text{Set of aircraft types } (= \{\text{Small, Medium, Large}\}),$$

$$m \in M \equiv \text{Set of operating modes } (= \{\text{Takeoff/Climb, Landing/Approach}\}),$$

$$t \in T \equiv \text{Set of time periods } (= \{\text{Business Hours, Non-Business Hours}\}).$$

There is a probability p_{amt} that an amt flight will crash.

A flight will be said to operate "from" a particular runway if it is assigned the runway for either takeoff or landing operations. Let R be the set of available runways and suppose a particular flight is operated from runway $r \in R$ according to a runway-selection process that may depend upon the flight characteristics a, m, and t. Suppose further that the flight is assigned route (SID or STAR) $q \in Q_r$, where Q_r is the set of routes available for operations from runway r. If the plane crashes, the location of the crash site relative to the assigned route is regarded as stochastic. In particular, a stochastic model is used to determine the location of the crash as measured by its distance s along the route (whether or not the course was strictly followed) and its perpendicular distance l from the route.

For computational purposes, the area surrounding the airport is discretized into a grid of K rectangular cells. When the site of a crash has been selected stochastically, it is mapped into one of the grid cells, indexed by $k \in \{1,2,\ldots,K\}$. The crash kills some number (possibly zero) of people within cell k and its neighboring grid cells. The number of fatalities depends upon the population within the affected cells (which depends upon the time of the crash), as well as upon the size of the impact area and lethality of the crash (both of which are related to aircraft type and mode—determinants of such things as skid distance, destructive force, and explosion potential and magnitude).

For a given year, let λ_{amt} denote the number of flights with the attributes a, m, and t. Since all flights are divided among runways and routes, we have

$$\lambda_{amt} = \sum_{r \in R} \sum_{q \in Q_r} \lambda_{amtqr},$$

where the summand λ_{amtqr} has the obvious interpretation as a refinement of λ_{amt}. These are treated as known quantities, determined by current and projected operational behavior at the airport.

Occurrence of a crash (but certainly not its location) is considered to be independent of a flight's assigned runway and route. Thus, the probability that a given $amtqr$ flight crashes remains p_{amt}, from above. Furthermore, all flights are treated as stochastically independent. The number of crashes of $amtqr$ flights during the year, N_{amtqr}, is therefore a binomial random variable with index λ_{amtqr} and probability p_{amt}. Since λ_{amtqr} is large and p_{amt} is small, the binomial distribution of N_{amtqr} can be approximated with a Poisson distribution having mean $\lambda_{amtqr}\, p_{amt}$.

For *amtqr* flights that crash, determination of the crash location is made by drawing from a joint probability distribution of distances s along the route and perpendicular distances l from the route. The distribution of s and l is obtained by fitting a distribution to locations of actual crashes relative to routes (see Appendix B). Once the location of the crash has been determined, identifying the grid cell of the crash is straightforward. The computational procedure for determining crash location is described in more detail below.

When a plane crashes at location (grid cell) k, it kills d_{amtk} people. This number of fatalities is naturally regarded as stochastic—that is, d_{amtk} is drawn from some distribution. For reasons discussed below, however, we work with the expected value

$$E(d_{amtk}) = O_{amtk} M_{amtk} ,$$

where O_{amtk} represents the expected number of people on the ground who are involved in the crash (a function of the population at k during time t, as well as the size, in area, of a typical *amtk* crash) and M_{amtk} is the expected proportion of people involved in the crash who actually lose their lives (mortality factor). Estimation of O_{amtk} and M_{amtk} is detailed below.

We are now prepared to measure the consequences of the crash of a particular flight. If an *amtqr* flight crashes, the assigned runway and route (r and q) help to determine a crash location k. The result is an *amtk* crash with fatalities d_{amtk}. So, the number of people killed if an *amtqr* flight crashes is

$$D_{amtqr} = \sum_{k=1}^{K} I(k|amtqr) d_{amtk} ,$$

where the indicator function $I(k|amtqr)$ equals one if the *amtqr* flight crashes in grid cell k and is zero otherwise. Recall that there are N_{amtqr} crashes of *amtqr* flights during a given year. If the number of deaths from the i-th such crash is $D_{amtqr,i}$, then the number of deaths resulting from *amtqr* flights during the year is

$$\sum_{i=1}^{N_{amtqr}} D_{amtqr,i} .$$

(Note that these results can also be derived using compound Poisson methods, with the number of deaths from a crash independent of the crash "arrival" process.) The total number of deaths during the year is then

$$T = \sum_{r\in R} \sum_{q\in Q_r} \sum_{t\in T} \sum_{m\in M} \sum_{a\in A} \left(\sum_{i=1}^{N_{amtqr}} D_{amtqr,i} \right) .$$

UNCERTAINTIES

In this subsection we discuss uncertainty. We begin by discussing how the model treats uncertainty. We follow that with a description of sources of uncertainty in the data. We end by illustrating how uncertainty is treated quantitatively.

How the Model Treats Uncertainties

Many of the quantities required by the model above are not directly available. We therefore must supply numerous quantities for estimating the various model components. For example, the number of *amtqr* flights during a year, λ_{amtqr}, is computed using estimates of total flight operations, along with the estimated proportion of all flights that have attributes a, m, and t, the proportion of *amt* flights that use runway r and, subsequently, the proportion of such flights that use route $q \in Q_r$. These quantities introduce uncertainty into our computations, although the model treats them as if they are known.

Two quantities are modeled stochastically. These are N_{amtqr}, the number of crashes of *amtqr* flights during the year, and k, the location of a crash, if one occurs. As discussed above, the number of crashes is assumed to have a Poisson distribution, given λ_{amtqr} and p_{amt}, and the location of a crash is determined by drawing from the distribution of s and l. The parameters that determine this latter probability distribution are modeled as if they are fixed and known; however, they are actually estimated (with uncertainty) from data on previous crashes.[1] This provides another source of uncertainty, albeit one that has a somewhat different flavor than does uncertainty about the number and location of crashes. As described in Chapter Four, we must also estimate the probability p_{amt} using proportions of previous crashes with certain characteristics.

Finally, there is an uncertain quantity—one that would be modeled naturally as stochastic if enough was known to do so: d_{amtk}, the number of third-party deaths if a

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[1] RAND's data encompasses the locations of 53 crashes. These were all of the 114 hull loss accidents in Boeing's database between 1 January 1982 and 31 December 1992 that had a recorded crash location and were more than 500 meters from the runway. Of the 53 crashes, 41 were on landings and 12 on takeoffs. All crashes had both x and y directions; none had distances along or from the intended flight path. These were not limited to Europe and included crashes in mountainous areas on the grounds that they would have occurred had the mountains not been there.

RAND's representation of crash location is not mechanistic. Instead, distributions were fitted to the prominent features of the data. The most prominent features were the clustering of crashes on the extended runway centerline and the differences between crashes on and off the centerline. Crashes on the centerline tended to be much closer to the end of the runway than were crashes off the centerline. Also, crashes on the centerline had (by definition) no dispersion about the centerline, whereas crashes off the centerline had a substantial dispersion. These qualitative features were true of takeoff and landing crashes, and formal statistical tests gave no indication that different distributions should be used for takeoff and landing, although for a sample as small as our takeoff sample, the power of such tests is low.

Thus, RAND's model of crash location first determines whether a crash is on or off the centerline, placing a crash on the centerline with probability .58, the fraction of crashes on the centerline in RAND's data. If the crash is on the centerline, its distance in the x direction is determined by a draw from an exponential distribution. If the crash is off the centerline, its distances in the x and y directions are drawn from independent normal distributions. These fitted distributions are in reasonable accord with the data according to standard diagnostic plots.

Although RAND's data were measured relative to the extended runway centerline, when the fitted distributions are inserted into RAND's model of crashes, they are used as distributions of crash sites as measured along and perpendicular to flight paths. For landings, this has no effect, because all landing flight paths in RAND's model are along the extended runway centerline. For takeoffs, curved SIDs are usually used; however, results with SIDs on the extended centerline differ little from runs with curved SIDs.

crash occurs in grid cell k. Our attempts to model third-party deaths in detail would be compromised by the lack of sufficient available data and historical studies of the phenomena associated with third-party deaths in air crashes. Therefore, we assess only the expected number of third-party deaths via O_{amtk} and M_{amtk} above and treat the uncertainty qualitatively.

In our analysis, we take account of uncertainty from three sources: the number of crashes; the location of a crash, if one occurs; and the uncertainty arising from having estimated p_{amt}, the probability of the crash of an *amt* flight. We use a quantitative measure of uncertainty, the so-called *predictive variance*, derived by combining the uncertainty arising from these three sources.

The predictive variance is most naturally defined using Bayesian terminology: It is the variance of the unconditional probability distribution for the (unknown) quantity in question—in our case, the number of fatalities in a given year. The term "unconditional" indicates that the distribution is not conditional on unknown parameters—namely, in our case, the p_{amt}. The unconditional distribution for deaths in a given year would be obtained by specifying the conditional distribution for deaths—described by the stochastic model above—and computing the integral of that distribution with respect to the posterior distribution of the unknown parameters in the stochastic model.

It would be ideal to represent uncertainty using a full probability distribution. However, given the limitations of the data and the difficulty of working with full distributions, we choose to use variance as a measure of uncertainty. Thus, we avoid specifying all the relevant distributions beyond the first two moments.

We want the predictive variance of

$$D_T = \sum_{r\in R}\sum_{q\in Q_r}\sum_{t\in T}\sum_{m\in M}\sum_{a\in A}\left(\sum_{i=1}^{N_{amtqr}} D_{amtqr,i}\right).$$

For the moment, treat the p_{amt} as known. We need to derive $\mathrm{E}(D_T|\mathbf{p})$ and $\mathrm{Var}(D_T|\mathbf{p})$, where $\mathbf{p}$ is a vector formed from the p_{amt}. In the sequel, we drop the notation "$|\mathbf{p}$" for simplicity. Now,

$$\begin{aligned}\mathrm{E}(D_T) &= \sum_{r\in R}\sum_{q\in Q_r}\sum_{t\in T}\sum_{m\in M}\sum_{a\in A}\mathrm{E}(N_{amtqr})\mathrm{E}(D_{amtqr,i})\\ &= \sum_{r\in R}\sum_{q\in Q_r}\sum_{t\in T}\sum_{m\in M}\sum_{a\in A}\lambda_{amtqr}\,p_{amt}\,\mathrm{E}(D_{amtqr,i}).\end{aligned}$$

The first equality follows from the presumed independence of the stochastic process that generates crashes and the process that generates deaths given that a crash has occurred. The second equality follows because N_{amtqr} is Poisson with mean $\lambda_{amtqr}\,p_{amt}$. Invoking a standard conditioning decomposition for variances, we obtain

$$\mathrm{Var}(D_T) = \mathrm{E}(\mathrm{Var}(D_T|\mathbf{N})) + \mathrm{Var}(\mathrm{E}(D_T|\mathbf{N})),$$

where $\mathbf{N}$ is a vector formed from the N_{amtqr}. But, since

$$\mathrm{Var}(D_T \mid \mathbf{N}) = \sum_{r\in R} \sum_{q\in Q_r} \sum_{t\in T} \sum_{m\in M} \sum_{a\in A} N_{amtqr} \, \mathrm{Var}(D_{amtqr})$$

and

$$\mathrm{E}(D_T \mid \mathbf{N}) = \sum_{r\in R} \sum_{q\in Q_r} \sum_{t\in T} \sum_{m\in M} \sum_{a\in A} N_{amtqr} \, \mathrm{E}(D_{amtqr}),$$

we have

$$\begin{aligned}\mathrm{Var}(D_T) &= \sum_{r\in R} \sum_{q\in Q_r} \sum_{t\in T} \sum_{m\in M} \sum_{a\in A} \lambda_{amtqr} \, p_{amt} \, \mathrm{Var}(D_{amtqr}) + \sum_{r\in R} \sum_{q\in Q_r} \sum_{t\in T} \sum_{m\in M} \sum_{a\in A} \lambda_{amtqr} \, p_{amt} \, \mathrm{E}(D_{amtqr})^2 \\ &= \sum_{r\in R} \sum_{q\in Q_r} \sum_{t\in T} \sum_{m\in M} \sum_{a\in A} \lambda_{amtqr} \, p_{amt} \, \mathrm{E}(D^2_{amtqr}).\end{aligned}$$

The p_{amt} have been treated as known in deriving $\mathrm{E}(D_T \mid \mathbf{p})$ and $\mathrm{Var}(D_T \mid \mathbf{p})$. Since they are not known, however, we have (using Bayesian terminology) a joint distribution for the vector $\mathbf{p}$. More specifically, we have a mean vector $\mathrm{E}(\mathbf{p})$ and a covariance matrix $\mathrm{Cov}(\mathbf{p}) = \Gamma$. Using the standard decomposition

$$\mathrm{Var}(D_T) = \mathrm{E}(\mathrm{Var}(D_T \mid \mathbf{p})) + \mathrm{Var}(\mathrm{E}(D_T \mid \mathbf{p})),$$

we obtain

$$\mathrm{Var}(D_T) = \sum_{r\in R} \sum_{q\in Q_r} \sum_{t\in T} \sum_{m\in M} \sum_{a\in A} \lambda_{amtqr} \, \mathrm{E}(p_{amt}) \mathrm{E}(D^2_{amtqr}) + \mathrm{Var}\left(\sum_{t\in T} \sum_{m\in M} \sum_{a\in A} p_{amt} \, \Delta_{amt} \right),$$

where

$$\Delta_{amt} = \sum_{r\in R} \sum_{q\in Q_r} \lambda_{amtqr} \, \mathrm{E}(D_{amtqr}).$$

If the Δ_{amt} are used to form a vector Δ, with ordering of components consistent with that of $\mathbf{p}$, then

$$\mathrm{Var}(D_T) = \sum_{r\in R} \sum_{q\in Q_r} \sum_{t\in T} \sum_{m\in M} \sum_{a\in A} \lambda_{amtqr} \, \mathrm{E}(p_{amt}) \mathrm{E}(D^2_{amtqr}) + \Delta^T \Gamma \Delta,$$

where the superscript T indicates matrix transposition.

Uncertainties in Data

Aircraft accidents are low-probability events. A typical accident rate is on the order of a few accidents per million flights. Even with a quarter of a million flights a year at busy airports such as Schiphol, there are insufficient accident data to allow a statistical analysis of the current and future safety at that airport to be based solely on data at that airport. Instead, one could use incident data, which are related to near accidents or events that could have potentially led to accidents. These data are much more numerous. Although incidents provide useful information about safety problem areas and the adequacy of responses, these data alone, however, cannot be used to predict accident rates, because one does not know what fraction and types of incidents will turn into accidents. Thus, one is compelled to use accident data at other airports to bolster the number of data points. The probability that a specific type of accident will occur at another airport is not the same as at Schiphol. The terrain and the weather conditions may be different, as may be the ability of the ground and air crews in handling unexpected problems and emergencies. The fleet may consist of less-well-maintained aircraft and may be equipped differently. As discussed in Chapter Five, all these factors affect air safety significantly. The applicability of global data or data at other airports to Schiphol is one area of uncertainty.

Another problem area involves the global accident data themselves. First, the Western world knows little about accidents inside the former Soviet Union (FSU) and Warsaw Pact, especially in the past. Yet, we have to deal with the potentially increasing number of East European aircraft flying into Schiphol. Judging by data released by the FSU, the West often reports the dubious result that Eastern aircraft are as safe as, or even safer than, Western counterparts.[2] On the other hand, a recent analysis indicates that the accident rate of controlled flights into terrain (CFIT) by jet transport aircraft occurring in the Eastern Bloc countries during 1959-1991 was 6.6 times as high as that in Europe.[3] Second, even when we know the accidents occurred, we still lack detailed information about some of them. The West knows very little about accidents taking place in the third world, either because accident investigation is not performed or its report is not available to the West.

The third area deals with nonaccident data. To arrive at accident rates, one divides the number of accidents by the number of departures, flight hours, air miles, or some sort of operational proxy. Generally available are number of accidents and accident rates. The latter is available only in very aggregate forms, such as number of accidents per million departures. Accident rates by aircraft types are more difficult to find, but they are made available to us by Douglas Aircraft Company.[4] There is a lack of other accident rates, such as those under severe weather conditions, at night, or flying over mountains. The paucity of such rates has little to do with accident data but much to do with nonaccident data. We call it the "denominator" problem. The

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[2]For example, using data released by the State Supervisory Commission for Flight Safety (Gosavianadzor), Council of Ministers, FSU, Shung C. Huang reported that the fatal accidents per 100,000 flight hours for FSU and the member states of the International Civil Aviation Organization (shown in parentheses) during 1981-1985, 1986, 1987, 1988 and 1989 were 0.09 (0.14), 0.12 (0.09), 0.05 (0.12), 0.08 (0.12), and 0.03 (0.14), respectively. These figures, if valid, would have indicated that the FSU aircraft were safer. "Worldwide Airline Fatal Accidents and Jet Transport Aircraft Hull Losses," *Flight Safety Digest*, February 1991, p. 20. On the other hand, ICAO reported that FSU flights had similar rates under a different measure. During 1986, 1987, and 1988, the passenger fatalities per 100 million passenger-kilometer for scheduled services including and excluding (in parentheses) the FSU flights were 0.04 (0.03), 0.06 (0.06), and 0.04 (0.05), respectively. *Civil Aviation Statistics of the World*, ICAO Statistical Yearbook, 1988, p. 11.

[3]Boeing (1992), op. cit.

[4]Some of the same data also appear in Douglas (1991), op. cit., p. 15.

accident investigation reports by the NTSB give detailed information about the accidents, the surrounding environment, and the likely causes. One can readily classify these accidents by weather conditions, time of day, geographical topology, etc. Lacking are the corresponding nonaccident data or denominator. One does not know how many flights were successful even under severe weather, at night, or over mountains. Without the denominator, we cannot estimate the effect of "avoidance" measures, such as restricting flying under adverse weather conditions. There is also little information about accident rates under multiple variables, such as the rate under low visibility *and* at night. Fortunately, the lack of denominator does not preclude us from examining "overcoming" SEMs.[5] These are the SEMs that allow the air or ground crew to overcome, instead of avoid, the adverse situation. The use of an automatic landing system (coupled approaches) during low visibility, if not creating a problem of its own, would be such a SEM, because it would overcome the difficulties of landing during low visibility. In other words, one can reduce or eliminate the number of accidents under such conditions without adjusting the denominator.

The fourth area deals with crash distribution data. Given that a crash will occur, one still has to determine where the aircraft will actually crash. Traditionally, one gets an idea by plotting crash locations with respect to the centerline of the runway from which the troubled aircraft took off or on which it was intended to land. One then models the crash distribution as a function of longitudinal distance along the centerline and the lateral distance from it. A more appropriate reference path could be the intended route of the aircraft or, as an approximation, the SID or STAR, if one is used. Accident investigation reports might record the name or the number of the SID or STAR used by the crashed aircraft, but the route is not graphically displayed in the reports. We know of no one who has compiled and published in one document the routes and crash locations of aircraft accidents. Neither did we have the time to search old records at airports for the SID or STAR at the time of the accident. Determination of the crash distribution is further complicated by the fact that the actual path even for a trouble-free flight often deviates considerably from the SID. An aircraft in distress is more unlikely to follow a SID. All these factors make the crash location distribution highly uncertain.

The fifth area deals with crash footprint and mortality factor. Even when the crash location is known, one needs to determine the impact damage area or footprint, which is affected by the size of the aircraft, the angle of impact, and the obstacles and types of structure/vegetation on the ground. The angle of impact sometimes is not known, if no one survives the crash, if the flight recorder is not recovered or usable and if there is no ground observer. The problem, however, is not so much lack of information, but no model to correlate footprint size to the combined effect of these parameters and no database to describe the structures, topology, and other features around the airport, which are relevant to predicting footprint sizes of crashes around the airport. Similarly, the percentage of inhabitants within the footprint who will be killed is also hard to ascertain, even if one knows the fuel load of the aircraft, the combustibility of the ground structure, and all other pertinent information.

Quantitative Treatment of Uncertainty

We computed a quantitative measure of uncertainty about the number of third-party fatalities from aircraft crashes. We were willing to quantify uncertainty from three

[5] Safety Enhancement Measures.

sources. Two sources were naturally quantified within our model: the number of crashes in 2003 and 2015, and the location of a crash, if one occurred. Also, because we estimate the probability of a crash using historical data, we can represent quantitatively our uncertainty about the true probability of a crash using standard statistical methods. Our method of combining the uncertainty from the three sources is derived below.

The resulting measure does not incorporate all sources of uncertainty. For example, the number of third-party deaths in a crash at a given spot would vary depending on a variety of factors. However, as discussed above, there has been so little study of the associated phenomena and so little relevant data have been collected that any attempt by us to model third-party deaths in detail would be, at best, guesswork in detail. We chose instead to assess only the expected number of third-party deaths if a crash occurs and to treat the uncertainty qualitatively.

ESTIMATES OF RISK

Computing Estimates

We now turn our attention to actually computing estimates of the expected total number of fatalities, as well as the expected number of fatalities at each location, or grid cell, during a given year. These are measures of "group risk" that also allow us to estimate the likelihood that an arbitrary person in a particular location will be killed by a crash—that is, the "individual risk."

Distinct differences exist between our efforts to design and implement a computational procedure and our attempts to characterize the underlying stochastic model. The description above highlights the differences in the stochastic and (presumably) deterministic components of the model. Estimating all quantities using proportions gleaned from empirical data blurs this distinction and allows us to rearrange terms in the model in an appealing way—at least from a computational perspective. Data are not available to sufficiently supply the model as it is described above. Rather, we must estimate quantities in the model by values derived from a large number of data sources. The number of terms to be manipulated grows significantly, so we shall divide the computations into manageable pieces for our discussion. All estimates required by our computational method are defined below; the sources of data for each estimate are outlined in Appendix B.

We wish to estimate (among other measures) the expected total number of fatalities, $\mathrm{E}(D_T)$. We have

$$\begin{aligned}\mathrm{E}(D_{amtqr,i}) &= \mathrm{E}(D_{amtqr}) \\ &= \mathrm{E}\left[\sum_{k=1}^{K} I(k|amtqr)d_{amtk}\right] \\ &= \sum_{k=1}^{K} \mathrm{P}(k|C_{amtqr})\mathrm{E}(d_{amtk}),\end{aligned}$$

where C_{amtqr} is the event that an $amtqr$ flight crashes and $\mathrm{P}(k|C_{amtqr})$ is the estimated probability that such a crash will be located at cell k. Therefore, we have

$$\begin{aligned}
\mathrm{E}(D_T) &= \sum_{r\in R}\sum_{q\in Q_r}\sum_{t\in T}\sum_{m\in M}\sum_{a\in A}\lambda_{amtqr}\,p_{amt}\,\mathrm{E}(D_{amtqr,i}) \\
&= \sum_{r\in R}\sum_{q\in Q_r}\sum_{t\in T}\sum_{m\in M}\sum_{a\in A}\left[\lambda_{amtqr}\,p_{amt}\sum_{k=1}^{K}\mathrm{P}(k|C_{amtqr})\mathrm{E}(d_{amtk})\right] \\
&= \sum_{k=1}^{K}\sum_{t\in T}\sum_{m\in M}\sum_{a\in A}\left[\mathrm{E}(d_{amtk})\sum_{r\in R}\sum_{q\in Q_r}\lambda_{amtqr}\,p_{amt}\,\mathrm{P}(k|C_{amtqr})\right] \\
&= \sum_{k=1}^{K}\sum_{t\in T}\sum_{m\in M}\sum_{a\in A}\mathrm{E}(D_{amtk}),
\end{aligned}$$

where $\mathrm{E}(D_{amtk})$ is the expected number of fatalities during the year (group risk) at location k caused by crashes of flights with the characteristics a, m, and t. This formulation allows us to identify by location the comparative levels of risk around the airport. Moreover, by computing the values $\mathrm{E}(D_{amtk})$ for all a, m, t, and k, we can build a large collection of aggregate risk measures through manipulation of the summations shown above. For example, the measure

$$\mathrm{E}(D_k) = \sum_{t\in T}\sum_{m\in M}\sum_{a\in A}\mathrm{E}(D_{amtk})$$

gives the expected number of fatatilities at location k caused by all crashes during the year. The measure

$$\mathrm{E}(D_a) = \sum_{k=1}^{K}\sum_{t\in T}\sum_{m\in M}\mathrm{E}(D_{amtk})$$

gives the expected number of fatalities during the year caused by all crashes of aircraft of type a, regardless of crash location, whereas

$$\mathrm{E}(D_{ak}) = \sum_{t\in T}\sum_{m\in M}\mathrm{E}(D_{amtk})$$

allows a location-specific comparison of aircraft types. Additional aggregate risk measures can be built in a similar fashion. Our selection of risk-measure outputs are described in later paragraphs. Here, we shall focus on the computation of the building block

$$\mathrm{E}(D_{amtk}) = \mathrm{E}(d_{amtk})\sum_{r\in R}\sum_{q\in Q_r}\lambda_{amtqr}\,p_{amt}\,\mathrm{P}(k|C_{amtqr}).$$

The formula for $\mathrm{E}(D_{amtk})$ is the product of two principal components. The first component, $\mathrm{E}(d_{amtk})$, is the expected number of fatalities from any *amtk* crash. The remaining (double summation) component is the expected number of *amtk* crashes.

The summand focuses on crashes from a particular runway and with a particular assigned route. The term $\lambda_{amtqr}\, p_{amt}$ yields the total number of *amt* crashes for the runway and route—that is, the number of *amtqr* crashes. $\mathrm{P}(k|C_{amtqr})$ apportions these crashes among the grid-cell locations. We shall discuss the individual terms from the formula for $\mathrm{E}(D_{amtk})$ in the following order: λ_{amtqr}, p_{amt}, $\mathrm{E}(d_{amtk})$, and $\mathrm{P}(k|C_{amtqr})$.

We estimate the total number of *amtqr* flights for a given year with

$$\lambda_{amtqr} \cong \mathrm{E}(T)\, P(q|q \in Q_r, r, amt)\, P(r|amt)\, P(amt),$$

where $P(amt)$ is the proportion of all local flights that have characteristics a, m, and t; $P(r|amt)$ is the proportion of *amt* flights that use runway r; $P(q|q \in Q_r, r, amt)$ is the proportion of *amt* flights from runway r that are assigned route $q \in Q_r$; and T is the number of operations (flights) of all types during the year. $P(amt)$, in turn, is defined by the conditioning rule

$$P(amt) = P(a|mt)\, P(m|t)\, P(t),$$

with $P(t)$ equal to the proportion of local operations that occur during time period t; $P(m|t)$, the proportion of flights during time t that operate in mode m; and $P(a|mt)$, the proportion of such operations that are conducted by aircraft of type a.

Note that the above quantities can be obtained from current and projected operations information for the airport. For example, $P(t)$ comes from the airport's records of distribution of flights by time of day. For some terms, reasonable independence assumptions allow us to relax some conditions. For instance, since most aircraft passing through Schiphol land and take off during the same general time of day, $P(a|mt)$ is replaced in our analysis by $P(a|t)$, ignoring the operational mode. Similarly, the time period is ignored for assignment of runways and routes, weakening the conditions in $P(r|amt)$ and $P(q|q \in Q_r, r, amt)$. These simplifications merely represent special cases of the problem, however. They can be accommodated with the above formulas exactly as written, although many proportions would be unnecessarily repeated across conditions that are judged irrelevant in the data. For efficiency, our model implementation takes account of the modifications described here. The expected flight operations level, $\mathrm{E}(T)$, is varied among computational runs for scenarios involving different years. As noted, Appendix B details the data used to represent these quantities.

The crash probability p_{amt} is a central driving force for the model—and perhaps the most intriguing value to estimate. The estimation of the probability of the occurrence of a crash with particular characteristics during an arbitrary flight operation requires intensive data-preparation efforts. Care must be taken in using *historical* accident data to predict *future* accidents. The probability that a certain type of crash will occur must be derived from information about known crashes, but *it must also account for the fact that such crash data represent only a small portion of all flight operations.* Bayesian analysis provides the mechanism for doing this, but it requires that existing crash data be examined in a particular way. An additional concern stems from the fact that a particular airport does not have sufficient local crash data for predicting future accidents, requiring the use of *global* data for estimating the likelihood of a *local* crash. Appropriate assumptions regarding similarities between the world's airports and the airport under study must be made, with corresponding screening of accident data that violate these assumptions (for example, accidents influenced by mountainous terrain should be removed from the data when a low-lying airport is being studied—or aggregate, marginal data should be properly treated by conditioning on terrain conditions).

The use of appropriately screened global data to estimate p_{amt} for Schiphol prompts us to enhance our notation slightly. In the following, all terms subscripted with w refer to global (worldwide) values. We have

$$\begin{aligned}
p_{amt} &= \text{probability a local } amt \text{ flight will crash} \\
&\cong \text{probability a global } amt \text{ flight will crash} \\
&= p_{w,amt} \\
&\cong \frac{P_w(amt|C)P_w(C)}{P_w(amt)} \quad \text{(Estimate with proportions and Bayes rule)} \\
&= \frac{P_w(amt|C)P_w(C)}{P_w(a)P_w(m)P_w(t)},
\end{aligned}$$

where the last identity assumes independence (at the cumulative worldwide level) of aircraft type, mode, and time of flight. Here, C indicates that a crash occurs, $P_w(C)$ is the proportion of relevant global operations resulting in a crash near the airport, and $P_w(amt|C)$ is the proportion of known crashes that have flight characteristics a, m, and t. $P_w(a)$, $P_w(m)$, and $P_w(t)$ are, respectively, the proportion of global operations flown by aircraft of type a, the proportion flown in mode m, and the proportion flown during time period t.

As noted above, $\mathrm{E}(d_{amtk})$, the expected number of fatalities from an $amtk$ crash, is the product of two components:

$$E(d_{amtk}) = O_{amtk} M_{amtk} .$$

We estimate O_{amtk}, the expected number of people on the ground who are involved in the crash, using

$$O_{amtk} = \mathrm{E}(P_{tk}) \frac{\mathrm{E}(Z|C_{amtk})}{A_k},$$

where P_{tk} is the population at location k during time period t, Z is the size (area) of the crash impact zone, and A_k is the area of grid cell k. (In our analysis, we use square, equally sized grid cells, so A_k is identical for all k.) Expected crash size, $\mathrm{E}(Z|C_{amtk})$, is estimated with average impact areas (from historical data) for each combination of aircraft type and flight mode only. (Location and time are not considered significant compared to aircraft size and fuel load—as determined by operational mode.) Note that the formula estimates the number of fatalities as a multiple (which can be greater than one) of the expected population in the grid cell considered to be the center of the crash. More elaborate numerical techniques for spreading the crash effects to portions of the neighboring cells can be devised. However, the character of the available population data has not supported such an effort for our purposes.

The mortality factor M_{amtk} is estimated using historical average fractions of people in the impact zone of a crash who actually die. Although not required by the model, in our study mortality factors are identical across time periods and locations.

Finally, we describe the estimation of the locational crash probabilities $\mathrm{P}(k|C_{amtqr})$. Although the aircraft type, mode, and time period influence the choice of runway and route—as provided by the conditional components of λ_{amtqr}—it is reasonable to assume that these factors (and even the runway) do not further influence the crash location, once the intended route has been chosen. That is,

$$\mathrm{P}(k|C_{amtqr}) = \mathrm{P}(k|C_q),$$

where C_q indicates the crash of a flight operation assigned to route $q \in Q_r$. The quantity $\mathrm{P}(k|C_q)$ is computable using only a route description, along with a distribution of crash sites about intended routes.

Suppose that the crash occurs at a point c and that route q can be described by a set of n piecewise linear segments. Mathematically, the ν-th route segment is represented by the line segment from $x^{\nu-1}$ to x^{ν}, with x^0 representing the start of the route (the takeoff or touchdown point) and x^n representing a point along the route beyond the boundary of the airport study area. Suppose that empirical data on crash location (see Appendix B) have been used to estimate the bivariate density function $f(s,l)$, where the pair (s,l) provides coordinates of the crash site according to the following scheme: The coordinate l is the orthogonal distance from the crash site to the nearest segment of q—if such an orthogonal projection exists. When an orthogonal projection to a segment of q does not exist, l is the minimum distance from the crash site to a line-segment endpoint $x^0, x^1, \ldots, x^n$. That is,

$$l = \min\left\{\min_{\nu \in \mathrm{N}}\left\|c-\omega^{\nu}\right\|, \min_{\nu=0,1,\ldots,n}\left\|c-x^{\nu}\right\|\right\},$$

where $\|\cdot\|$ is the Euclidean norm, ω^{ν} is the orthogonal projection of c onto the *line* containing the line segment $\left[x^{\nu-1}, x^{\nu}\right]$, and

$$\mathrm{N} = \left\{\nu \,\middle|\, \nu = 1,2,\ldots,n;\ \omega^{\nu} \in \left[x^{\nu-1}, x^{\nu}\right]\right\}.$$

(The condition on ω^{ν} permits only those projections that fall on actual flight segments—not merely along extended lines containing flight segments.) Ties are broken by choosing the lowest index ν. The coordinate s is the distance from x^0 to the point along q chosen in the minimization above.

The procedure used for estimating $\mathrm{P}(k|C_q)$ identifies the centerpoint c^k of grid cell k, determines its coordinates s^k and l^k using the above procedure, and estimates the probability by multiplying $f(s^k,l^k)$ by the area A_k. Following this computation for all $k \in \{1,2,\ldots,K\}$, each individual product is divided by the total probability assigned to the grid so that the probabilities sum to one. (This normalization step allows us to use $A_k = 1$, thus avoiding the multiplication above, when all grid cells are equally sized.)

Output Measures of the Model

Discussion of the results of computations based on the above model is presented throughout this report. However, here we shall briefly note the nature of the principal outputs provided by our implementation of the model. Most output measures are built using the computed locational fatality estimates $\mathrm{E}(D_{amtk})$. However, the basic model is used to extract additional useful quantities during a run, as well.

The principal risk measures are variations of group risk and individual risk. Group risk is the expected number of fatalities, aggregated in a number of ways, as described above. Individual risk is computed by dividing certain group risks by the number of individuals exposed to that group risk. In particular, if the expected fatalities at location k during time period t is $\mathrm{E}(D_{tk})$, as defined above, then each individual has an expected likelihood (individual risk) of $\mathrm{E}(D_{tk})/\mathrm{E}(P_{tk})$ of dying from an airplane crash during the year. Obviously, individual risks are only computed per time period because of their reliance on population values.

The following risk measures are included in the selected outputs of our risk-model implementation: (All measures are aggregated over all aircraft types and modes.)

Expected number of fatalities (group risk) for each time period and location,

$$\mathrm{E}(D_{tk}) = \sum_{m \in M} \sum_{a \in A} \mathrm{E}(D_{amtk});$$

Expected number of fatalities (group risk) for each time period aggregated over all locations,

$$\mathrm{E}(D_t) = \sum_{k=1}^{K} \sum_{m \in M} \sum_{a \in A} \mathrm{E}(D_{amtk});$$

Expected number of fatalities (group risk) for each location aggregated over all time periods,

$$\mathrm{E}(D_k) = \sum_{t \in T} \sum_{m \in M} \sum_{a \in A} \mathrm{E}(D_{amtk});$$

Expected number of fatalities (group risk) aggregated over all time periods and locations,

$$\mathrm{E}(D_T) = \sum_{k=1}^{K} \sum_{t \in T} \sum_{m \in M} \sum_{a \in A} \mathrm{E}(D_{amtk});$$

Expected square of number of fatalities (squared group risk) for each time period aggregated over all locations,

$$E(D_t^2) = \sum_{k=1}^{K} \sum_{m \in M} \sum_{a \in A} E(D_{amtk}^2);$$

Expected square of number of fatalities (squared group risk) aggregated over all time periods and locations,

$$E(D_T^2) = \sum_{k=1}^{K} \sum_{t \in T} \sum_{m \in M} \sum_{a \in A} E(D_{amtk}^2);$$

Individual risk for each location and time period,

$$E(D_{tk})/E(P_{tk});$$

Estimates of the probability of having m, $m = 1, 2, \ldots$, or more people killed in a single crash during the year.

Additional descriptive output includes:

- Population summary by time period, including total expected population, location and value of maximum expected population, and population histogram with user-specified histogram levels;
- Group-risk summary by time period and aggregated over all time periods, including location and value of maximum group risk, group-risk histogram with user-specified histogram levels;
- Individual-risk summary by time period, including population, location, and value of maximum individual risk, individual-risk histogram with user-specified histogram levels;

Finally, two variance estimates are reported to partially quantify the uncertainty in the group risk measures by time period and aggregated for all time periods:

Incidental variance, in which route-choice, crash, and damage estimates are assumed known,

$$E(D_t^2) - [E(D_t)]^2 \quad \text{and} \quad E(D_T^2) - [E(D_T)]^2;$$

Our use of variances and standard deviation is limited, since little can be determined about the underlying distribution of group risk. However, we can invoke Chebyshev's inequality in the usual way to make statements about the likelihood of experiencing real fatality levels beyond a certain range of values.

DATA DESCRIPTION

INTRODUCTION

We have collected four types of quantitative data to use in our model. The first is the business and nonbusiness hour population distribution around Schiphol. The second is the aircraft operational data (by business and nonbusiness hours, by size of aircraft, and by SID and STAR). The third is the aircraft global crash rate data (by mode of flight, size of aircraft, and category of aircraft). And, the fourth is the impact footprint of a potential crash.

In this appendix we first discuss the joint probability crash function. We then discuss three of the four types of data. The crash rate data were discussed in Chapter Six.

JOINT PROBABILITY CRASH FUNCTION

Our model of crashes needs a probability distribution for the location of the flight's SID or STAR. This distribution should describe the dispersion of distance from the runway along the SID or STAR and distance perpendicular to the SID or STAR (1), as depicted in Figure 6.1. The data available to us included all hull loss crashes worldwide since 1 January 1982 for which a crash location was recorded in the Boeing data. The crash sites were measured relative to the centerline of the applicable end of the runway (exiting end for takeoffs, entry end for landing). We used an x-y representation of crash sites, where x is the coordinate of the site parallel to the extended runway centerline and measured from the end of the runway, and y is the coordinate of the site perpendicular to the extended centerline.

The available data presented several problems to us. First, few crashes had site locations: 41 landings and only 12 takeoffs. Second, our model uses locations relative to the SID or STAR, but our data were measured relative to the extended runway centerline. Third, we had locations for only a selected group of crashes, and it was unclear how they were selected. For example, if all crashes within five miles of the airport were measured, but only some crashes outside five miles of the airport were measured, a distortion would be introduced if, of the distant crashes, only those nearest the centerline were measured. Fourth, pilot behavior can be presumed to affect the locations of crashes, in particular if pilots attempt to avoid populated areas. It is unclear how this would be reflected in our data and unclear how it would affect the possible location of a new crash near Schiphol. Fifth, the data are coarse: Almost 60 percent of the crashes were measured as being exactly on the extended runway centerline. Finally, as with other data sources we used, the relevance of crashes at other airports to Schiphol is unclear.

These problems affected several decisions about how to summarize these data and how to represent crash sites in the model. To the extent that we could, we made conservative choices in the sense they tended to disperse the probability, which we judged was an appropriate way to reflect our uncertainty about crash location. The effect of these choices is to diminish the apparent effectiveness of safety measures that involve manipulating runways and SIDs.

The principal feature of our data was its clear bifurcation: 31 of 53 crash sites were clustered on the centerline near the end of the runway, and the 22 crash sites not on the centerline made a highly dispersed pattern in both x and y directions. When all 53 crashes are taken together, the crash sites show increasing dispersion in the y direction as x (distance from the end of the runway) increases, because the centerline crashes tend to be much closer to the end of the runway than the off-centerline crashes.

However, for crashes not on the centerline, there is little if any indication in these data that dispersion in the y direction increases with distance from the end of the runway. The 16 landing crashes off the centerline show no increasing dispersion. The six takeoff crashes off the centerline are consistent with increasing y dispersion as x increases, but with so few points it is folly to make such a judgment.

This finding grated on our intuition: We had expected to see y becoming more dispersed as x increased, from the effect of diverging flight paths. Therefore, we formally compared two competing models:

1. No increasing dispersion: First, flip a biased coin to determine whether the crash is on the centerline or not; with probability 31/53 it is, and with probability 22/53, it is not. If the crash is on the centerline, draw its distance from the end of runway from an exponential distribution with mean about 3.5 miles. If the crash is off the centerline, make independent draws to determine its x and y coordinates. The x coordinate is drawn from a normal distribution with mean and standard deviation about 5 miles, and the y coordinate is drawn from a normal distribution with mean zero (i.e., centered on the runway centerline) and standard deviation about 6 miles. The specific means and variances were estimated from the data, and the distributional forms (exponential and normal) were adequate according to standard diagnostic plots.
2. Increasing dispersion: Draw the y coordinate from a normal distribution with mean 0 and variance a + b x^2, where a and b are adjustable constants estimated from the data. The x coordinate could be drawn from any of several distributions; we tried a normal distribution and an exponential distribution, with the respective adjustable constants estimated from the data.

Model (1) allows crashes with negative x values (past the end of the runway for landings, before the end of the runway for takeoffs), of which our data contained two, both landings. Model (2) embodies our intuition, in that the dispersal of crash location increases with distance from the end of the runway. It could produce data consistent with ours: As the x distance increases, there are fewer crashes, and thus fewer opportunities to observe extreme draws from the y distribution, so that dispersion might not be apparent. Model (2) does not allow crash sites with negative x values if x is drawn from an exponential distribution.

In the formal comparison, model (1) prevailed, even when we attempted to favor model (2) by changing the distribution in the x direction and by dropping a few crashes that counted most heavily against model (2).

On the basis of these formal tests, we elected to use model (1). Further, we decided to use model (1) to represent crashes relative to SIDs and STARs, although we also ran a case that ignored SIDs and STARs and used model (1) relative to the runway centerline.

The most noteworthy characteristic of model (1) is the dispersion of crash probability, which is much greater than the dispersion used in the previous Technica[1] analysis. Technica's analysis used judgmental assessments of the dispersion of crashes, resulting in much less dispersion than we found. The only other data-based analysis we have found was done by AEA Reactor Services. They used some of the same data we used but they also used two British data sources, one civilian and one military. (We cannot tell from the documentation which specific crashes they used.) Their analysis is reasonably consistent with ours: They used different probabilistic model forms but their result is similar to ours, certainly much closer to ours than to Technica's.

The dispersion of the crashes, it turns out, is consistent with the intuition of air traffic controllers and others, who expressed the opinion that the pilot of a distressed aircraft will not pay much attention to the planned flight path and may have little control over the aircraft, so that crash sites should show considerable dispersion and little relationship to planned flight paths.

POPULATION DATA

The population data around Schiphol was provided to us by the Advanced Decision Systems (ADS) at Delft. There are six sets of data representing population distributions in 1991, 2003, and 2015 during business hours and nonbusiness hours. Since ADS did not define business and nonbusiness hours, we classified 8 am to 6 pm during weekdays as business hours. All other hours are nonbusiness. The cell size for each data point is 100 meters by 100 meters and the overall grid size covers an area centering around Schiphol and 50.5 km in the north-south direction and 54 km in the east-west direction. The actual boundaries within which population data are available are shown in Figures B.1 and B.2. Moreover, since the original data came in a much more aggregate scale, the figures in the 100 m by 100 m cells are often average values of cell sizes much larger. The primary source of information was Dutch census data in the form of the number of registered houses per municipality or block. Since ADS had to use the same average number of occupants per house across all houses, the derived population distribution is subject to this translation error. ADS supplemented the basic data with information (location, number of beds, students, etc.) about individual hospitals, schools, retirement homes, mental homes, psychi-

[1] Smith (1990), op. cit.

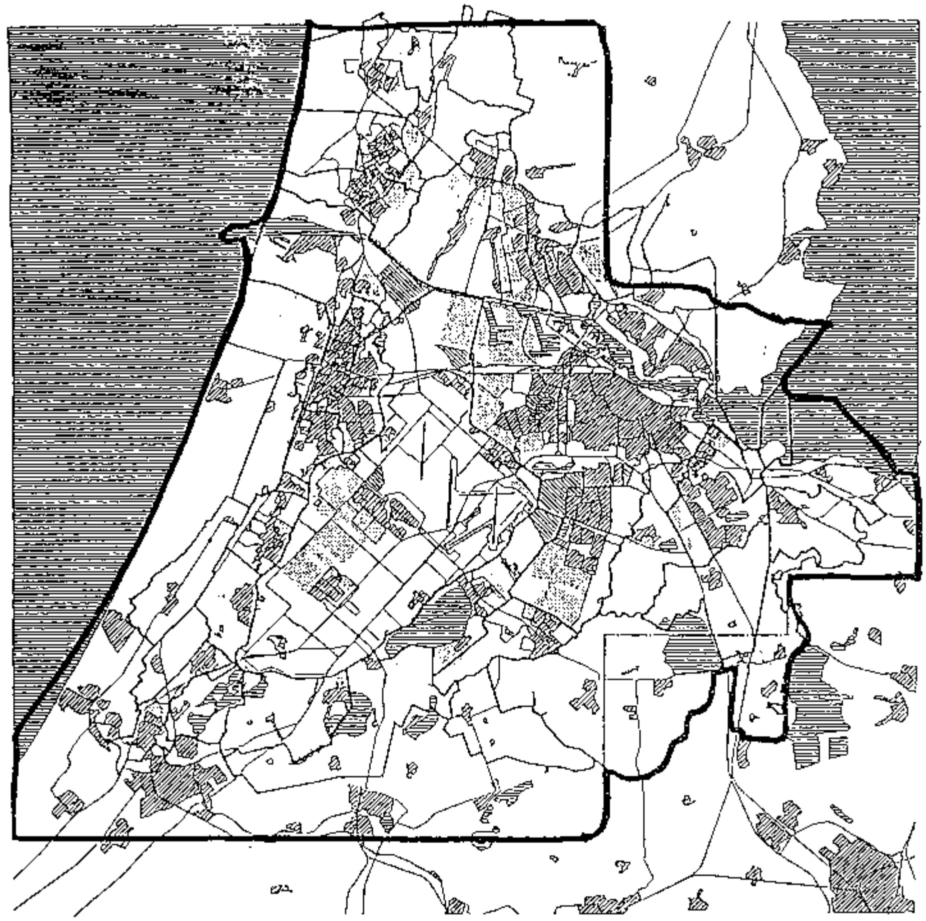

Figure B.1—Boundary Within Which Housing Data of Municipalities Are Available

atric centers, and student housing near Schiphol. It also incorporated into the database the distribution of about 517,000 laborers. Finally, ADS provide some data about the types of structures occupied during business and nonbusiness hours.

OPERATIONS DATA

Listed below are operational data used in the analysis and model runs but not already described in the main body of the report. Table B.1 shows the sizes of the aircraft types serviced by Schiphol. Also shown are their aircraft movements in 1991. These data are used to calculate the weighted average of accident rates for large, medium, and small aircraft serviced by Schiphol.

Tables B.2 to B.5 describe the distributions of takeoffs and landings by runway and aircraft size. Runway 04/22 is a short runway and suitable for use only by small air-

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Figure B.2—Boundary Within Which Housing Data Are Available in Addition to Those by Municipalities

craft, and the same practice will continue for the years 2003 and 2015. There are two cases for the year 2003. The one with four runways is labeled as 2003.4 and that with five runways as 2003.5.

Tables B.6 and 7 give information about the distribution among various SIDs for takeoffs.

CRASH FOOTPRINT AND NUMBER OF FATALITIES

Estimating the number of fatalities and injuries on the ground from an aircraft crash is very difficult at best. The variables to consider include:

- Size and weight of the aircraft,
- Amount of fuel on board,

Table B.1

Schiphol Aircraft Sizes and Movements

Aircraft Type	Aircraft Size	Number of Aircraft Movements at Schiphol in 1991[a]
Boeing 747-400	L	5,682
Boeing 747-300/200/100/SP	L	12,089
DC-10-30/40	L	4,327
Tristar L-1011-500/100	L	2,555
Boeing 767	L	3,288
Airbus A-300	L	450
DC-8-60/70/30/50	L	636
Airbus A-310	L	13,499
Boeing 707	L	1,882
Boeing 757	L	4,029
Boeing 727	M	3,060
A-320	M	4,302
MD 80	M	7,192
DC-9-50/40/30/10	M	12,562
Boeing 737-500/400/300	M	42,280
Boeing 737-200	M	16,176
BAE 1-11	M	4,222
BAE 146	M	8,936
Fokker F100	M	1,654
Fokker F28	M	6,383
Other medium commercial aircraft	M	692
Small commercial aircraft	S	47,849
East European countries and FSU		
• An 124, Illyushin 86/76/62, Tu 154	L	1,979
• Illyushin 18, An 12, Tu 134	M	529
• Yak 40	S	16
Other commercial flights	S	13,990
Non-commercial flights	S	26,326
Total		246,585

[a]Derived from Schiphol Airport Authority, *Statistical Annual Review* 1991, pp. 34–38.

- Angle of impact of the aircraft with the ground or the structure,
- Size and orientation of structure,
- Strength of structure,
- Combustibility of structure,
- Skid path before collision with structure,
- Effectiveness of emergency response, and
- Size of the area hit.

The number of fatalities and injuries on the ground from an aircraft crash can be estimated in two parts: First, calculate *mortality rate given a crash* (M) per 100 by 100 meter grid (the probability that there is a fatality in the grid cell assuming there is a crash) and second, estimate the number of grids affected (*the impact area or* A).

Table B.2

Distribution of Takeoffs by Runways in Percentages: 1991 and 2003.4

	Aircraft Size		
Runway	Small	Medium	Large
01L	22.3	27.4	27.4
19L	5.0	6.1	6.1
09	7.1	8.8	8.8
24	46.9	57.7	57.7
04	18.7	0	0
01LL	0	0	0
	100.0	100.0	100.0

Table B.3

Distribution of Takeoffs by Runways in Percentages: 2015 and 2003.5

	Aircraft Size		
Runway	Small	Medium	Large
01L	8.1	8.2	8.2
19L	20.4	20.7	20.7
19R	3.4	3.5	3.5
09	2.4	2.4	2.4
24	45.7	46.2	46.2
04	1.1	0	0
27	2.7	2.7	2.7
01LL	16.2	16.4	16.4
	100.0	100.1	100.1

Table B.4

Distribution of Landings by Runways in Percentages: 1991 and 2003.4

	Aircraft Size		
Runway	Small	Medium	Large
19R	29.5	33.1	33.1
01R	8.9	10.0	10.0
27	20.1	22.6	22.6
06	30.6	34.3	34.3
22	10.9	0	0
19RR	0	0	0
	100.0	100.0	100.0

Table B.5

Distribution of Landings by Runways in Percentages: 2015 and 2003.5

	Aircraft Size		
Runway	Small	Medium	Large
19R	12.1	12.2	12.2
01R	6.6	6.7	6.7
27	7.4	7.5	7.5
06	17.5	17.7	17.7
22	1.1	0	0
01L	1.1	1.2	1.2
09	.2	.2	.2
24	1.3	1.4	1.4
19RR	52.7	53.3	53.3
	100.0	100.2	100.2

Table B.6

Distribution of Takeoffs by SIDs in Percentages: 1991 and 2003.4

	Runway				
SID	01L	19L	90	24	04[a]
Pampus	10.82				
Pampus Special	20.44				
Lekko	8.62	25.20	25.15	17.94	20.00
Lekko Special	16.43				
Lopik	1.60	4.64	4.61	4.61	
Lopik Special	3.00				
Spykerboor	1.40			4.01	
Spykerboor Special	2.61				
Bergi	15.43	15.42	15.33	9.52	20.00
Bergi Special	17.13			5.81	
Valko	2.51	17.64	14.63	17.54	
Refso/Volla		2.12	4.91	2.10	20.00
Woody				7.21	
Nykc		23.29	23.65	14.63	20.00
Nykc Special				8.92	
Andik		11.69	11.72	4.81	20.00
Andik Special				2.91	

[a]For weekends, add Lopik and assign 16.67 percent to each of six SIDs.

To estimate M, we begin by assuming the condition "there is a crash."

There are few data on M from prior crashes. (Over the last 20 years, there may have been only a few dozen cases of ground mortalities following aircraft crashes and most have been one to a few score mortalities per crash). Hence, no one can predict with high certainty the value of M. Several analysts in the past have devised analytic

Table B.7

Distribution of Takeoffs by SIDs in Percentages:[a] 2015 and 2003.5

	Runway							
SID	01L	19L	19R	09	24	04	27	01LL
Pampus	21.81						10.91	21.81
Pampus Special								
Lekko	21.49	21.49	21.49	21.49	21.49	21.49	21.49	21.49
Lekko Special								
Lopik	5.10	5.10	5.10	5.10	5.10	5.10	5.10	5.10
Lopik Special								
Spykerboor	16.10				8.05		16.10	16.10
Spykerboor Special								
Bergi	15.95	15.95	15.95	15.95	15.95	15.95	15.95	15.95
Bergi Special								
Valko and Falcon	19.55	19.55	19.55	19.55	19.55	19.55	19.55	19.55
Refso/Volla								
Woody								
Nyke		21.81	21.81	21.81	21.81	21.81		
Nyke Special								
Andik		16.10	16.10	16.10	8.05	16.10		
Andik Special								

[a]For weekends, add Lopik and assign 16.67 percent to each of six SIDs.

techniques for addressing the value of M.[2] Although their approaches are quite sound analytically, typically, their approaches are very specific to a hardened structure (nuclear reactor Class 1 buildings such as the reactor containment) and assume a worst-case impact. Using these approaches as a basis, we can devise a parametric means for determining M. The value of M takes into account the size and weight of the aircraft, the fuel it has on board, and the nature of the structure hit by the aircraft.

Based on the prior studies, limited data on prior accidents, and a heuristic parametric approach, Table B.8 offers a rule for estimating the percentage of people killed relative to the total number of people in the structure (M or mortality rate given a crash). The value of M varies between 0 and 1.

The "no building assumption" would be valid for residential and smaller (i.e., four or fewer apartments) buildings.

To estimate total area when there is a taller building, we must consider three components to the impact area. The first component is the vacant lot area (discussed above); second is the shadow area defined by the impact angle; and third is the skid area, defined as the area immediately in front of the building when an aircraft crashes and skids into the building. The skid area and the shadow area calculations are given in Solomon et al. (1974), Solomon (1975a), Solomon (1975b) and Solomon (1987). As a rule of thumb, for larger buildings, the total impact area (vacant lot,

[2]See, for example, Wall and Augenstein (1970), op. cit.; Chelapati and Kennedy (1972), op. cit.; and Kennedy (1966), op. cit.

Table B.8

Mortality Rate Given a Crash

M	Aircraft	Structure
0.90	Large,[a] takeoff	Single family to few-story apt.
0.75	Large, landing	Single family to few-story apt.
0.40	Medium, takeoff	Single family to few-story apt.
0.30	Medium, landing	Single family to few-story apt.
0.20	Small, takeoff	Single family to few-story apt.
0.15	Small, landing	Single family to few-story apt.
0.50	Large, takeoff	Office, high rise apt., theater, etc.
0.40	Large, landing	Office, high rise apt., theater, etc.
0.30	Medium, takeoff	Office, high rise apt., theater, etc.
0.20	Medium, landing	Office, high rise apt., theater, etc.
0.10	Small, takeoff	Office, high rise apt., theater, etc.
0.10	Small, landing	Office, high rise apt., theater, etc.

[a]A reasonable definition of large and small aircraft based on the literature would categorize large as holding more than 30 passengers; all else would be small. If we have three categories (small, medium, and large), then holding fewer than 30 passengers would be considered small; DC10s, L1011s, and B747s would be large; and all else would be medium. These categorizations have been used in the literature to some extent. See, for instance, Wall and Augenstein (1970), op. cit.; Chelapati and Kennedy (1972), op. cit.

shadow, and, skid) could be up to three times that of the vacant lot area that the building occupies. Of course, many larger buildings could be surrounded by parks, open areas, parking lots, and other areas not heavily populated.

The impact area for a vacant lot could also be estimated as in Solomon et al. (1974). For example, the wing span of a B747 is 195′ 8″. The skid distance during a shallow-angle, takeoff crash (based on some prior studies of accidents) is up to a half to three-quarters of a mile (say around 3500 feet). Multiplying 3500′ by 200′ equals an area of 700,000 square feet or about 0.025 square miles. The value 0.025 square miles affects several 100 meter by 100 meter grids.

Based on prior studies and standards,[3] the impact area (A) can be estimated for the several conditions assuming an open field, i.e., no buildings (Table B.9).

For the purpose of the runs made in the present study, we assumed that the mortality rate is consistent with the single family to few-story apartment building version of Table B.8. We further assumed that the impact angle (see Table B.9) is steep. Our model is fully capable of running other mortality and impact area values. Table B.10 reflects our model inputs for the sets of runs reflected in the present study.

[3]Wall and Augenstein (1970), op. cit.; Chelapati and Kennedy (1972), op. cit.; and Kennedy (1966), op. cit.

Table B.9

Impact Area Following a Crash

A (sq mi)	Aircraft	Impact Angle
0.020	Large, takeoff	Steep[a]
0.015	Large, landing	Steep
0.015	Medium, takeoff	Steep
0.010	Medium, land	Steep
0.010	Small, takeoff	Steep
0.005	Small, landing	Steep
0.025	Large, takeoff	Shallow
0.020	Large, landing	Shallow
0.020	Medium, takeoff	Shallow
0.015	Medium, land	Shallow
0.015	Small, takeoff	Shallow
0.010	Small, landing	Shallow

[a]Greater than 20 degrees.

Table B.10

Impact Area and Mortality Rate Values Used in Our Runs

	Impact Area, A (sq mi)		Mortality Rate, M	
Size	Takeoff/Climb	Landing/Approach	Takeoff/Climb	Landing/Approach
Large	0.020	0.015	0.90	0.75
Medium	0.015	0.010	0.40	0.30
Small	0.010	0.005	0.20	0.15

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