Prevention of Runway Incursions due to closed runways or unsuitable runway choices by enhanced crew situational awareness and alerting

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ABSTRACT

Of all incidents on the aerodrome surface, Runway Incursions, i.e. the incorrect presence of an aircraft on a runway, are the by far most safety-critical, resulting in many fatalities if they lead to an accident. A lack of flight crew situational awareness is almost always a causal factor in these occurrences, and like any Runway Incursion, the special case of choosing a closed or unsuitable runway - including mistaking a taxiway for a runway - may have catastrophic consequences, as the Singapore Airlines Flight SQ006 accident at Taipei in 2000 and, most recently, Comair Flight 5191, tragically show. In other incidents, such as UPS Flight 896 at Denver in 2001 departing from a closed runway or China Airlines Flight 11 taking off from a taxiway at Anchorage in 2002, a disaster was only avoided by mere luck.

This paper describes how the concept for an onboard Surface Movement Awareness & Alerting System (SMAAS) can be applied to this special case and might help to prevent flight crews from taking off or landing on closed runways, unsuitable runways or taxiways, and presents initial evaluation results. An airport moving map based on an ED-99A/DO-272A compliant Aerodrome Mapping Database (AMDB) is used to visualize runway closures and other applicable airport restrictions, based on NOTAM and D-ATIS data, to provide the crew with enhanced situational awareness in terms of position and operational environment. If this is not sufficient to prevent a hazardous situation, e.g. in case the crew is distracted, a tailored alerting concept consisting of both visual and aural alerts consistent with existing warning systems catches the crew’s attention.

For runway closures and restrictions, particularly those of temporary nature, the key issue for both extended situational awareness and alerting is how to get the corresponding data to the aircraft’s avionics. Therefore, this paper also develops the concept of a machine-readable electronic Pre-flight Information Bulletin (ePIB) to bring relevant NOTAM information to the flight deck prior to the flight, with a possibility to receive updates via data link while the aircraft is airborne.

Keywords: Airport Moving Map, Situational Awareness, Runway Incursion, Closed Runway, NOTAM, Taxiway Takeoff

1. INTRODUCTION

Today, safe operations on the runway are maintained using strict procedures and rigorous surveillance. Explicit approval is required to cross or enter the runway surface and its associated protection zone, and additional clearances are required for line-up, takeoff and landing. A failure of this procedural Runway Safety Net may result in Runway Incursions, the most serious type of incident in the airport environment.

Initially, Runway Incursion prevention programs around the globe focussed on those incidents and accidents involving two aircraft, and developed strategies to detect potential collision risks in the runway environment. In fact, the worst-ever accident in civil aviation to date, the collision of two Boeing B747s on Tenerife in 1977 with 583 fatalities, was...
caused by a Runway Incursion. It is not surprising, therefore, that the most common definition of a Runway Incursion, first introduced by the Federal Aviation Administration (FAA) in 2001, uses a "collision hazard" or a "loss of required separation" as the defining characteristics of a Runway Incursion (FAA, 2001, 2005). However, it has been argued that an erroneous runway entry or usage, and not a loss of separation, is the crucial step leading to a Runway Incursion, because the presence of and the distance to any other aircraft – and thus the collision hazard – is largely determined by chance, particularly in low visibility conditions (Vernaleken et al., 2006, 2006a). Furthermore, even if no other traffic is present, erroneously using a closed or otherwise unsuitable runway for takeoff and landing may have catastrophic consequences, as the Taipei accident of Singapore Airlines Flight SQ006 in Taipei in 2000 (ASC, 2002) and the Comair crash at Lexington airport, Kentucky1, in 2006 (Learmount, 2006) show.

Therefore, the more global definition of Runway Incursions by the International Civil Aviation Organisation (ICAO) effective since November 2004 will be used in this paper (Eurocontrol, 2004):

*Any occurrence at an aerodrome involving the incorrect presence of an aircraft, vehicle or person on the protected area of a surface designated for the landing and take off of aircraft.*

Of course, the term “incorrect presence” also takes into account controller errors, such as the violation of separation minima set forth in ICAO Doc 4444 (ICAO, 2001). This ICAO definition extends the scope of Runway Incursions to the cases of primary interest for this paper: taking off or landing on a wrong (and potentially unsuitable) runway or using a closed runway can now also be considered a Runway Incursion according to this definition even if there is no traffic hazard.

### 2. CAUSES OF RUNWAY INCURSIONS

It is out of the scope of this paper to give an exhaustive analysis of various Runway Incursion accident and incident reports. However, crew disorientation due to a lack of situational awareness played a substantial role in two recent fatal Runway Incursion accidents in Milan and Taipei. In both cases, crew disorientation was at least partially caused by adverse weather conditions and the non-conformance of airport lights, signs or markings to ICAO regulations (ANSV, 2004; ASC, 2002). Although no final accident investigation report is available for the Comair CRJ 200 accident at Lexington yet, the pilots seem to have chosen the wrong RWY 26, which is too short to perform a successful takeoff, instead of RWY 22. It seems apparent that crew disorientation was a contributing factor in this accident (Learmount, 2006). Controllers erroneously clearing two aircraft for the same runway were the key causal factors in both the 1991 Los Angeles and the 2000 Paris accidents. In the latter case, the use of two different ATC languages prevented the crew of a British Shorts 330 from noticing the controller error (BEA, 2001).

From an onboard perspective, however, the focus should naturally be on Runway Incursions eventually caused by the flight crew. In view of the brief analysis above, it is assumed that crews fail to obey ATC instructions because of:

- a lack of situational awareness, which in turn might result from poor visibility or other adverse weather conditions,
- high crew workload, e.g. due to checklists, last-minute runway changes and/or changes in SID & departure transitions
- communication problems between controller and flight crew,
- insufficient familiarity with the airport,
- fatigue and lack of concentration,
- airport infrastructure deficiencies, e.g. missing or non-standard markings, signs and lights

or any arbitrary combination of these factors, which are not fully independent, because all of them ultimately influence crew situational awareness, and a lack thereof may impair communication with ATC without being noticed by either pilots or controller. With this in mind, a lack of crew situational awareness on the aerodrome surface can be subdivided further into:

1 For the Comair accident, no final accident investigation report is available yet.
Lack of positional awareness. The crew is either not sure of the position on the airfield and gets lost, or believes the aircraft to be elsewhere on the airport, particularly in situations of poor visibility. Especially the latter case can lead to inadvertent entry into a runway (e.g. entering or crossing the wrong runway, e.g. 30L instead of 30R).

Lack of operational awareness. The crew lacks awareness of the operational configuration of the airport, i.e. they are not aware of closed runways or taxiways, or of the runways in use.

Lack of clearance awareness. The crew is not fully aware what the current clearance mandates or allows them to do, or whether the appropriate clearance has been requested or issued. This includes the crew being in the wrong ‘mindset’ and failing to request clearance for the manoeuvre; having a false impression of being cleared for the manoeuvre (e.g. to enter runway, to land or to take-off) and failure to correctly execute an ATC sequencing instruction.

Lack of traffic awareness. The crew lacks awareness of the position, intention and cleared manoeuvres with respect to relevant traffic in the vicinity of the aircraft.

Thus, the main goal to be achieved from an onboard perspective is a global increase in crew situational awareness, supplemented by alerting in situations where the enhanced awareness is not sufficient to avoid hazardous situations. This is in line with the European Action Plan (Eurocontrol, 2004) and the main rationale behind the concept for a Surface Movement Awareness and Alerting System (SMAAS) outlined in the following section. A more detailed discussion on onboard systems as key technology for Runway Incursion Avoidance is given in (Vernaleken et al., 2007).

3. SURFACE MOVEMENT AWARENESS AND ALERTING SYSTEM

The Surface Movement Awareness and Alerting System (SMAAS) aims at improving safety and efficiency of aircraft movements on the aerodrome surface, i.e. during taxi, takeoff and landing, including final approach. The main purpose of this system is the avoidance of Runway Incursions by:

(a) Preventing the own aircraft, by enhanced situational awareness and alerts, from entering, crossing, taking off or landing on runways without a corresponding clearance, and
(b) providing traffic awareness and giving timely alerts if other vehicles or aircraft infringe the protection zone of a runway that is used or has been cleared for own-ship operations.

Generally, the SMAAS supports the aircrew by providing enhanced situational awareness and, if necessary, timely alerts in case of potentially dangerous situations. This functionality is also envisaged as a potential enhancement of the ASAS Package 1 application “Enhanced Traffic Situational Awareness on the Airport Surface” (ATSA-SURF).

The SMAAS consists of two complementary parts (see Figure 1), one aimed at maximizing crew situational awareness in the various domains identified in the previous section, and the other part dedicated to alerting in case this is not sufficient to prevent a hazardous situation.

The core element of the SMAAS encompasses an airport moving map based on an ED-99A compliant aerodrome database, which is intended to provide the crew with enhanced positional awareness to avoid disorientation on the airfield, a common precursor of Runway Incursions. The concept proposed is that of a dedicated taxi mode for the classic Navigation Display (ND) with all the usual modes, ARC, ROSE and PLAN. The reason for this choice is quite simple. In order not to extend the pilot’s scanning pattern to further displays, which might be associated with additional workload, airport and traffic information should be displayed on the Electronic Flight Instrument System (EFIS) displays, all the more as the airport moving map forms the basis of the SMAAS. Consequently, there have to be provisions to display high level alerts, as Runway Incursion alerts,
for example, are highly safety-critical and will certainly use Level 2 (Caution) or Level 3 (Warning). Apart from a connection to the Flight Warning System to ensure an appropriate prioritisation and presentation of alerts, this also requires a high-level certification of the display hardware and software employed. Furthermore, the use of the ND has the additional advantage that the airport moving map can be operated without additional controls, provided that the range selector is enhanced to lower ranges, accordingly.

The basic airport moving map can be enhanced by three further situational awareness functions. By displaying traffic on the ground and in the takeoff or landing phases in relation to the airport moving map, Cockpit Display of Traffic Information (CDTI)\(^2\) functionality can be added to the basic airport moving map in order to increase traffic awareness.

In addition to this, the Operational Awareness Function (OAF) processes and presents relevant information on the operational configuration of the airport, such as runways in use, runway closures, whether Low Visibility Procedures (LVP) are in force and other information typically contained in Automatic Terminal Information Service (ATIS) transmissions (voice or digital) or Notices to Airmen (NOTAM). Furthermore, the takeoff or landing runway used in the Flight Management System (FMS) flight plan is highlighted on the airport moving map to remind the crew of the FMS settings, which is intended as another measure to prevent takeoff and landing operations on the wrong runway.

Last but not least, the Clearance Awareness Function (CAF), mainly by presenting the assigned taxi route, raises the crew’s awareness. While it is obviously preferable to obtain the data required for OAF and CAF in a machine-readable format via data loader and data link, there are provisions to enter these data manually using the MCDU, the MFD or a dedicated hardware control panel to ensure that the system can work independently of ground infrastructure.

Only if the pure display of all this information fails to prevent a hazardous situation, the second part, the Surface Movement Alerting subsystem, which builds on the same information as the awareness part, comes into play. It can be subdivided into two integral parts, a preventive and a reactive one. The first goal of the Surface Movement Alerting system is to ensure that ownship does not cause a Runway Incursion, i.e. Preventive Surface Movement Alerting. To achieve this, the alerting part is armed using the same airport, operational and clearance data as the awareness part of the SMAAS. This enables specific alerting tailored to the particular operational situation, which is by itself a prerequisite for preventive alerts up to Master Warning level (Level 3). Without operational and clearance information, it would, for example, be impossible to alert the flight crew specifically when they enter a runway that is completely closed due to heavy construction, or when they enter or try to take off from a runway without the appropriate clearances.

In parallel to this rigorous ownship surveillance, relevant surrounding traffic will continuously be monitored to alert the crew if a Runway Incursion caused by others poses a significant collision hazard (Reactive Surface Movement Alerting).

Nonetheless, the main idea behind the SMAAS is not to create additional alerts on the flight deck. Rather, the intention is to enable the crew, by means of improved situational awareness, to avoid potential conflicts proactively at a strategic or pre-tactical level, and to provide alerts only for last resort conflict avoidance. Like the tactical alerts from safety net functions such as ACAS or the Terrain Awareness and Warning System (TAWS), the alerting part of the SMAAS has to be seen as a backup or safety net function for those situations where the pure awareness functions are not sufficient to avoid a hazardous situation.

The Operational Awareness Function (OAF), which is, among others, intended to provide the crew with information on active runways, runway closures and other restrictions, and thus most relevant for this paper, will be described in the following section. It is an add-on to the basic airport moving map, which is the key technology to prevent crew disorientation on the airport surface.

### 4. OPERATIONAL AWARENESS FUNCTION (OAF)

Awareness of the operational status of an airport is crucial for safe and efficient surface movement operations. In particular, it is essential that the crew is aware of the runways in use and potential runway closures or restrictions to avoid Runway Incursions.

\(^2\) The term CDTI is used here for an enhanced display of traffic information beyond current ACAS in the cockpit. While this may include an additional, separate cockpit display, the preferred solution is an ND-integrated traffic display.
Currently, like paper charts, the airport moving map display is limited to quasi-static airport information, because the underlying aerodrome database is envisaged to be updated only every 28 days with the regular AIRAC cycle (ARINC, 2006). This is a significant limitation when it comes to short-term and/or temporary changes typically conveyed by NOTAM.

Today, therefore, crews receive a plain-text language compilation of current NOTAM and other urgent information of operational significance prior to flight that is called “Pre-Flight Information Bulletin (PIB)” and required by ICAO Annex 15. Usually, it is prepared by the flight dispatcher and handed out to the crew on paper (or an electronic equivalent such as PDF), and may have in excess of 30 A4 pages for an intercontinental flight. This has a variety of disadvantages, e.g. that

- the accessibility of the NOTAM information is somewhat limited, particularly if the crew has to find a certain information again in flight under time pressure;
- the information is fragmented, and needs to be combined with other sources like paper charts and the flight deck displays to create a complete mental model and a sufficient level of situational awareness;
- the information is not available to any aircraft system, and can thus not be displayed or used to create alerts, e.g. for closed runways, malfunctioning Nav aids or restricted airspaces.

In this context, one of the lessons to be learned from the Taipei disaster is that conveying runway closure information in this textual form is not the optimum solution. In fact, the flight crew of SQ006 had reviewed NOTAM information and was aware that RWY 05R was closed (ASC, 2002), but the disorientation leading to the assumption that they were on RWY 05L while they had, in fact, lined up on RWY 05R rendered this information useless.

Furthermore, the time the crew commonly has for the briefing is not sufficient for a detailed review of all this information. Thus, there is a small, but not vanishing risk that important information is simply overlooked.

Consequently, the goal of the Operational Awareness Function (OAF) is to aid the flight crew in creating a mental picture of the airport including all short-term changes and other operationally relevant information, which is achieved by preprocessing and combining this information with the airport moving map. This is particularly important for airports that the crew is not very familiar with, i.e. airports they visit only once every few months, and is also expected to reduce work-

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3 Short-term changes are alterations that occur between AIRAC effective dates; the changes may be either of temporary or permanent nature.

4 According to current ICAO regulations, a compilation of current NOTAM and other information of urgent character shall be made available to flight crews in the form of plain-language Pre-flight Information Bulletins (ICAO, 2004).
load as well as the risk of error and confusion, because the crew does not have to look for information in various places to build a mental model of the situation.

The Operational Awareness Function (OAF) therefore uses the airport moving map display to visualize information on closed runways (see Figure 2), closed taxiways and restrictions of either runways or taxiways. From a human factors perspective, it is immediately obvious that it is essential to display a closed runway on the airport moving map in an integrated fashion to prevent crews from taking off from or landing on a closed runway. Moreover, with respect to airport moving maps, the absence of integrated NOTAM information, particularly when pertaining to runway closures or restrictions, is a more severe issue than for paper charts. First of all, with paper charts, pilots can combine this additional information with the airport representation simply by sketching or writing the changes on the paper, a method practiced by many flight crews today, whereas the basic airport moving map display does not have any comparable provisions. But the main reason is that an airport moving map, particularly when integrated with the flight deck displays as proposed, provides information at a quality and level that can be compelling, in the sense that a runway that is displayed on the airport moving map without any closure markings might be perceived as open even if contrary NOTAM information exists on paper elsewhere in the cockpit.

The takeoff or landing runway set as part of the FMS flight plan is, in most cases, the runway actually used for takeoff and landing. Today, on Airbus aircraft, if a runway is specified in the FMS flight plan, an oriented white runway outline is presented on the ND in conjunction with the FMS flight plan as the sole airport element. If the selected range is 10, 20 or 40 nm, the runway is even drawn to scale with respect to the paved length (Airbus, 1995). This emphasizes the high operational relevance of the runway selected in the FMS flight plan, and an airport moving map function on the ND should definitely not provide less information than the conventional ND. For those reasons, a specific representation of the FMS-entered runway on the airport moving map with a white outline was chosen (see RWY 07R in Figure 2 and Figure 3). Furthermore, especially when taxiing out for takeoff, it is intended to provide the crew intuitively with a positive confirmation of where to go, instead of merely relying on negative feedback in the form of alerts when they already are at risk of entering a runway erroneously. Highlighting the FMS-selected runway should enable improved awareness particularly in those cases where no taxi route is displayed on the airport moving map, including final approach and landing.

Likewise, the runways in use and temporary obstacles both on and in the vicinity of the aerodrome can be visualized. Optionally, further information, such as Low Visibility Procedures (LVP) status, Runway Visual Range (RVR), braking action and other relevant meteorological data, can be indicated to the crew in suitable form.

Except for the FMS-selected runway, the crucial issue for the OAF is how the data required to drive these representations, such as NOTAM and other operationally relevant information, can be supplied in a machine-readable format to enable the automatic display of this information without pilot interaction, because this is clearly preferable over manual entry of the corresponding data. Nonetheless, there has to be a back-up to enter at least runway closure data manually.

To address this issue, the concept of an electronic and machine-readable version of the Pre-Flight Information Bulletin, the modular and scalable ePIB, was proposed (Vernaleken et al., 2006a). The ePIB is intended to supply aircraft with a machine-readable version of NOTAM and other operationally relevant information contained in a conventional PIB. In its basic version, the ePIB is completely independent of the availability of any avionics data link and can be implemented by an individual airline for any of its sub-fleets without any impact on
other operators. Many airlines up-link the flight plan to the flight deck prior to the flight, and conceptually, the ePIB upload could be seen as an extension of this, even if the crew’s laptops or a different type of data link are eventually used. A change of ATM procedures is not necessary in this case.

At the same time, due to its modularity and scalability, the concept proposed supports both in-flight updates of the onboard NOTAM package and additional information from sources like D-ATIS, D-OTIS or FIS. Nonetheless, waiting for the availability of these services for the introduction of digital, machine-readable NOTAM information on the flight deck does not seem appropriate in view of recent incidents. Figure 5 shows a proposed crew interface for the structured review of NOTAM information during flight that the ePIB enables as a by-product.

The main purpose of the ePIB is to drive the OAF representation. Figure 4 presents a proposed design for a MCDU Airport Menu that could be used to review and, if necessary, supplement or amend ePIB information. Depending on the flight phase and the position of the aircraft, information is by default either displayed for the origin or the destination airport, but the crew can change the airport by entering the appropriate ICAO identifier.

5. ALERTING CONCEPT FOR CLOSED AND UNSUITABLE RUNWAYS

Based on position data, Aerodrome Mapping Database (AMDB) data and the information utilized by the Operational Awareness Function (OAF), the flight crew can be alerted if they are at risk of operating on a closed runway. If a runway is completely closed, a caution alert will be triggered if the aircraft is approaching the holding position. If the holding position is crossed in spite of this alert, a warning alert will be triggered as soon as the holding position is crossed. Of course, the alert will persist if the aircraft enters the runway surface or attempts to take off. For a partially closed runway or a runway that may still be used as a taxiway, there is no need to alert the flight crew if the runway is entered. However, as soon as the crew attempts to take off, which can, on most aircraft, be detected comparatively easily using the aircraft’s internal flight phase logic, there will be a warning. Like virtually all cautions and warnings on the flight deck, these alerts are accompanied by callouts to attract the attention of the crew even if the display configuration selected by the crew does not permit them to see the airport moving map in sufficient detail.

The same triggering condition can also be applied if the pilots attempt to take off from a runway that is unsuitable (e.g. too short) or a taxiway. Operationally, there is a parallel to existing takeoff configuration warning systems, which alert for aircraft-internal unsafe conditions, whereas SMAAS warns the flight crew if the external conditions are unsafe. If the aircraft takes off from a runway other than the one selected as part of the FMS flight plan, an alert advising the crew of this situation is presented, consistent with the warning philosophy of the aircraft type concerned. A caution or warning alert in the case of an aircraft landing, however, seems to be inappropriate, because the runway change could have been advised by ATC at too short notice for the crew to make the required changes, since the priority is on flying the aircraft in this flight phase. Of course, to prevent dangerous situations more proactively on the system side, future FMS versions could block the selection of closed or otherwise unsuitable runways.

For aircraft attempting to land on a closed or unsuitable runway, an advisory or Level 1 alert can be triggered as soon as the crew arms the autoflight system for a closed runway. A higher level alert is not desirable in this case, because the crew has sufficient margin to resolve the situation, or the approach might have been routinely selected as part of a circling approach to another runway. Safety-net type alerts are only required if the aircraft continues the approach. During final approach, airliners lose approximately 500-800 ft per minute on a typical 3° ILS glide slope. It seems reasonable to couple the alerts to the radio altitude. When approaching a closed or unsuitable runway, a caution alert is triggered at 450 ft to alert the crew slightly less half a minute before touchdown. An altitude of 450 ft was chosen to avoid interference with the automatic radio altitude callout at 500 ft installed on many aircraft. If the aircraft descends further, a warning is triggered at 250 ft. If there is misalignment with the landing runway, as would be the case when attempting to on a taxiway, the same altitude trigger conditions and alert levels are used.

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5 As an example, both crew members could have selected ND ranges typically used when airborne, e.g. to review the SID or to take a look at the weather.
6 Provided that the aircraft is equipped with GPS and does not use the start of takeoff for a position update (setting of RWY coordinates).
7 Especially on older aircraft, an extension of the existing takeoff configuration warning system to these external unsafe conditions might be a suitable option instead of an additional surveillance system like SMAAS.
6. CONCEPT VALIDATION BY EVALUATION AT AIRPORTS

Between November 2005 and February 2006, several components of the Surface Movement Awareness and Alerting System (SMAAS), among them the OAF and the alerting for closed runways, were evaluated in live trials at Frankfurt (EDDF) and Prague (LKPR) airport with 15 airline pilots from five European airlines. TUD’s Navigation Test Vehicle, a Volkswagen LT 28 van equipped with a Honeywell H764 INS, various GPS receivers and a Filser RT60 ADS-B receiver (1090 ES), was used in this validation exercise to simulate an aircraft taxiing on an airfield. The passenger seat was fitted with an LCD display and a basic Crew Control Device (CCD) and served as a very simple cockpit mock-up. This particular test bed was chosen because it enables low-cost live field tests of onboard functions in a real airport environment. Thus, it provides not only unparalleled realism that can hardly be achieved in simulators, but also a possibility to assess the potential impact of environmental factors such as database and navigation accuracy (e.g. IRS drift and GPS outages) or the quality of ADS-B data. A more detailed test bed description can be found in (Vernaleken et al., 2006).

Figure 6: TUD’s Navigation Test Vehicle during tests on the closed runway 04/22 in Prague (LKPR)

However, the purpose of the SMAAS trials was a validation of the operational usability and the human-machine interface of the functions. In the trials, a PC-based standalone airport moving map (MMS), emulating a Navigation Display (ND) and controls was used. The ePIB concept and associated MCDU pages were not yet part of the evaluation.

Pilots would first be asked to evaluate the core system, the airport moving map display, supplemented by elements to increase operational and clearance awareness. In a second session, the Preventive Surface Movement Alerting concept was demonstrated to the maximum extent possible, i.e. up to advisory level in Frankfurt and up to Master Warning level in Prague, where a runway permanently closed for takeoffs and landings creates ideal prerequisites for the assessment of Runway Incursion alerting. Evaluation sessions concluded with a presentation of ADS-B ground traffic on the airport moving map display. Subjective feedback was collected using questionnaires filled by the pilots during and after the trials (both electronically and on paper) and open loop comments recorded during the sessions.

6.1 Scenarios

Scenarios were developed based on the assumption that cockpit procedures for using an airport moving map display and associated functions will give the role of monitoring the display to the pilot non-flying (PNF) to avoid that the aircraft is taxied head-down by the pilot flying (PF). Thus, the impact of the passive, monitoring role that pilots assumed in the trials on the results is believed to be very low. However, with responsibility for checklist reading and managing radio communications, the workload of a PNF will be higher in reality.

With 11 pilots, the majority of sessions took place in Frankfurt. Due to the high traffic density at Frankfurt airport, using the taxiway system during daytime was impossible. However, there are vehicle roads largely adjacent to the long taxiways A, D and N that extend parallel to the main runways all along the northern part with the two terminals and the cargo apron, and these were used for the trials. Typically, a scenario for the airport moving map assessment (including the display of a closed runway) would consist of driving from Terminal 1C up taxiway N and N North up to taxiway Z, and then back...
on A and down to position V102 near the eastern end of Terminal 2. After this scenario, pilots were asked to fill a first set of questionnaires and a first System Usability Scale (SUS).

Prague airport with its RWY 04/22 permanently closed for takeoffs and landings provides an ideal location for live trials on Runway Incursion alerting. As for Frankfurt, however, the basic airport moving map assessment session, including an evaluation of the display of closed runways, and, later on, the traffic assessment session mainly involved driving on vehicle roads near the passenger terminal. But the scenarios for evaluating the Preventive Runway Incursion Alerting concept were carried out on the taxiway system around RWY 04/22.

One of the Preventive Runway Incursion Alerting scenarios dealt with a closed runway. The purpose of this scenario was to assess the behaviour of the SMAAS if the aircraft is inadvertently heading for a runway that is completely closed. For the briefing, pilots were told to imagine that Runway 04/22 was planned to be re-opened as an active runway again, and that for this reason, there was heavy construction work in progress. The starting point would be on taxiway L, with the aircraft scheduled for takeoff on RWY 31. The controller would then make an error and not correctly advise the “detour” via M as expected (green route in Figure 7), but give a route via L instead (red route). Assuming that the crew would be distracted by the purser reporting a problem with some passengers, this controller error would go unnoticed, and the aircraft would go straight ahead on L and eventually come dangerously close to the runway under reconstruction. For this scenario, RWY 31 was set and displayed as the FMS Runway, and RWY 04/22 was set and displayed as completely closed. No taxi route was displayed for this scenario.

6.2 Participants
A total of 15 male airline pilots with an average age of 43.2 years (between 26 and 59 years old), among them nine Captains (CPT), three Senior First Officers (SFO) and three First Officers (FO), from five European airlines participated in the experiment described in this paper. During their entire career in commercial aviation, the participating pilots had logged between 1,500 and 20,000 hours (\(\bar{\sigma} 9335\) h). Incidentally, there was an almost even distribution over Airbus and Boeing aircraft types, as six pilots are currently on Airbus A320 (2) and A330/340 (4) family aircraft, while seven fly the Boeing B-737 (4), B747 (2) and B-777 (1). The remaining two pilots fly the MD-11. Familiarity/type-specific experience with the current aircraft type ranged from 200 to 9,000 hrs (\(\bar{\sigma} 3287\) h). On average, pilots had spent 15.1 years with their current airline, with a minimum of two years and a maximum of 37 years.

6.3 Results
The basic airport moving map received, as expected, very high ratings. According to pilots’ perception, it helped to increase their situational awareness and gave them support they miss with current systems. With an average of 88.8 out of 100, the system usability was rated very positively. Thirteen out of fifteen pilots (or 86%) think that it will not be possible to get lost on an airfield with an airport moving map, while two participants consider that this is still possible, particularly if the crew is distracted by other tasks. Furthermore, there is a clear pilot preference for an ND-integrated airport moving map display, thus confirming the SMAAS concept. Some more details can be found in (Vernaleken et al., 2006).

6.3.1 Operational Awareness Function
After having seen the FMS-selected runway representation on the airport moving map display, pilots were asked to rate this feature both in terms of operational relevance and with respect to the particular implementation chosen in post-run questionnaires. The results are presented in the following.

As can be seen from Figure 8, all pilots appreciated the concept of presenting the takeoff or landing runway selected as part of the FMS flight plan on the airport moving map, thus confirming the design hypothesis that this feature has operational relevance. With seven pilots, almost one half of the participants gave the highest rating, and the same number of pilots chose the second-highest rating. Only Pilot #11 was somewhat hesitant in his agreement, which is in line with the general reservations towards airport moving map technology he expressed. Except for Pilot #8, who gave a neutral rating, and Pilot #11, who skipped this question, all other participants also agreed with the way the FMS-selected runway was presented on the airport moving map, although only 36% gave the highest rating. Nonetheless, the concept of using the runway outline to represent the FMS-selected runway on the airport moving map seems to be valid.
The presentation of the FMS runway on the MMS is relevant from an operational point of view.  

- strongly disagree  
- disagree  
- rather disagree  
- neutral  
- rather agree  
- agree  
- strongly agree  

It is operationally relevant to display closed runways on the airport moving map display.  

- strongly disagree  
- disagree  
- rather disagree  
- neutral  
- rather agree  
- agree  
- strongly agree  

Regarding the display of closed runways, Figure 9 illustrates that all of the participating pilots acknowledged the operational relevance of displaying closed runways on the airport moving map. Both the level and the quality of agreement are very high. Only Pilot #1 and Pilot #14 were more reluctant in their feedback and “rather agreed” with the statement presented (see Figure 9), but generally considered presenting closed runways relevant. 73% of the pilots also chose the two highest ratings for the symbology, thus acknowledging that they found it intuitive and easy to understand. Two participants were not convinced: Pilot #11 slightly disagreed, and Pilot #10 disagreed. Unfortunately, their comments during the sessions did not shed any light on the reasons for their rating.

6.3.2 Closed Runway Alerting Concept

As can be deduced from Figure 10, an overwhelming majority of pilots strongly agrees that being alerted when in danger of causing a runway incursion is an operationally useful feature, and there is the same level on agreement on another question that this will contribute to an increase in flight safety. The only tentative agreement on the operational usefulness of runway incursion alerting was given by Pilot #15, who nonetheless commented that the alerting was very useful.

Assuming that most pilots might be more familiar with the FAA definition of Runway Incursions, which does not include closed runways explicitly or implicitly, it was decided to treat Runway Incursions due to operation on closed runways separately in the questionnaire. Furthermore, this provides an opportunity of checking pilot ratings for consis-

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8 For each questionnaire results diagram shown, the number N of valid answers is given. Occasionally, pilots skipped individual questions by error.
It is unlikely that I will ever try to enter or land on a runway that is displayed as a closed runway on my moving map display.

It should be noted, though, that only the last four pilots, the participants of the Prague experiment session, were exposed to the full scope of runway incursion alerting and assessed the closed runway alert in the scenario shown in Figure 7. Therefore, the results shown here are, at least partially, more a survey stimulated by the representation of closed runways on the airport moving map than evaluation results by character.

In order to obtain a rough estimate on the impact of having only the basic OAF representation and no alerts, pilots were asked to give their rating on the question presented in Figure 12. A clear majority of pilots is of the opinion that the basic representation of closed runways on the airport moving map display will reduce the probability of Runway Incursions due to closed runways. However, there is also dissent, because Pilot #9 and Pilot #14 rather disagree on this. Pilot #7 gave a neutral rating. This once more underlines the capability of the OAF in preventing hazardous situations if the crew is monitoring the airport moving map. At the same time, as the crew might be temporarily using a different display configuration or be distracted, the representation of closed runways does not eliminate the need for alerting, even if it reduces the risk of Runway Incursions.

7. CONCLUSION

The Surface Movement Awareness and Alerting System (SMAAS) outlined in this paper can be applied to improve crew situational awareness and to alert the flight crew in case closed or unsuitable runways are chosen by the crew. In a first step, for improved operational awareness, an extension of the basic airport moving map by a read-only connection to the Flight Management System (FMS) and a MCDU page (or comparable interactive setup) that the crew can use to set the closure state of runways might be the most feasible way of introducing part of the technology described in this paper on the flight deck. If this additional workload in flight preparation is acceptable, no further data link services are required to benefit, as the first partial validation results suggest, from the improved situational awareness created by the display of the takeoff or landing runway set in the FMS and the representation of closed runways on the airport moving map. Of course, ePIB technology, which has not yet been validated in trials so far, should be more beneficial in terms of crew workload and eliminate the – albeit small – risk of pilots entering wrong or incomplete closure data.

First partial validation results indicate that approach taken is valid both for the situational awareness and the alerting part, with very positive feedback from the participating pilots. Of course, the alerting part of the system will require further evaluation before a definite recommendation regarding the introduction of such an alerting system can be made, but so far results are very encouraging, and seem to validate the dual approach of improved situational awareness and supplemental safety-net alerting consistent with existing flight warning system philosophies as a last resort.
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REFERENCES

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