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Management of ATM performance in operational concept development and validation: a case study

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***Abstract*—The NextGen and SESAR programs plan fundamental changes in air traffic operations in the US and Europe to reach ambitious performance objectives. A specific challenge in the development and validation process of advanced air traffic operations is to satisfy multiple and by nature almost contradictory objectives in key performance areas. The aim of this paper is to illustrate and analyze how this worked in a specific example development of an air traffic operation at Amsterdam airport by the Air Navigation Service Provider LVNL, where standard ICAO operations often do not suffice to satisfy ambitious performance objectives in multiple dimensions. In order to learn from this example, first a factual description is given of the cycles of operational concept development and validation performed, with a focus on validation with respect to safety. Subsequently, the factual example development and validation process is compared versus literature and versus FAA/ Eurocontrol overall validation guidance.**

Keywords- validation; operational concept development; safety; efficiency; environment; key performance areas

I. INTRODUCTION

The NextGen and SESAR programs plan fundamental changes in air traffic operations in the US and Europe to reach ambitious performance objectives. Validation of the operational concepts developed by these programs will aim to ensure that the eventually implemented operation will meet the performance objectives. FAA/ Eurocontrol guidance is available for validation of operational concepts in air traffic operations ([15], [13], [6]). Experiences with the validation and implementation of such fundamental changes in air traffic operations are however scarce; an example exception is [23]. A specific challenge in the development and validation process of advanced air traffic operation is to satisfy multiple and by nature almost contradictory objectives in key performance areas. The management of effective feedback loops between iterative development and validation activities is then crucial for the eventual success of the envisaged operation.

Experiences in development and validation of air traffic operations on Amsterdam airport may provide useful lessons for validation of operational concepts. On Amsterdam airport standard ICAO operations often are insufficient to satisfy ambitious performance objectives set in safety, capacity, environmental sustainability, and other areas. Safely operating in the context of the given runway structure, the high traffic demands, and the strong Dutch environmental laws put significant constraints on the developments. This formed the motivation for the Air Navigation Service Provider LVNL to establish the use of an organized development and validation process ([34], [33]). Lessons learned from LVNL experiences are expected to be of value for NextGen and SESAR.

This paper aims to analyze how operational concept development and validation have co-operated and interacted in a specific practical example of the development of an air traffic operation on Amsterdam airport by LVNL. Remarkable aspect of this specific example, is that after initially several advanced solutions had been considered, eventually a simpler but also more expensive solution was implemented. The validation processes are considered with a focus on safety, as validation of the safety performance played a crucial role in the operational concept development considered.

Definitively, it is not the objective of this paper to defend or promote development choices made. These choices have been made by the responsible decision-makers for the specific situation and context of Amsterdam airport. The focus is on the validation process conducted and the interaction with concept development.

The paper is organized as follows. Section 2 explains the design challenge that was faced by LVNL at the beginning of the example development and validation process. Section 3 gives a short description of the overall development and validation process. Section 4 provides a factual description of the cycles in which operational concept development and validation interacted, including descriptions of decisions made in each cycle. Section 5 analyzes (in hindsight) how operational concept development and validation interacted. Section 6 draws concluding remarks.

An initial version of the analysis shown in this paper has been presented in [28]. The current paper however has a different scope, and includes a comparison with FAA/ Eurocontrol overall validation guidance.

II. THE DESIGN CHALLENGE CONSIDERED

In 2000, the physical construction of an additional runway on Amsterdam airport was started, at a location to the North

West of the original runway layout (see Fig. 1), where the noise impacts of air traffic on the airport's environment would be more limited than when using other runways. Due to the vicinity of the village Hoofddorp in the South, the new runway 18R/36L would only be used for departures to the North, and for arrivals from the North.

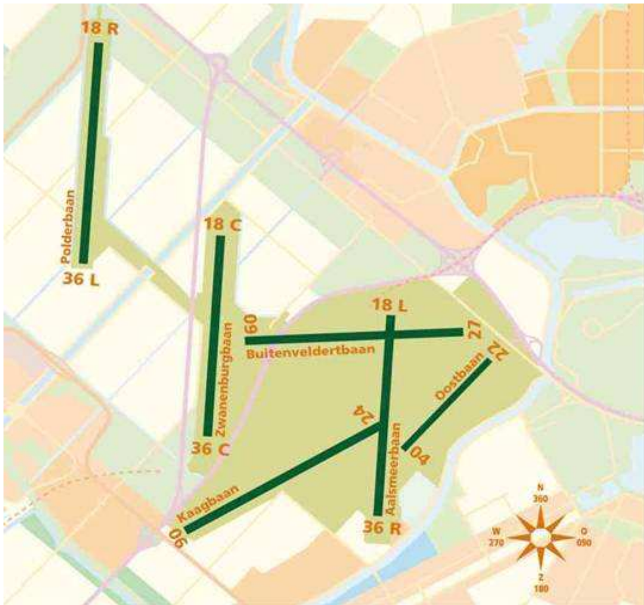


Figure 1. Amsterdam airport runway layout, including the new runway 18R/36L, and excluding taxiway layout.

The then already existing runway 18C/36C is in between the selected location of the new runway 18R/36L and the centre of the airport. As all terminals and parking positions were at or around the centre of the airport, all aircraft departing from runway 36L or landing on runway 18R must pass in one way or another runway 18C/36C. The simultaneous usage of these two runways is often necessary, both to ensure a sufficiently high capacity of the airport, and to satisfy environmental restrictions regarding noise impact. Considering also airline demands, availability of other runways, and the usual variation in wind conditions, the usage of runway 18C for landings (Inbound Modes 2 and 3 in Fig. 2) and of runway 36C for departures (Outbound Modes 1 and 4) is specifically frequent, but also the opposite directions are sometimes needed (IM4 and OM3).

An operation was to be developed in which aircraft taxi between runway 18R/36L and the centre of the airport, while simultaneously runway 18C/36C is used. Part of the design challenge faced was that the capacity of each of the two runways should be comparable to the normal runway capacity, and that the operation should be acceptably safe.

Further objectives had to be taken into account, such as the minimization of delays for efficiency reasons, the minimization of taxi times for stakeholders' economical reasons, the acceptability of the operation to pilots and air traffic controllers, and minimization of related development costs for LVNL and stakeholders.

Before the start of the development process by LVNL, the airport operator in consultation with its stakeholders had already decided on the development of a taxiway infrastructure. In this early stage, three main operational development options had been considered:

- Active runway crossings via one or more crossing locations over runway 18C/36C;
- Taxiing via a perimeter taxiway to the North of runway 18C/36C (Northern Taxiway or NTW); and
- Taxiing via a perimeter taxiway to the South of runway 18C/36C (Southern Taxiway or STW).

These three options are illustrated in Fig. 3.

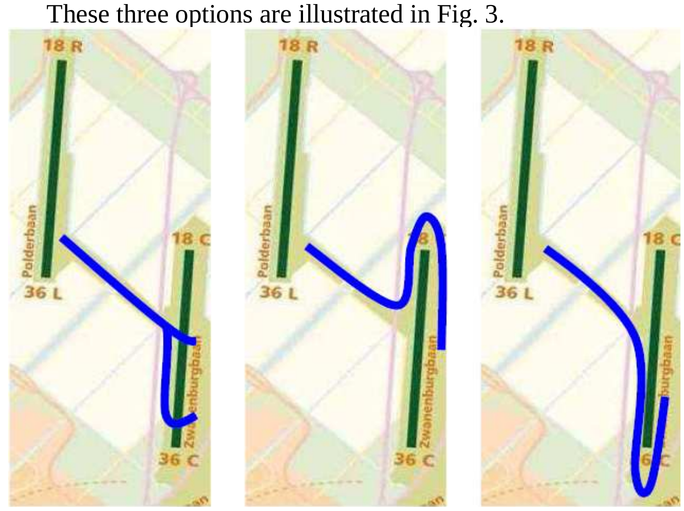


Figure 3. Schematic representation (in blue) of three main development options identified in an early stage: active runway crossings, NTW and STW.

The decision was taken to develop an infrastructure including several crossing locations and a STW. The crossing locations were intended to keep taxi times between airport centre and the far-off runway as low as possible, and the related development costs for the airport operator were relatively low

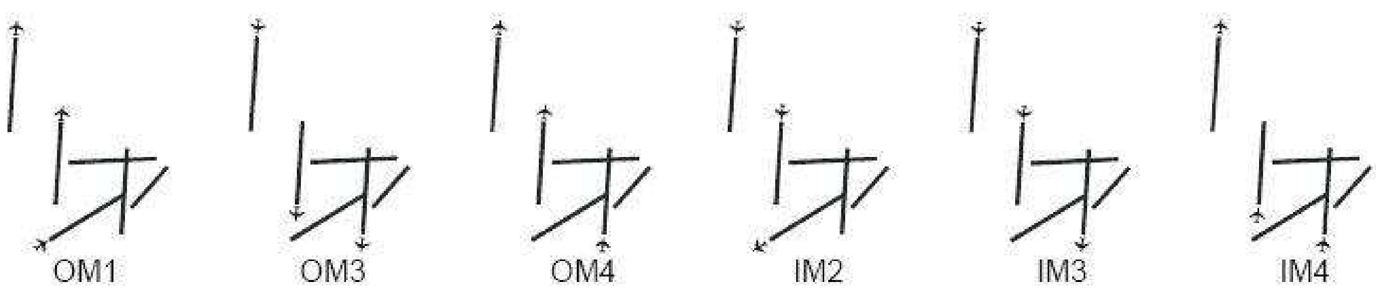


Figure 2. Schematic presentation of the most relevant configuration modes with simultaneous use of runways 18R/36L and 18C/36C.

when compared to perimeter taxiways. Additionally, one perimeter taxiway was selected, e.g., for use in situations in which traffic on runway 18C/36C momentarily does not allow active runway crossings. The STW was preferred over the NTW as operations on the STW have no effect on the most frequent operations of runway 18C/36C (departures on runway 36C and landings on runway 18C).

Above decisions were supported by an early safety study [16], which subsequently formed key inputs to LVNL's development process considered in this paper. These safety studies were done by identification of hazardous scenarios following a formal HAZid method, and apportionment of a total available risk budget over these hazardous scenarios using engineering judgment. In these early safety studies it had been concluded that each of the three main development options can be made acceptably safe, with the STW option having lowest safety risk, followed by the NTW option, and finally the active runway crossing option. For the NTW option and the active runway crossing option, design requirements had been defined under which they would be acceptably safe. As ICAO recommends not introducing taxiway crossings of runways in developing taxiway systems [17], the design requirements for the active runway crossing option included advanced items as:

- The development of a new 'runway control concept', in which a so-called runway controller is responsible for all traffic on/ around runway and where (s)he has direct communication with all this traffic; and
- The development and installation of a high-integrity stop bar system and a runway incursion alert system (RIAS) for Amsterdam airport.

Finally, the design requirements for the active runway crossing option had been further detailed into requirements as: the probability that RIAS fails to detect a runway incursion is at most 10^{-5}; and the probability that the runway controller fails to react appropriately to an alert is at most 5×10^{-5}.

From this point on LVNL as Air Navigation Service Provider took over the further development and validation processes for the taxiing operation during simultaneous usage of runways 18R/36L and 18C/36C. It is noted that the related potentially safety critical issue of runway incursion risk caused by aircraft accidentally entering a runway via an exit, e.g., because of pilots being lost, is not considered in the scope of this paper, as this safety risk is relevant on the entire airport, and therefore LVNL put a separate program in place to manage this safety risk.

III. DEVELOPMENT AND VALIDATION PROCESS

In this section the organization of the overall development and validation process at LVNL is described. First a description is given of generic development and validation models from literature, which formed the blueprint for this process.

A. *Development and validation basis*

Overviews of models for the development of complex products are given by e.g., [37] and [26]. The most relevant models are described here in short.

For the development of relatively simple products, a sequential model can be used in which clear stages can be distinguished that do not need to be repeated once the stage is over. Each stage delivers input to the next stage, and between the stages clear braking points exist in which no on-going tasks take place. This sequential model is the waterfall model [25].

For the development of complex systems, it is usually necessary to check that the outputs of a stage satisfy the specifications of the inputs, and that the outputs meet the requirements that are in some way imposed to it by the real world application. For such developments, the V-model ([22]; see Fig. 4) is available: following this model, it is verified after each stage whether it has been correctly performed, and the production of each stage is validated against the requirements.

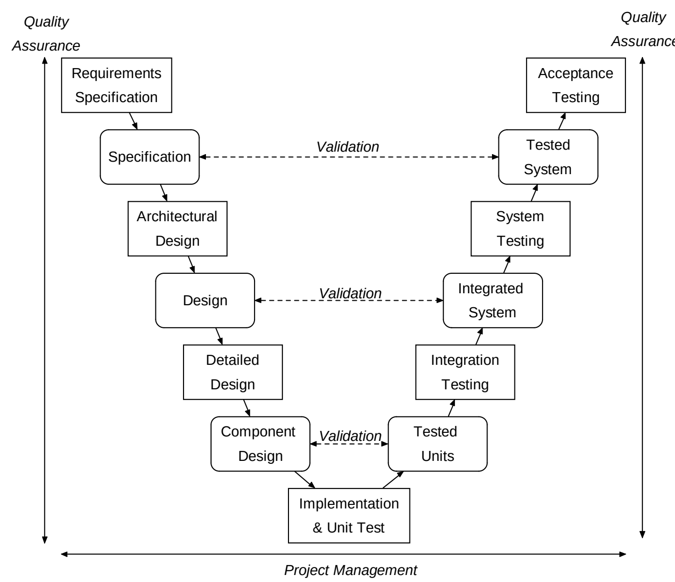


Figure 4. The V-model from [22]

Both the waterfall model and the V-model assume that all problems that will arise during development can be foreseen. The spiral model [5] acknowledges that this is not always possible, and proposes to go iteratively through a number of steps to progressively develop a solution. Fig. 5 illustrates this spiral model.

The development starts at the inner circle, with the progress measured in the angular dimension, and the cumulative costs represented on the radial axis. A typical cycle in the spiral starts with identification of the objective of the portion of the product to be developed, the alternative means of implementing the portion, and of the constraints imposed on the application of the alternatives. Next, the alternatives are evaluated relative to the objectives and constraints, such that project risks related to the alternatives are identified and resolved. If risks remain regarding performance or user interfaces, the suggested next step is to use a minimal effort to specify the overall nature of the product, and use verification and validation, and planning of the next cycle before further detailing the design. If previous prototyping efforts have already resolved all performance or user-interface risks, then further development of the portion of the product may follow the basic waterfall model.

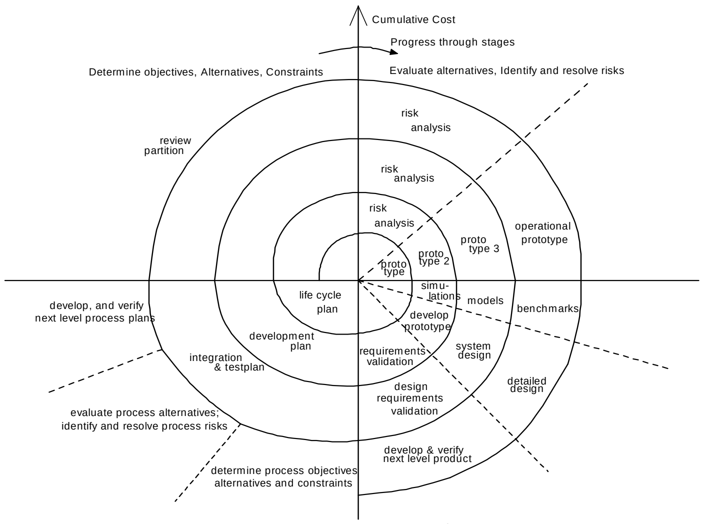


Figure 5. The spiral model from [5]

B. LVNL's development and validation process

LVNL started the development and validation process organization a decade ago, and has taken advantage of the spiral development and validation model, with an adaptation to the specific additional needs posed by the multi-actor setting of air traffic operations [1]. The most recent descriptions of these processes at LVNL are given in [34] and [33]. In these documents, the rationale, drivers and fundamentals behind these processes are explained in detail. The processes are organized around VEM Management, where VEM stands for 'Veiligheid, Efficiency en Milieu' (in English, Safety, Efficiency and Environment). VEM Management constitutes a combination of activities and decision-making within LVNL with the objective that ATM services are provided in accordance with the required performance.

The required performance is defined by the combination of stakeholder and LVNL corporate objectives. This performance is a function of time, and is thus defined for both the present and the future operation, making use of experience from the past.

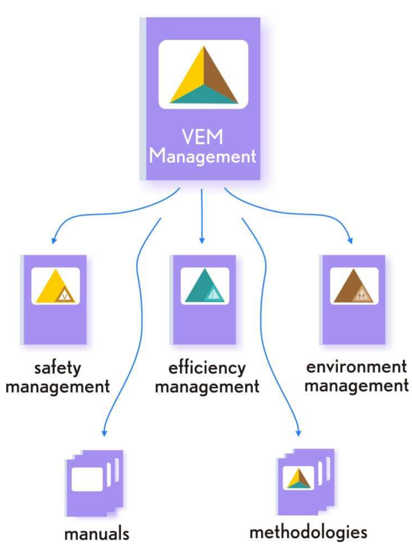


Figure 6. VEM management hierarchy

Regarding the quality of its provided services LVNL considers safety, efficiency and environment in an integrated way. Once the desired performance in terms of these three values is defined, the performance can be assessed and controlled largely individually for safety, efficiency or environment. Where applicable, the three performance values are considered jointly again in decision-making at different levels of the organizations. For safety, use is made of apportioned ATC safety criteria based on accident rates [8]. Within this structure, safety management is the total of controlled activities, procedures and processes that are designed to attribute to the desired safety performance. It can be said that safety management falls under the umbrella of VEM Management, the same as efficiency management and environment management do (see Fig. 6).

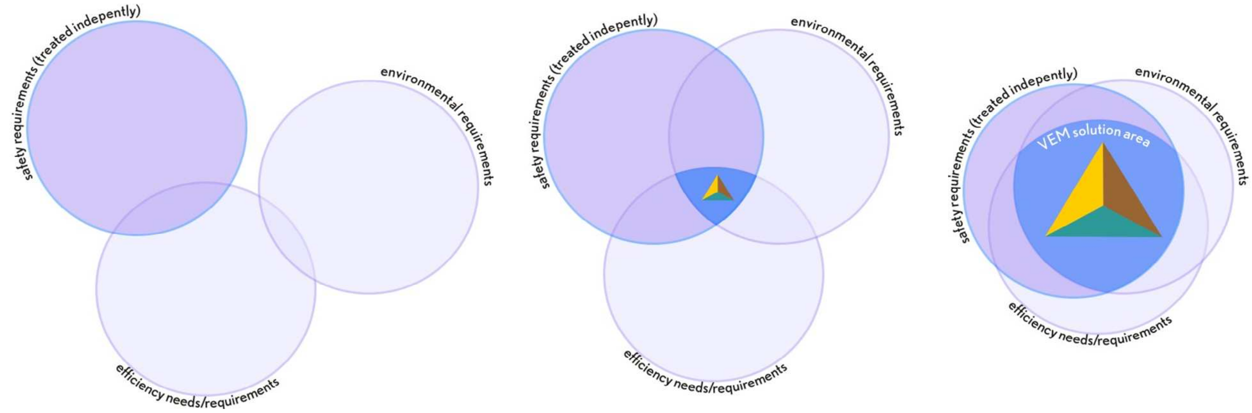
In Fig. 7, the working of VEM management is illustrated. This figure shows three times three circles. Each individual circle represents the solution area for that specific performance area. The three circles marked blue represent the solution area for safety. The VEM solution area is the overlap of the solutions areas for safety, efficiency and environment. In the left part of the figure, the VEM solution area is empty. In this case, the feedback will be that the assessed operational concept is not valid, and this means either redesign or search for other types of operational concept. In the middle part of the figure, the solution area is minimal, which means that there is at least one operational concept that fulfills the desired performance for safety. If this is the case for an assessed new operational concept, the validation process gives back to the decision makers that from a VEM performance perspective, the operational concept is assessed valid. In the last part the solution area is even large, which means that decision-makers can choose between several valid operational concepts.

It is the experience of LVNL that in practice, often no VEM solution area is found after the first validation exercise for a proposed new operational concept. Therefore, iterations of redesign or new solutions are necessary to move towards existing VEM solution areas (from the left part towards the middle or right part of the figure). The validation cycles presented in this paper illustrate the search for an operational concept to fall within the solution area for safety without abandoning the joint efficiency and environment solution areas.

The development and validation process is accomplished in cycles, each of which includes the following sequence of activities:

- Decision-making on new cycle;
- Identification and selection of design alternatives;
- Development of selected design alternative;
- Evaluation of proposed design; and
- Decision-making on proposed design.

For the design challenge of Section II this sequence of activities has been conducted through a number of cycles as part of LVNL's overall validation process.



Empty solution area   Minimal solution area   Large solution area

Figure 7. Illustration of three possible outcomes of VEM solution areas

IV. Factual Description of the Development and Validation Cycles

A. *Cycle 1: An active runway crossing operation*

Decision-making on new cycle: LVNL decided in September 1999 to start a process with the objectives of further developing the active runway crossing operation on runway 18C/36C, and developing the RIAS system. This decision was in line with the earlier decisions described in Section II and with the design requirements from the early safety study [16].

Identification and selection of design alternatives: Design alternatives were considered for the active runway crossings including detailed crossing procedures, phraseology, and air traffic controller response to alerts from RIAS. Furthermore, design alternatives for the development of RIAS were considered, including e.g., the system architecture, the sensors used, and traffic scenarios for which it should provide an alert.

Development of selected design alternative: A concept of operation was developed [19] involving both active runway crossings and usage of the STW. The proposed design was handed over to the validation team in January 2001, and included the following features:

- Active runway crossings starting at holding points at 90 meter from the runway centerline, with switchable stop bars at 153 meter of the runway centerline;
- The RIAS system providing stop bar violation alerts and runway incursion alerts, with assumed performance characteristics; and
- The new ‘runway control concept’ introduced in Section II.

Evaluation of proposed design: The evaluation cycle focused on safety, and a safety risk assessment was done to investigate whether the proposed design, under the assumption of the traffic numbers aimed for, was acceptably safe. A safety risk assessment approach was used that consists of a number of basic steps, see Fig. 8.

In step 0, the objective of the assessment is determined, as well as the safety management and regulatory context, the scope and the level of detail of the assessment. The actual safety risk assessment starts by determining the operation that is assessed (step 1). Next, hazards associated with the operation are identified (step 2), and aggregated into safety relevant scenarios (step 3), for which the potential severities are identified (step 4). The risk quantification is done in the frequency assessment (steps 5). Then, the safety risk associated with each safety relevant scenario is classified (step 6). For each safety relevant scenario with a (possibly) unacceptable safety risk, the main sources (safety bottlenecks) contributing to safety risks are identified (step 7), which help operational concept developers to learn for which safety issues they should develop improvements in the design. A more detailed discussion of the processes in these steps is provided in [3].

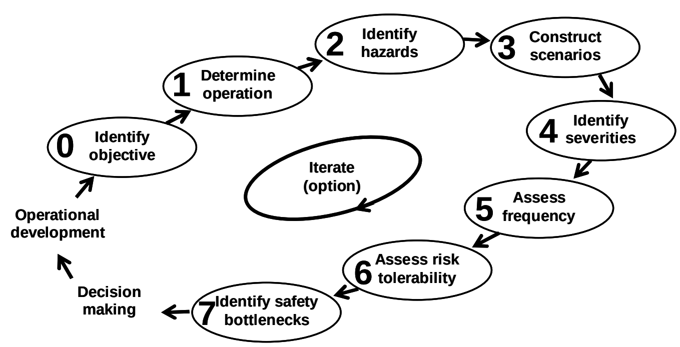


Figure 8. Overview of basic risk assessment steps used (e.g., [14], pp. 95-102)

In this case, the safety risk assessment was supported by an evaluation of the safety risk of identified safety relevant scenarios. Per such scenario an event sequence model has been developed. Subsequently a quantification of the event sequence model has been performed. A limited scope was selected: only the active runway crossing operation on a departure runway was considered, and only for good visibility conditions.

The safety risk assessment was completed in April 2001 [9]. The main results were that it could not be assured that all operational safety risks would be acceptably low, that the operation would introduce several new hazards that would make the operation potentially less safe than the then existing operations; and that those hazards were not related to the RIAS functionality. The possible unacceptability of the risks was related to situations in which an aircraft takes off or crosses without clearance. Resolution of those situations appeared to be critically impaired by hazards such as R/T confusion, unavailability of the R/T frequency, and pilots' selection of an incorrect R/T frequency. Several of these additional hazards had been identified using a novel brainstorming approach (e.g., [7]), and had not been identified in the original safety studies mentioned in Section 3.

Decision-making on proposed design: The decision-makers based their decisions on [10], which is a decision-makers version of [9]. As the safety risk assessment showed that the risks were possibly unacceptable, LVNL management took, in consultation with its stakeholders, the decision not to implement the proposed design. Independent of this LVNL decision, NLR recognized this case as a valuable one for advancing research, and decided to conduct a new safety evaluation cycle on the design of cycle 1, which made use of dynamic modeling and Monte Carlo simulation.

B. Cycle 2a: An adapted active runway crossing operation

Decision-making on new cycle: The possibly unacceptable risks in the safety risk assessment of Cycle 1 were related to several newly identified hazards, which had not been taken into account in the proposed design of Cycle 1. Accordingly, in 2001, LVNL started a new development cycle to redevelop the active runway crossing operation, using the results of the safety risk assessment of Cycle 1.

Identification and selection of design alternatives: The identification of design alternatives focused on mitigating the hazards that were assessed to play a key role in the criticality of the safety risk in cycle 1. Hence, potential solutions were considered for e.g., decreasing the R/T load of the runway controller of runway 18C/36C, and for giving the runway controller more time to react in case a pilot crosses or takes off without clearance.

Development of selected design alternative: The new design [36] was handed over to the validation team in June 2001. It had as main differences with the design of Cycle 1:

- The runway controller of runway 18C/36C controls only one runway;
- Aircraft start crossing further away from the runway, at holding points at 153m of the runway centerline.

Evaluation of proposed design: A complete VEM analysis was done, including a safety risk assessment of the new design, under the assumption of the traffic rates aimed for. This safety risk assessment was done with a broad scope, including active runway crossings on a departure runway and one a landing runway, and both in good and in poor visibility conditions. The safety risk assessment used the event sequence model that had been used in shadow-mode in the Cycle 1, and partial results as many identified hazards, and safety relevant scenarios were re-used. The VEM analysis included as additional activity an investigation of active runway crossing operations on other airports, including a literature study, a questionnaire, and an accident statistics review.

Both the safety risk assessment [27] and the complete VEM analysis [20] were delivered in February 2003. This new analysis showed that the risk related to the active runway crossings on a departure runway in good visibility conditions was still critical. The broader scope revealed that the design was also safety critical with respect to active runway crossings on a landing runway, and that the risks considered were somewhat higher in poor visibility conditions than in good visibility conditions.

Investigation of other airports [35] showed that crossing operations similar to the proposed design existed in Western Europe and North America, that for none of these operations a detailed safety risk assessment could be identified, and that the assessed accident frequencies in [27] were in the same order of magnitude as accident statistics for similar situations on airports comparable to Amsterdam airport.

Decision-making on proposed design: As the safety risk assessment had shown that safety risks were not acceptable, it was decided not to implement the proposed design.

C. Cycle 2b: The original active runway crossing operation

Decision-making on new cycle: Cycle 1 had revealed unexpected safety risks associated to an active runway crossings design involving RIAS. Also in cycle 1 it had appeared to be specifically difficult to take into account the dynamic and dependent character of all actors playing a role in the operation. Therefore, research activities were conducted by NLR in collaboration with NASA independently of and in parallel to Cycle 2a. In this Cycle 2b, the objective was to further investigate the safety risk related to the operation using dynamic risk modeling and Monte Carlo simulations.

Selection of design to be evaluated: The design considered in Cycle 2b was the original active runway crossing operation of Cycle 1.

Evaluation of proposed design A dynamic risk model was developed that captures the nominal and non-nominal (stochastic and dynamic) behavior of the aircraft, the relevant technical systems, the relevant human operators (pilots and runway controller), and the interactions between all these entities. Monte Carlo simulations were done using the dynamic risk model, as part of the safety risk assessment cycle presented in Section IV.A. Hazards, safety relevant scenarios, and event sequence models from Cycle 1 were taken into account in the development of the model. The human performance models and their interactions were calibrated and validated through a comparison with an Air-Midas surface operations model [2].

The results ([29], [2]) confirmed the safety criticality of the runway crossing operation considered, and indicated that the event sequence based approach that had been used in Cycles 1 and 2a could even underestimate the risk. These results lead to a much improved understanding of the safety risks. The key new insight gained was that even when RIAS alerting was working according to the requirements, then the air traffic controller's halting instructions may often arrive at a moment in time that the pilots themselves already had identified and started solving the conflict. In such case, the air traffic controller still may perceive him/ herself to have played a key role in resolving the conflict well.

Decision-making on proposed design: As this cycle was done for research purposes, no decision was made regarding the proposed design. The results of the design evaluation were communicated with LVNL.

D. Cycle 3: A taxiing operation on the southern taxiway

Decision-making on new cycle: In April 2003, LVNL management decided in consultation with its stakeholders to abandon the idea of structurally using active runway crossings on runway 18C/36C, and to put temporarily on hold the development of the RIAS system. The following arguments played a major role in these decisions:

- Following the results of Cycles 1, 2a, and 2b, confidence that an active runway crossing operation could be developed in line with both the safety and the capacity objective had decreased significantly;
- Acceptance of changes started to play a more significant role in decision-making, and LVNL's air traffic controllers were critical to the structural use of active runway crossings with high traffic rates; and
- LVNL management more and more became of the opinion that the ICAO recommendations of not introducing new active runway crossing operations when developing airports should be taken into account.

Counter arguments were the higher development costs for the airport operator of the alternative solutions (perimeter taxiways), the higher costs related to longer taxi times for the airlines, and the existence of active runway crossing operations on other airports. The decision taken reflected that reaching the safety and capacity objectives would now be given priority over the higher costs for airport operator and airlines.

In line with this, LVNL decided in consultation with its stakeholders that the eventual implementation would feature taxi operations independently of the active runway 18C/36C on one of two available perimeter taxiways. Thus, in addition to the STW that was already being constructed, an NTW would be constructed.

The independent taxiing operations on the NTW and STW did not demand an extensive safety risk assessment. Instead, a relatively simple safety check was done.

Whereas the STW was already in development, the NTW would not yet be available at the moment on which simultaneous operations on runways 18C/36C and 18R/36L would start. Therefore a temporary solution was needed for modes in which runway 18C/36C would be used for landings on runway 18C or departures on runway 36C. It was decided to start a new development and validation cycle for such temporary solution.

Identification and selection of design alternatives: A joint development team of LVNL, the airport operator and the main airline, with the regulator taking part as observer, started a brainstorm process for identifying partial solutions that might be selected to be part of the proposed design. To illustrate the broadness of this process, Table I shows a number of partial solutions that were identified, including some for which it was straightforward to see that they were not feasible:

TABLE I. EXAMPLE PARTIAL SOLUTIONS IDENTIFIED IN [24]

Displacing the threshold runway 36C
Displace the runway start for departures runway 18C
Shortening the departure distance for aircraft departing from runway 18C
Dependent taxiing operation on STW, for all aircraft types
Taxiing operation on STW, dependent for some aircraft types, independent for others
Independent taxiing operation on STW, for all aircraft types
Putting signs at taxiways showing the correct R/T frequency
Using active R/T hand-overs from Ground control to Runway Control
Improving information given to pilots in AIP
Training of pilots
Having heavy aircraft departing from other runways than runway 18C
Making large gaps in arrival sequence runway 36C
Increase ILS glide-slope angle

Using the results of previous cycles, the validation team evaluated the partial solutions and relevant combinations on likeliness to successfully reach the objective. Here, safety, capacity, acceptability to air traffic controllers and pilots, and practical feasibility (including e.g., related costs and development time) was considered. Based on this evaluation, one combination was selected for further development.

Development of selected design alternative: The proposed design that was developed from the selected combination of partial solutions was a dependent taxiing operation on the STW, supported by switchable stop bars, and under control of the runway controller of runway 18C/36C (see Fig. 9). This design was delivered in July 2003 to the validation team.

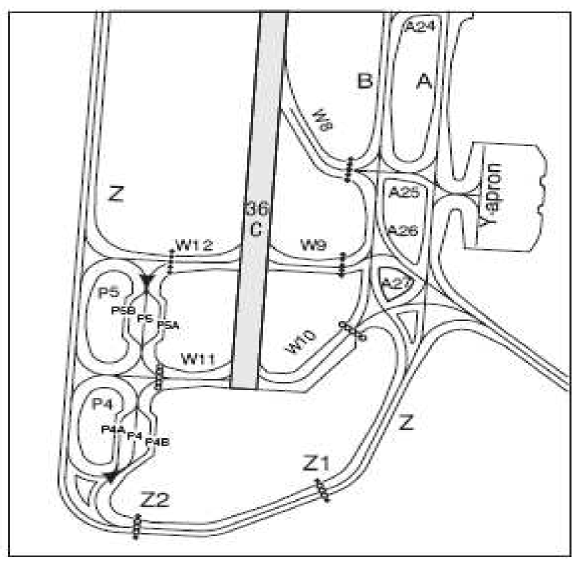


Figure 9. Detail of the infrastructure for dependent taxiing operations on the STW with stop bars at Z1 and Z2.

Evaluation of proposed design: A VEM analysis was done supported by the safety risk assessment cycle introduced in Section IV.A. The risk assessment included a risk tree, and dynamic risk modeling and Monte Carlo simulations were used for assessing conditional collision risks for specific initial STW operation conditions.

The safety risk assessment [18] and complete validation results [21] were delivered in October 2003. Main result was that the accident risk on the STW was not critical, and that the assessed capacity of runways 18C/36C and 18R/36L was similar to that of operations on fully independent runways.

Decision-making on proposed design: As the proposed temporary solution was assessed to meet the safety and capacity objectives, and as the operational acceptance was also assured, LVNL management, in consultation with its stakeholders, took the decision to implement the dependent operation of southern taxiway and runway 18C/36C as temporary solution for modes in which runway 18C is used for departures or runway 36C for landings.

E. From validated design to operation

The design was further detailed, and these further development activities were accompanied by further validation activities. These activities are not detailed in the current paper.

V. HINDSIGHT ANALYSIS OF THE DEVELOPMENT AND VALIDATION CYCLES

A. Comparing the development and validation example versus literature

The development and validation process that was eventually in place indeed shows a remarkable resemblance with the spiral development model. In Table II this is illustrated by a comparison of the main activities from the spiral model with the activities performed in Cycle 3.

TABLE II. COMPARISON OF ACTIVITIES FROM CYCLE 3 TO ACTIVITIES IN THE SPIRAL MODEL

Activity from spiral model	Activity in Cycle 3	Performed by
Determine objectives	Objectives were identified in terms of safety and capacity of the operation to be developed. A previous objective of short taxi times was given lower priority.	Decision-makers
Identify alternatives	A long list of design alternatives was made; see Table I for a selection.	Development team
Identify constraints	Constraints were identified including acceptance of the operation to air traffic controllers and pilots.	Development and validation teams
Evaluate alternatives	The likeliness of the alternatives reaching the objective was evaluated by considering safety, capacity, operational acceptability and practical feasibility.	Validation team
Identify and resolve risks	Based on the evaluation of alternatives, partial solutions were improved and combined to a design to be evaluated	Development team
Develop prototype	A high-level concept of operation was developed for the selected solution	Development team
Verify and validate prototype	A VEM analysis of the concept of operation was done, with a focus on the operational safety risk assessment	Validation team
Plan next cycle	It was decided to further develop and implement the proposed concept, and a new cycle was planned for that.	Decision-makers

As described by [37] and [26], a crucial difference between the spiral model and the other considered development models is the suitability of the spiral model for dealing with unforeseen problems. The early safety study [16] had shown that the active runway crossing operation could be made sufficiently safe, and these had used safety risk assessment methods that were then state of the art. Additionally, research and development into Advanced Surface Movement Guidance and Control Systems (A-SMGCS) at that time raised high expectations of the safety-added value of a system like RIAS. There was thus no reason to doubt the feasibility of developing an active runway crossing operations in accordance with safety and capacity objectives. The results of Cycles 1, 2a, and 2b thus came as a surprise. The occurrence of such unforeseen problem confirms that having operational concept development and validation organized in agreement with the spiral model contributed to the eventual successful implementation.

B. Analysis of the functioning of the cycles

Striking aspect of the process considered is that Cycles 1, 2a and 2b focused on an active runway crossing operations, whereas the operation that was eventually implemented is one with dependent taxi operations via perimeter taxiways. A lesson that can be learned from this is that if a certain concept alternative is selected for further development, other alternatives should not be discarded. A seemingly promising alternative may turn out not to be feasible, let alone to be the optimal solution, as one may run into unexpected problems during its further development. This emphasizes the need to store design alternatives and their validation results, including the reasons why an alternative is considered to be less preferred or invalid.

As design alternatives previously not selected for further development may in later stages be preferred, one should consider design alternatives again when starting further development in a new cycle. Indeed, [5] and [26] include the generation of design alternatives and project risk assessment as activities to be done before selection of the alternative to be further developed. The overall process of maintaining all design alternatives identified and their validation results, recurrent generation of new design alternatives, and recurrent selection of alternatives for further development and validation, can be called management of a portfolio of design alternatives.

A related lesson is that after an initial evaluation of the performance of design alternatives, decision-makers should not base their decision regarding further development on performance of the evaluated concept alone. Also, the options remaining for possible redesign play a key role in deciding what to do next.

The example also shows that both quality of concept development and quality of validation can have a major impact on the cycles conducted and hence on the development and investment path to realize an operation. Having powerful validation tools available may save a lot of time and budget. For example, if the Monte Carlo simulation approach towards active runway crossing operations had been available at the time of Cycle 1, then the validation and development path would have been different. Additional important factors are the quality of the safety criteria used, and an open attitude of the organization to validation.

It is also observed that this interplay between advancing operational concepts and advancing validation approaches was part of a more general learning curve for all actors involved:

- The developers of the operation experienced how to communicate with and learn from feedback from particularly operational safety risk assessment experts;
- The validation team experienced practical aspects of how to assess advanced operations on safety, and to communicate on this with concept developers and decision-makers;
- The decision-makers experienced how the interplay between development and validation impacts the organization of the development and validation of advanced operations.

Finally, this example has shown to be very valuable in learning from applying various methods towards safety risk assessment. This is well documented in the following papers:

- Reference [11] studies the key roles that air traffic controllers and pilots have fulfilled in the safety risk analysis of Cycles 1 and 2b. They appear to play a variety of clearly discernable roles in most steps of a safety risk analysis.
- The hazard identification approach and its results obtained in Cycle 1 have been studied in [12].
- References [3], [30] and [31] describe the dynamic risk modeling and Monte Carlo simulation approach of Cycle 2b, and the safety risk results obtained.
- In [4] and [32], the Monte Carlo approach of Cycle 2b is benchmarked against the event sequence based approach of Cycle 1. This showed a significant difference in results obtained, which is due to explicit modeling in the Monte Carlo approach of the dynamics of an active runway crossing operation, and the concurrent and interacting behaviors of pilots and controllers.

C. *Comparison with FAA/ Eurocontrol validation guidance*

In this subsection the development and validation processes of Section IV are compared with FAA/ Eurocontrol guidance material in overall validation of novel air traffic operations.

The aim of FAA/ Eurocontrol Action Plan 5's Operation Concept Validation Strategy Document (OCVSD) [15] is to develop common goals and principles and to facilitate effective collaboration between the US and Europe. The key elements of the strategy consist of a validation methodology, key performance and behaviors, operational scenarios, creation of confidence, and effective collaboration. The validation methodology, which is of specific importance here, consists of three aspects that help to provide structure to an iterative and incremental approach to concept development and validation: A Concept Lifecycle Model that reflects the maturity of the concept under investigation (see Fig. 10), a Structured Planning Framework that guides planning validation activities, and a Case-Based Approach which provides key stakeholders focused information in an easily understood format. A more detailed version of this methodology is known as the European Operational Concept Validation Methodology (E-OCVM) [13].

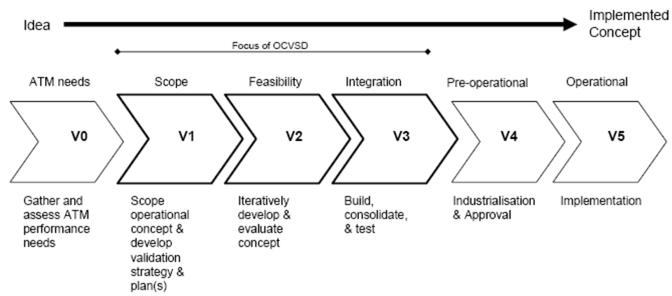


Figure 10. The Concept Lifecycle Model of OCVSD [15] and E-OCVM [13].

When comparing the development and validation process described in this paper with the processes proposed by OCVSD and E-OCVM, a practical problem is that the latter documents restrict to validation, whereas interaction with development is not really covered. As such, these sources do not tell how the development process can deal with heterogeneous, potentially contradictory requirements from different validation perspectives. In the current paper an effective way has been identified: developers communicate to validation teams by operational concept versions of generally increasing maturity, and validation teams explain to developers to which extent the operational concept version is valid with respect to the various key performance areas, and why this is the case. Also, for communication with decision-makers the lessons drawn in the previous subsection are of value here.

A second observation can be made when comparing the development and validation cycles of Section IV with the Concept Lifecycle Model. Although it is not straightforward to evaluate to which phase of that model the cycles correspond, it is clear that the activities aimed to investigate the feasibility of the concept. Therefore, it is most logical to place all cycles performed in phase V2 of the Concept Lifecycle Model.

The lesson learned in the previous subsection that design alternatives previously not selected for further development may in later stages be preferred, is also a valuable addition to the guidance available from OCVSD and E-OCVM.

VI. CONCLUDING REMARKS

In this study an analysis has been performed of how development and validation of an advanced operation works at LVNL. This has been done by studying the factual development and validation process conducted by LVNL in order to solve a challenging practical problem. The main findings of this study are:

1. The factual process followed appears to fit (in hindsight) very well with the spiral model of [5].
2. The effective interaction of validation experts, operational concept developers and LVNL decision-makers played a key role in the process.

3. Design alternatives should never be discarded because previously less preferred design alternatives may eventually turn out to be preferred by decision-makers.

4. Both quality of concept development and quality of validation can have a major impact on the development and investment path to realize an operation.

The findings go further than existing FAA/ Eurocontrol guidance, and hence may be of value for further development of this guidance, such as is ongoing through the European Commission co-ordination action CAATS II [6].

REFERENCES

[1] Blom, H.A.P., C.F.W Hendriks, and H.B. Nijhuis, Assess necessary validation developments in ATM, VAPORETO WP3 report, NLR-CR-95524, 1996.

[2] Blom, H.A.P., K.M. Corker, S.H. Stroeve, On the integration of human performance and collision risk simulation models of runway operation, Proc. 6th USA/Europe ATM R&D Seminar, Baltimore, USA, 27-30 June 2005.

[3] Blom, H.A.P., S.H. Stroeve, H.H. de Jong, Safety risk assessment by Monte Carlo simulation of complex safety critical operations. In: Redmill F, Anderson T (eds.), Developments in risk-based approaches to safety, Springer-Verlag, London, 2006, pp. 47-67.

[4] Blom, H.A.P., S.H. Stroeve, J.J. Scholte, and H.H. de Jong, Accident risk analysis benchmarking Monte Carlo simulation versus event sequences. Proc. ICRAT, Fairfax, VA, June 1-4, 2008, pp. 177-184.

[5] Boehm, B.W., A spiral model of software development and enhancement, IEEE Computer, Vol. 21, No. 5, 1988, pp. 61-72.

[6] CAATS II website, http://www.caats2.isdefe.es/

[7] De Jong, H.H., Guidelines for the identification of hazards: How to make unimaginable hazards imaginable. NLR contract report 2004-094 for Eurocontrol, March 2004.

[8] De Jong, H.H., and J.C. van den Bos, LVNL safety criteria, Proc. Eurocontrol Safety R&D Seminar Rome, Italy, 24 – 26 October 2007.

[9] De Jong, H.H., R.S. Tump, H.A.P. Blom, B.A. van Doorn, A.K. Karwal and E.A. Bloem, Qualitative Safety risk assessment of a RIASS based operation at Schiphol airport including a quantitative model: Crossing of Departures on 10L/19R under good visibility conditions, NLR memorandum LL-2001-017, 2001.

[10] De Jong, H.H., R.S. Tump, H.A.P. Blom, B.A. van Doorn, A.K. Karwal and E.A. Bloem, Qualitative safety risk assessment of a RIASS based operation at Schiphol airport—crossing of departures on 10L/19R under good visibility conditions, NLR report CR-2001-157, April 2001.

[11] De Jong, H.H., S.H. Stroeve, and H.A.P. Blom, The roles of air traffic controllers and pilots in safety risk analysis, in: Safety and reliability for managing risk – Guedes Soares & Zio (eds.), Taylor & Francis, London, 2006, ISBN 0-415-41620-5

[12] De Jong, Hans H., Henk A.P. Blom & Sybert H., Stroeve Unimaginable hazards and emergent behavior in air traffic operations. In: Risk, Reliability and Societal Safety – Aven & Vinnem (eds), Taylor & Francis, London, 2007, ISBN 978-0-415-44786-7

[13] Eurocontrol, European operational concept validation methodology, version 2.0, 17 March 2007.

[14] FAA/Eurocontrol, ATM safety techniques and toolbox, Safety Action Plan-15, Issue 1.1: For Comment, February 10, 2005. http://www.eurocontrol.int/eec/gallery/content/public/documents/EEC_safety_documents/Safety_Techniques_and_Toolbox_1.0.pdf

[15] FAA/Eurocontrol, Operational concept validation strategy document, Action Plan 5: Validation and verificiation strategies, Ed. 2.0a, 31 March 2008.

[16] Gleave, D.P., and K.S. Thompson, Amsterdam airport Schiphol risk assessment of runway 18/36 taxiway options, Roke Manor Research, non-public Report No: 72/98/R026R, July 1998, Issue 1.

[17] ICAO, Doc. 9157-AN/901, Aerodrome design manual, Part 2: taxiways, aprons and holding bays, Third Edition, 1991.

[18] Klein Obbink, B., and J.J. Scholte, Safety evaluation for the dependent operation of the southern taxiway and runway 18C/36C Part 1: Top-level document, NLR report CR-2003-513, October 2003

[19] LVNL, Runway Incursion Alert System Schiphol, concept of operation (CONOPS), Edition 0.7, LVNL draft report, January 21, 2000.

[20] LVNL, VEM Effect Report Crossing Operations Runway 18C/36C – Originally Envisaged Infrastructure, LVNL report D/R&D/D 02/006, R&D/Performance Analysis, version 1.0, 14 February 2003.

[21] LVNL, VEM Effect Report dependent operation of the Southern taxiway and runway 18C/36C, LVNL report D/R&D/D 03/072, R&D/Performance Analysis, version 1.0, 20 October 2003.

[22] National Computing Centre, Starts purchasers handbook, Procuring software based systems, NCC Publications, Oxford Road, Manchester, Second edition, 1989.

[23] Pasquini, A., M. Leone, K. Vickery, and H. Wagemans, Validation management in an ATM research project, In: ATC Quarterly, Vol. 15/2, 2007.

[24] Pekela, W.D., 'Concept of Operation - Van en naar de polderbaan tijdens Inbound Mode 4 & Outbound Mode 3', non-public LVNL report D/R&D 03/041, version 1.0, ATM R&D/Research, 6 August 2003.

[25] Royce, W.W., Managing the development of large sotware systems: concepts and techniques – Proc. Wescon, Aug. 1970; WESCON Technical Papers 14, 1970, Section A/1, pp. 1-9. – Reprinted in: Proc. ICSE 9 IEEE Computer Society Press, 1987.

[26] Sage, A.P., Systems engineering, John Wiley & Sons, New York, 1992.

[27] Scholte, J.J., Safety risk assessment of the crossing operation of Schiphol runway 01L/19R, Part 1: Main document, NLR report CR-2003-038-PT-1, January 2003.

[28] Scholte, J.J., H.A.P. Blom, J.C. van den Bos, and R.B.H.J. Jansen, The role of safety validation in ATM concept development: how does it work in practice? Proc. Eurocontrol Safety R&D Seminar Southampton, UK, 22-24 October 2008.

[29] Stroeve, S.H., H.A.P. Blom, and M.N.J. van der Park, Multi-agent situation awareness error evolution in accident risk modelling. Proc. Fifth USA/Europe ATM R&D Seminar, Budapest, Hungary, 2003.

[30] Stroeve, S.H., H.A.P. Blom, G.J. (Bert) Bakker, Systemic accident risk assessment in air traffic by Monte Carlo simulation, Safety Science, Vol. 47 (2009), pp. 238-249.

[31] Stroeve, S.H., H.A.P. Blom, G.J. Bakker, Safety risk impact analysis of an ATC runway incursion alert system, Proc. Eurocontrol Safety R&D Seminar Barcelona, Spain, 25-27 October 2006.

[32] Stroeve, S.H., H.A.P. Blom, H.H. de Jong, J.J. Scholte. Comparison of accident risk assessment by event sequence analysis versus Monte Carlo simulation, Proc. Eurocontrol Safety R&D Seminar Southampton, UK, 22-24 October 2008.

[33] Van den Bos, J.C., J. Brüggen, R.B.H.J. Jansen, "Safety Management at LVNL. Strategic, Tactical and Operational perspectives", LVNL report D/R&D/ 07/014, version 1.0, April 2008.

[34] Van den Bos, J.C., R.B.H.J. Jansen, J.T.F.M. Obbens, L. Hoogerbrugge, "VEM Management for Mainport Schiphol", LVNL report D/R&D 07/014, version 1.0, July 2007.

[35] Van Ham, F.A.D., Inventory of crossing procedures on active runways, United States of America and Europe, NLR report CR-2002-596, December 2002.

[36] Westerveld, E., Project 1035 RIASS Concept of Operation (CONOPS), LVNL, non-public Doc. No. D&S/SR 00/001, Edition 2.0, 29 June 2001.

[37] Whytock, S., The development life-cycle, Ed B. Thomé, Principles and Practice of computer-based systems engineering, Wiley & Sons, 1993, pp. 81-96.

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