# Runway incursions, a cause for improved risk modeling?

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## Abstract

Although infrequent, serious accidents occur with large commercial aircraft during take-off and landing at major airports throughout the world. High numbers of casualties are involved and their occurrence draws public, media and political attention. Recently, the Transportation Safety Boards in the USA, the Netherlands and Taiwan have paid attention to this phenomenon of runway incursion. These occurrences seem to increase in numbers due to a series of developments in traffic growth, ATC pressure, technological deficiencies, changing roles and responsibilities in privatization and airport capacity constraints. These occurrences have their influence on the notion of ‘safety’. Internal and external safety merge as two components of an integral safety management responsibility of airport authorities. Rescue and emergency aspects are involved in the assessment of consequences, especially in the very low probability area. Applying conventional quantitative risk analysis techniques run short under these new developments. It may be necessary to re-model risk assessment strategies to these new needs. It is suggested to focusing on combining probabilistic and deterministic approaches and to apply a systems and process approach. Some recent transportation accidents and experiences in major projects in the Netherlands illustrate the cause.

## Introduction

The Netherlands faces an era of changes. Major infrastructure projects are under construction, traffic volumes are increasing, privatization is well under way and ICT applications become widespread in the transportation industry. Systems performance has benefited from these developments, since a rapid and extensive growth has been demonstrated over the past 10 years. These developments however do have their drawbacks on safety. Despite the efforts to maintain safety at the present high levels, risk and safety issues are in the spotlights of the political debate and in the press. On one hand, a small series of serious accidents have fuelled the debate on acceptability of risk. On the other hand, new players appear in the risk debate and decision-making arena, focusing on issues that have not taken into account before. Their involvement causes considerable change in the way risk is perceived by all stakeholders. Two major events in the Netherlands have revealed the need to readdress the risk issue to incorporate the needs and requirements of these new players.

First, a transfer of responsibilities in risk management has taken place from governmental agencies to privatized companies such as Amsterdam Airport Schiphol. The management of the airport is confronted with questions how to comply with risk standards. Their safety efforts must be made visible and taken into account quantitatively to demonstrate their compliance, accommodating the desired growth in traffic movements and planned increase in passenger and freight volumes. Their question can be stated as how to comply with risk standards and where to intervene to achieve safety enhancements. Transparency of the primary process becomes necessary. The Schiphol airport case will highlight this development.

Second, incorporating rescue and emergency objectives in an early phase of the design and construction of major infrastructure projects has been lacking. Fire fighting organizations only have an opportunity to participate in the risk decision making process during the detailing phase by issuing Construction and Operation Licenses. However, they have huge responsibilities to cope with consequences of a disaster. Such responsibilities should be expressed in early phase of the design and construction and adequately balanced against other design aspects. The design of the Westerschelde Tunnel has demonstrated the need for more specific risk approaches focusing on rescue and emergency management, in addition to conventional quantitative risk assessment techniques.

## The Schiphol Airport case

Despite the strong reduction of the number of aviation accidents per million aircraft movements over the period 1965 until 1985, the aviation community is dissatisfied with the stagnation of the accident rate. Over the past 10 years, the decrease in accident rate has stabilized at an almost constant level.

In 1998, leading aviation organizations and countries provided a strong impulse for the improvement of aviation safety. The Gore Commission chaired by the Vice President of the USA and the Federal Aviation Administration (FAA) launched the Safer Skies-A Focus Agenda program. This program aims at a five-fold reduction of the aviation accident rate within 10 years. In Europe, the Joint Aviation Authorities (JAA) launched the JAA Safety Strategy Initiative (JSSI) as a basis for an American-European co-operation. The motive for this massive initiative is in the reduction of major aviation accidents, irrespective of the worldwide growth in aviation traffic volumes. In addition, an ICAO (International Civil Aviation Organization) initiative focuses on the Safety Oversight Program and the European Civil Aviation Conference (ECAC) stimulates teams, assigned to SAFA (Safety Assessment of Foreign Aircraft).

In addition to focusing on specific accident types envisaged in this program, such as controlled flight into terrain, loss of control runway incursions or weather-related accidents, the Dutch Government has given priority to the development of policy instruments.

This policy orientation has emerged from a crash of an El-Al Boeing 747 in an apartment block in the Bijlmermeer near Amsterdam in October 1992. As a part of the revision of the Dutch aviation safety policy, an extra set of measures was initiated in the Nota Veiligheidsbeleid Burgerluchtvaart (civil aviation safety document) (VenW 1999). One of these measures defined a new approach by designing a new measuring system for the external safety of the airport. This system comprises of three principal elements: measuring, calculation modeling and data collection. The objective is the availability of parameters, indicators and causal models which are not only appropriate for measuring safety, but also to supply instruments for measuring the effects of a safety policy, preferable in a prognostic manner. A causal model should supply insight into cause-effect relations within the network of functions in the aviation system, qualitatively as well as quantitatively. International co-operation is considered to be crucial. A first start has been made with a Dutch–UK investigation into the causes of full freighter accidents, since their accident rate is four times higher than passenger carrying aircraft over the 1980 to 1996 period is. Simultaneously, an Integrated Safety Management System has been implemented at Schiphol Airport, focussing on the co-operation between all stakeholders at the airport regarding safety. The intended ‘causal model’ should establish a more direct causal relation between measures which enhance the internal safety, the effects on safety in general and residents in the area in particular (VenW 1999). Finally, a set of measures in case of emergencies should intend to reduce the consequences of an air disaster as much as possible. The new ‘causal’ approach therefore addresses safety more integral: internal safety, external safety, rescue, and emergency are all involved in the approach.

## The Westerschelde tunnel case

In the southwestern part of the Netherlands, a new stretch of highway will connect the two banks of the Western Schelde estuary. The most important part is the bored tunnel, stretching over 6.600 meters with a deepest point of 60 meters below sea level. Estimated costs count up to 1.18 million Dutch guilders, of which 350 million are allocated to safety measures. Many extensive discussions have had their influence on the eventual safety level of the design, leading to a new safety concept for such large infrastructure projects. The tunnel safety concept combine probabilistic and deterministic aspects into the concept of ‘integral’ safety. The ‘integral’ safety concept deals with five steps in the ‘chain of safety’ approach.

The first step is the pro-active stage: this stage deals with strategic choices, which aim to prevent unsafe alternatives wherever possible. Any identified hazardous element within the design scope can be eliminated. The second step aims at prevention: this stage concerns the reduction of the probability of events and limitation of their consequences. The third step focuses on the preparation for emergencies. This approach addresses the mitigation of the consequences. The fourth step deals with repression: the provisions to be taken by police, fire brigade, ambulance services and crisis management organizations. The fifth step focuses on the salvage and restoration to the regular functioning of the tunnel. Repairs on technical facilities and equipment and trauma care are involved in this stage. During the conceptual and functional design phase of the a third category of safety parameters was incorporated in the safety debate of the Western Schelde Tunnel. In addition to the conventional individual and group risk estimates, the safety for passengers and workers from a rescue and emergency point of view became a topic once the Fire Brigade had to assess the safety as a part of their Construction and Operations Certification process. Due to the infrastructure measures, which they required, and their inherent high costs, reconsideration on the safety measures was performed. Consequently, additional scenarios for safety critical intervention by rescue and emergency organizations were formulated, focusing on a critical size of events involving numerous victims, fire fighting and rescue resources. The accessibility of the site and the self-relianceness of passengers and road users became focal issues.

This development marked a change in focus in the development of major infrastructure projects in The Netherlands. Until a few decades, the Dutch took a pragmatic approach in the design of safety in tunnels. Based on past performance, -expressed by the nature and severity of accidents that had occurred- safety measures were balanced with respect to their anticipated costs and benefits. Spurred by the design and development of the Oosterschelde flood barrier, a second dimension was added to safety considerations: a probabilistic approach was introduced, assessing the risk level provided by the design and determining the measures which could improve the safety level. During the development of the Westerschelde Tunnel, a third dimension emerged in the form of scenario analysis. If the risk assessment indicates a compliance with standards, the self-relianceness and accessibility represent additional scenarios despite the low probability of these scenarios. This approach is indicated as ‘deterministic’. Both probabilistic and deterministic approaches should not be taken in isolation, but are complementary and even interactive. They both fit into a process in which the iterative nature is expressed (Worm and Hoeksma 1999)

- a first step which analyses the safety level by means of a quantitative risk analysis until compliance with risk standards is met
- a second step, analyzing a restricted number of scenarios, focusing on self-relianceness, survivability and accessibility for rescue and emergency services
- A third step, considering the integral design in the detailing phase, considering possibilities to achieve an even higher level of safety at low costs conform the ALARA principle (As Low As Reasonable Achievable).

## A cause for improved risk modeling?

Based on these two case studies, deficiencies in the risk debate can be observed with respect to apparent discrepancies in risk perception among stakeholders and a lack of consensus on the methods and risk mitigation strategies. Such a consensus is required to realize policy goals and stakeholders ambitions or to complete an infrastructure project without endless design modifications and construction delays.

### *Risk perception*

Some observations can be made concerning the risk and safety deficiencies as they appear in the newspapers.

First, disasters seem to come as a complete surprise to everybody. Immediately, the public and governmental responses express their disbelief that such an event could have been happening and request an in-depth investigation.

However, many of the precursing factors, which may lead to such an ‘unforeseeable’ event, are present and known by the experts in the sector from previous, similar occurrences. The probability of such an event is only zero if the activity is eliminated from the site. Expert judgements on the frequency of such events as ‘negligible’ prove to be disputable.

Second, the extend of events is beyond imagination. The failure mode and sequence is said to be unforeseen. The consequent effect and impact is therefore also unforeseen and proves to extend far beyond the limits of acceptable impact. Accident scenarios are incorrectly excluded from regular risk assessment procedures.

Third, several defenses have failed. Once the activity was accepted in the area, regulations and enforcement proved to be not fail-safe. Quantities were exceeded, inadequate maintenance was tolerated, enforcement lacked and firefighters and rescue services were not informed about the nature and extend of the possible event.

Questions raised after major disaster focus on size of the event and the perceived consequences, questioning credibility of the risk policies and decision making.

### *Deficient risk modeling?*

Current practices in quantitative risk analysis for major infrastructure projects and other hazardous undertakings are based on generic applicable risk models. Since no specific systems descriptions are available, because they conflict with the generic nature of the model, no specific scenarios will be incorporated in the risk assessment (Molag 1998). A further reduction of scenarios may take place if a scenario is ranked with a very low probability and therefore neglected, irrespective of the possible consequences. Risk models and scenarios have their origins in the hazardous material sector and have thereby an inherent characterization of the hazards involved. Other hazards, originating from the characteristics of another sector, such as transportation, are less likely to be incorporated. Hazards origination from the transportation of large amounts of passengers and goods have different characteristics, dealing with rescue and emergency activities. At the same time, major infrastructure projects generally have a unique character by their size and nature. This may well legitimize a specific modeling and risk assessment.

If a major accident occurs, the consequences may not be in the absolute numbers of fatalities alone, but in the overall numbers of fatalities, injuries and other participants; the population at risk. A fN diagram relates the number of fatalities to the probability of the event and may compensate for the 'risk aversion' within a society by adding a factor to the slope of the curve, such as fN*e2. A 'population at risk' approach however may express the risk aversion more adequately.

## **Runway incursions, a testcase for a combined approach?**

In the debate about a more integral safety enhancement strategy in the Netherlands, an attempt became necessary to fulfill the requirements of all major players in the aviation safety arena. The Ministry of Transportation initiated a project to develop a more ‘causal’ model to compensate for the apparent deficiencies in the conventional probabilistic risk assessment methodology.

The case of runway incursions has been selected by the author to illustrate the potential of such a new approach. The risk of runway incursions and the causal chain of events leading to their occurrence are more closely taken into account.

### *Runway incursions, a risk problem?*

A fundamental question regarding runway incursions is whether they pose an actual risk to the safety of aviation. For our purpose a runway incursions is defined as an event in which an airplane in its early departure or final approach, finds the runway blocked by other airplanes or objects that may jeopardize its safety with catastrophic consequences. Are runway incursions really so frequent that they should be prioritized as a threat to the functioning of the aviation system?

Based on accident data, only very few runway collisions with disastrous consequences have occurred. The most well known accidents occurred at Tenerife in 1977 (AAIB 1979) and Taiwan in 2000.

On march 27th, 1977 a collision occurred at the airport of Los Rodeos at Tenerife (Spain) between two B747 aircraft of KLM and Panam, during take-off of the KLM Boeing, while the Panam Boeing was still taxiing on the runway in thick fog in the opposite direction. Nobody of the KLM 234 passengers and 14 crew members survived, while in the Panam Boeing 9 out of the 16 crew members and 317 out of the 380 passengers were killed, 7 crew members and 48 passengers were injured and 15 passengers remained unhurt.

The general summary of the investigation established that: ‘the accident was not due to a single cause’ (AAIB 1979). The misunderstanding arose from generally used procedures, terminologies and habit-patterns. The unfortunate coincidence of the misunderstanding with a number of other factors nevertheless resulted in a fatal accident. In the operation of the KLM crew, nor in those of the tower controller or the Panam crew, actions can be indicated which should be considered as serious errors. However, in varying degrees, a non-optimal functioning can be recognized with all parties’.

The cause of the accident discriminates between human factors of both crews and tower controller, radio communication using ambiguous terminology and coincidence of a number of circumstances which directly influenced the course of the events and ultimately resulted in the collision.

In Taiwan, on October 31, 2000, at approximately 23.18 local time, a Singapore Airlines Flight SQ006 Boeing 747-400 airplane entered the incorrect runway at Chaing-Kai-Shek Airport. Heavy rain and strong wind from the typhoon “Xiang Sane” prevailed at the time of the accident. The airplane was destroyed by its collision with the runway construction equipment and by post impact fire. Prior to the accident, a NOTAM was issued indicated that portion of the runway 05R was closed for construction. There were a total of 179 people on board with 159 passengers, 3 flight crewmembers and 17 cabin crews. At the time, 83 people died and 45 people were injured. The final accident investigation report still has to be issued.

Recently, on December 10th 1998, a runway incursion occurred at Amsterdam Airport Schiphol between a Delta Airlines flight 039 Boeing 767 and a towed KLM Boeing 747. The incident did not result in a serious accident. Nevertheless, it was reported to and investigated by the Dutch Transportation Safety Board (DTSB 2001). The findings and recommendations in the final report, issued in January 2001, bear some striking resemblance wit the two other occurrences.

At the time of the serious incident low visibility and a low cloudbase made visual control from the tower impossible. Low visibility procedures were in force. DAL 39 had been cleared for take-off from runway 24. Almost at the same time, a KLM

Boeing 747 being towed and accompanied by a yellow van was cleared to cross runway 24. During the take-off roll the pilots of the DAL 39 observed the towed Boeing 747 crossing the runway. The take-off was aborted and the aircraft brought to a standstill before reaching the position of the tow.

Contributing factors to the incident were: low visibility weather conditions, inadequate information during radio communication, misinterpretation of position and movement of the tow, take-off clearance without positive confirmation and insufficient teamwork and supervision in the tower.

The similarities between the cases raise some questions:

- are these events rare and unique deviations from operation standards under poor conditions
- or are these events indicating system deficiencies which hardly result in accidents with very serious consequences

Apparently, the use of accident data alone does not provide enough information. An extension towards incidents may be necessary to identify the actual frequency of runway incursions, irrespective of the outcomes.

### *Runway incursions, frequent incidents?*

The frequency of runway incursion incidents and accidents in the USA alone has raised concern with the National Transportation Safety Board (NTSB), expressed by the testimony of its chairman Carmody before a Committee of the House of Representatives on March 28, 2001 (NTSB 2001).

According to FAA, the number of air travelers will increase from 604 million in 2000 to over 926 million by 2012. In addition, the FAA projects that aircraft operations at air route traffic control centers will increase from 46 million to about 61 million and that the number of passengers on foreign flag carriers traveling to and from the USA is expected to increase from 140 million to 267 million in the same period.

FAA data show that there were 429 runway incursions in the USA last year, more than twice the 200 incursions occurring in 1994 and a significant increase from the 322 in 1999. The runway incursion rate per 100.000 operations was .63 in 2000, up from .47 in 1999. It should be taken into consideration that small business aircraft accounted for a major contribution to these numbers.

Since 1993, the NTSB has issued almost 100 safety recommendations to the FAA regarding runway incursion issues. In 1991, the FAA stated that the cornerstone of its runway incursion efforts was the development and implementation of the Airport Movement Area Safety System, or AMASS. The system works on audible and visual alert to controllers when an aircraft or vehicle is occupying a runway and the arriving aircraft is close to the threshold or a departing aircraft is detected on the runway by the system. However, the alert parameters were not based on human performance studies but empirically determined on a prototype of the AMASS system.

It has been nearly 10 years after the NTSB issued its recommendations on developing and implementing an operational system to alert controllers to pending runway incursions at all terminal facilities that are scheduled to receive airport surface detection equipment. So far, none of the systems has been commissioned f or full operational use at any airport in the USA. Criteria for installation of airport ground surveillance systems and commitment to a specific date for completion of the acquisition and delivery of the systems are still lacking (NTSB 2001).

In conclusion, runway incursions can be considered a low risk event with even very low risks for large commercial aircraft if their frequency, aggravating circumstances and their disastrous consequences are taken into account.

If the frequency is taken into account irrespective of the outcomes and circumstances, the risk is much higher, especially when the risk is related to the growth in traffic volume and traffic density. System deficiencies at the level of developing and implementing vital support systems become apparent and reoccurrence of causal chains seem to appear with respect to procedures, human factors, communication and equipment.

## Generalizing and combining the concept, a process approach

Focusing on system deficiencies requires structuring of the attention. A focus towards the primary processes requires a subdivision of these processes in several steps. Such steps mark the transition between flight phases, the actors involved, their supporting equipment and procedures, transfer of responsibilities and information needs (Van Mierlo 2000). Geographically, these flight phases for inbound aircraft can be distinguished in four areas: approach, landing, taxi lanes and aprons. A hands-over procedure for ATC distinguishes Area Control Centers, Approach Control Facility and Tower Control. The sequence may be repeated for departing aircraft, distinguishing eight flight phases.

Each flight phase requires specific information regarding heading, altitude, speed, flight conditions, surrounding traffic and specific instructions.

During approach, the aircraft is guided towards the runway. Communication aims at the positioning, navigation and communication with surrounding aircraft. Communication is transferred from Area Control Center to Approach Control Facility (ACF), allowing the aircraft to enter the first phase.

The boundary between phase one and two is the responsibility of ACF and Aerodrome Control Tower (ACT) for a further guidance during the landing phase.

In the landing phase the aircraft touches down, reduces speed and leaves the runway. Hands-over of the aircraft to Ground Control occurs during taxiing after which a gate is allocated.

In the third phase, the aircraft is the responsibility of Ground Control, which coordinates all aircraft movements in the taxiing area.

Phase 4 covers the handling of the aircraft during docking

The departure phases cover the same phase of approach and landing in a reversed manner.

During each of the phases, specific hazards can be allocated to activities and tasks, taking into account characteristics of equipment, people and procedures. A risk assessment can be made, based on a variety of risk performance indicators, including the potential of damage and injury. However, other performance parameters can be added in the process, referring to other systems aspects and functions such as punctuality, quality, reliability and costs. An overall assessment of the safety performance can be incorporated in the system performance. In addition, the processes and phases can be discriminated with respect to the decision making level at which safety could or should play a role. A distinction is possible between operational, tactical and strategical levels in the decision making, each requiring a dedicated assessment of safety issues. (Stoop, Hengst and Dirkse 1997). Such an encompassing system does however not yet exist (Van Mierlo 2000). It is one of the challenges of the ‘causal’ model for the airport risk-modeling project.

## Conclusions and discussion

Quantitative risk modeling has laid the basis for enhanced levels of risk decision-making in The Netherlands. Due to new developments, new areas emerge, calling for a more ‘causal’ approach. Experiences, based on some major projects and major accidents in The Netherlands, have indicated three areas for debate to develop the insights in dealing with risk:

- major infrastructure projects may benefit from a combined effort in probabilistic and deterministic risk modeling to facilitate rescue and emergency aspects
- scenario definition should incorporate system or project specific scenarios to legitimize the specific nature of such systems or projects
- risk assessment modeling should not only take into account compliance with risk standards, but should be linked with risk management strategies as well.

At present, external risk models are based on probabilities and consequences of a limited number of accident scenarios, derived from a worldwide representative sample of accidents. Airport safety management systems however are based on airport specific sets of multiple performance indicators, including accidents and incidents. The paper has described a conceptual framework for a ‘causal’ model for the integral safety of a major airport. The framework takes into account a multi-actor setting, multiple performance indicator data and primary phases of the flight process at an airport, including surface movements, ground handling and communication. The use of accident an incident data in the model is indicated. An analysis of some major accidents is made to allocate risk-contributing factors to specific deficiencies in the system.

## References

AAIB 1979
Verdict of the Aircraft Accident Inquiry Board, regarding the accident on March 27, 1977 at Los Rodeos Airport, Tenerife (Spain) involving the aircraft PH-BUF of Royal Dutch Airlines N.V. (KLM) and N736PA of Pan American World Airways Inc. (PANAM), The Hague, July 1979.

Stoop, Hengst and Dirkse 1997
Integrating safety into the shortsea shipping system. In: Proceedings form the Third European research Roundtable Conference on Shortsea Shipping. 20-21 June, Bergen, Norway, pp 386-403. Delft University Press.

Molag 1998
CUR/COB-onderzoeksrapport N 110-03. Conceptueel risicoanalyse model voor transport door wegtunnels. TNO rapport TNO-MEP-R 97/228. (In Dutch)

VenW 1999
Veiligheidsbeleid Burgerluchtvaart. Tweede Kamer, vergaderjaar 1998-1999, 24 804, nr 21. (Letter from the Minister of Transportation to the Dutch Parliament, in Dutch)

Worm and Hoeksma 1999

The Westerschelde Tunnel: development and application of an integrated safety philosophy. Ministry of Transport, The Netherlands.

Van Mierlo 2000
De ontwikkeling van Safety Performance Indicatoren ter verbetering van de integrale veiligheid op de luchthaven Schiphol. Afstudeerverslag Technische Bestuurskunde Technische Universiteit Delft, Jan 2000 (in Dutch).

DTSB 2001
Final report 98-85/S-14, N 193 DN, Boeing 767, 10 December 1998 Amsterdam Airport Schiphol. Dutch Transportation Safety Board, The Hague, the Netherlands

NTSB 2001
Testimony of Carol Carmody. Acting Chairman, National Transportation Safety Board before the Committee on Appropriations, Subcommittee of Transportation and Related Agencies, House of Representatives, Regarding Aviation Safety. March 28, 2001.

## Author biography

John Stoop is an associated professor at Delft University of Technology. He has experience in transportation issues, rescue and emergency management and in accident investigation and its methodology.