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AIRPORT GROWTH
AND SAFETY

Executive Summary of the Schiphol Project

* Richard Hillestad * Kenneth Solomon *
  * Brian Chow * James Kahan *
  * John Stoop *

Supported by the Netherlands Ministry of Transport, Public Works and Water Management
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 discussed in the main 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: A Study of the External Risk of Schiphol Airport and Possible Safety-Enhancement Measures* (referred to as the "main report") 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.
# CONTENTS

Preface ........................................................................................................... iii
Contents .......................................................................................................... v
Acknowledgments ........................................................................................... vii
Glossary ............................................................................................................ ix

Chapter One
- INTRODUCTION ......................................................................................... 1
  - Safety at Schiphol in Context ................................................................. 1
    - Nederland Distributieland ................................................................. 1
    - Safety and International Aviation .......................................................... 2
    - Safety at Schiphol ................................................................................. 3
    - Focus of the Study ............................................................................... 4

Chapter Two
- DEFINING RISK ...................................................................................... 7
  - Measures of Risk ................................................................................... 7
  - Third-Party Risk ................................................................................... 8
  - Important Uncertainties Associated with Airport Risk ......................... 9
  - Risk Standards in The Netherlands .......................................................... 10

Chapter Three
- ANALYTICAL APPROACH ..................................................................... 13
  - Time Duration of the Study .................................................................. 14
  - Uncertainties in Data ............................................................................ 15
  - Limited Investigation of Runway Alternatives .......................................... 15
  - No Access to the Ongoing El Al Crash Investigation ............................... 15
  - Limited Ability to Predict Low-Probability Events .................................. 15

Chapter Four
- CONCLUSIONS .......................................................................................... 17
  - Schiphol Is a Modern, Safe Airport ......................................................... 17
  - Safety Considerations May Change as Schiphol Evolves into a Mainport ......................................................................................... 18
  - Schiphol Airport Safety Must Be Taken in Context ................................. 19
  - Safety Is an Airportwide Problem ........................................................... 19
No “Magic Bullet” Dramatically Reduces the Quantitative Risk Estimates ................................................................. 20
Airport Third-Party Risk Assessment Is Not a Well-Developed Science ................................................................. 21

Chapter Five
RECOMMENDATIONS ................................................................. 23
Safety Management ................................................................. 23
Maintaining and Enforcing High Standards ................................. 24
Implementing Other Safety Enhancements ................................. 25
Informing the Public and Maintaining Trust in Safety Management ................................................................. 26
Additional Research ................................................................. 26
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Most of the descriptive material in Chapter Two of the main report and the initial safety survey for Chapter Three of that report were developed for RAND by Flight Transportation Associates (FTA), under subcontract. Flight Transportation Associates provides professional consulting services on the technical, operational, economic, and management problems of air transportation. Principal investigators for FTA's contribution include:

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).

We thank Jos Lavrijsen of KPMG for conducting the group interviews, the 22 private citizens who donated their time to speak with us about airport safety, Luisella Kraak of the EAC for coding the newspaper articles, Lori Parker of RAND for data analysis of the content codes, Professor (Emeritus) dr. E. Abma of the University of Leiden, Professor dr. C. Vlek of the University of Groningen, and Professor dr. W. Wagenaar of the University of Leiden for informative discussions about Dutch public policy and perceptions regarding transportation safety.

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Irene Gordon and Sharon Drummond were invaluable in integrating and formatting the reports for the project and spent many late nights and frustrating days attempting to create documents from the inputs of a multitude of researchers providing material in many different formats.

We also wish to thank the following for their advice and contributions to the report:

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1Flight Transportation Associates, Inc., 675 Massachusetts Ave., Cambridge, Massachusetts 02139.

One member of the research team, John Stoop, was seconded to EAC/RAND by the Faculty of Systems Engineering and Policy Analysis of Technical University Delft. The support of SEPA and Dean Henk Sol is gratefully acknowledged.
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>ATC</td>
<td>Air Traffic Control</td>
</tr>
<tr>
<td>CIS</td>
<td>Commonwealth of Independent States</td>
</tr>
<tr>
<td>CRM</td>
<td>Cockpit Resource Management</td>
</tr>
<tr>
<td>GPWS</td>
<td>Ground Proximity Warning System</td>
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<tr>
<td>ICAO</td>
<td>International Civil Aviation Organization</td>
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<td>JAA</td>
<td>Joint Aviation Authorities for Europe</td>
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<tr>
<td>KLM</td>
<td>Royal Dutch Airlines, the main Dutch carrier</td>
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<tr>
<td>LVB</td>
<td>Netherlands Air Traffic Control Organization</td>
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<tr>
<td>NLR</td>
<td>Nationale Lucht en Ruimtevaart Laboratorium (National Aerospace Laboratory)</td>
</tr>
<tr>
<td>NVLS</td>
<td>Schiphol Airport Authority</td>
</tr>
<tr>
<td>RLD</td>
<td>Netherlands Department of Civil Aviation</td>
</tr>
<tr>
<td>SID</td>
<td>Standard Instrument Departure</td>
</tr>
<tr>
<td>STAR</td>
<td>Standard Terminal Arrival Route</td>
</tr>
<tr>
<td>VROM</td>
<td>Dutch Ministry of Housing, Physical Planning, and Environment</td>
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</table>
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 entire countryside 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,” 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.

---

1 Netherlands Distribution land.
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.

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, 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.

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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

<table>
<thead>
<tr>
<th></th>
<th>1986</th>
<th>2003</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Work force</td>
<td>78,000</td>
<td>110,000</td>
<td>150,000</td>
</tr>
<tr>
<td>Added value</td>
<td>MII 7,500</td>
<td>MII 15,000</td>
<td>MII 35,000</td>
</tr>
</tbody>
</table>

SOURCE: Numbers were provided by Schiphol Airport Administration. It should be noted that the Dutch have 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: MII = millions of Dutch guilders.

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 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 the main report, we 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 evaluated 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.

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 main-port.
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 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. 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, 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.

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

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1See 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.

2Boeing 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.

3This 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 shall discuss below.
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 (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. 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.

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4NTSB (1992), op. cit.

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.\(^6\) Hence, any decisions involving the operation of an airport must consider third-party risk.

**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 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 in the main report. 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

\(^6\)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 about 200 people per year. Of those fatalities, about 20 percent, or about 40, are likely to be pedestrians (pedestrians are exposed to 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.
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 their likelihood, location, and severity. 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 enough 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 toward 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. An example of this approach is 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.\(^7\) A more recent example is the expected likelihood in any given year that Dutch river dikes will not contain floods.\(^8\)

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.\(^9\) Although these standards apply to activities and substances associated with fixed sites (such as toxic emissions from a factory), the Dutch government is

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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.\(^{10}\) Among the objections to uniform standards are:

- 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.

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 of the main report.

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 of the main report 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, 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 from KPMG. Chapter Four of the main report 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 used also to identify leverage points for improving safety. RAND specialists in aviation risk analysis and statistics performed this task. Chapter Five of the main report 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 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, 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 of the main report with additional detail about the model and data described in Appendixes A and B of that report.

6. **Develop Overall Conclusions and Recommendations Regarding Third-Party Risk and Possible Safety Enhancements at Schiphol.** Each of the steps, 1–5, suggests 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 of the main report and is repeated in this executive summary.

Before summarizing the analysis, it is important to remind the reader of several 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 to
relate those 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 in the main report. 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 have to 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 in 1992.
Each chapter of the main 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

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1Group 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.

²In Chapter Five of the main report, we examine the relative influence of various factors in aircraft crashes and the possible implications for third-party risk. In Chapter Six of the main report we calculate the external risk for a small subset of the quantifiable measures. From these chapters, one can see the important leverage areas for reducing external risk.
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 ICAO, the EC, JAA, or even a regional coalition of airports with higher standards and controls.

SAFETY IS AN AIRPORTWIDE 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. 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 main 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. In fact a number of these are planned (moving most 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 lesser amount. An important aspect of the quantitative risk-assessment model used in the analysis 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 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. (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 the 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, three 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 appendices of the main report, 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.

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

3Solomon (1975), op. cit.; Smith (1990), op. cit.
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.

\(^4\)Walker et al. (1993), op. cit.
Throughout the body of the main report we have suggested certain safety improvement options. In this section we organize and repeat these recommendations.

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. They include 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 of the main report.
  — The use of a single controller for both approaches and departures.
  — The safety aspects of new Standard Instrument Departures (SIDs) and Standard Terminal Arrival Routes (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 would be independent of the airport management. The advisory panel would have no executive power but its advice would be made public.\footnote{Because public perception is such an important part of risk, this structure should enhance the public confidence that airport safety is well managed.}

**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 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.

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 of the main report 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 Commonwealth of Independent States (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 aircraft crashes have historically 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 of the main report.

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 Ground Proximity Warning System (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 it is 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 Air Traffic Control (ATC). We also mention the practice of Cockpit Resource Management (CRM) 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 of the main report, 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 various organizations have valid concerns about disclosing information that cannot be judged in context, or that may lead to further misperceptions or exaggeration of risk, we have suggested 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.