How Can a Future Safety Net Successfully Detect Conflicting ATC Clearances – Yet Remain Inconspicuous to the Tower Runway Controller? First Results from a SESAR Exercise at Hamburg Airport

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Abstract. To increase runway safety a new safety net for Tower Runway Controllers was developed which detects if controllers give a clearance to an aircraft or vehicle contradictory to another clearance already given to another mobile. In a shadow mode validation exercise with eleven controllers at the operational environment of the airport Hamburg (Germany) operational feasibility was tested in order to clarify if operational requirements in terms of usability are fulfilled. At the same time operational improvements regarding safety were studied e.g. if the new safety net detects all conflicts and if nuisance alerts are suppressed.

Keywords: Safety, Air Traffic Control, Airport Operations, Runway Incursions, SESAR.

1 Introduction

On 31st July 2008 the flight crew of a Fairchild SA227 Metroliner III contacted the Zurich Tower Runway Controller to inquire if it is an option to land on runway 16 instead of runway 14. This is a frequent request by pilots because landing on runway 16 allows a shorter way to the terminal; in doing so runway 28 has to be crossed. In this case, the controller cleared the aircraft to land on runway 16. Shortly after that an Airbus A319-100 taxied to runway 28 for departure and was cleared to line-up and hold. Then the tower controller ordered the flight crew of a helicopter to hold position and not to cross the departure path of runway 28 because of the intended departure of the Airbus. Subsequently the controller cleared the Airbus for take-off. Suddenly the controller noticed that the landed Metroliner was still rolling on runway 16 while the Airbus was starting to accelerate down runway 28. This situation was obviously

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dangerous because both aircraft approached the intersection. Upon notice the Airbus crew was ordered to abort take-off [1] [2].

This incident illustrates the risk of a conflicting air traffic control (ATC) clearance and its potential consequence. In this case a fatal collision could be prevented. However a conflicting ATC clearance given on 1st February 1991 in Los Angeles led to a collision between two aircraft where 34 people lost their lives [3].

In 2011, altogether 66 runway incursions - not leading to an accident - have been reported in Germany. Only 12% of these rare events were caused by controllers [4] but it can be presumed that conflicting clearances were given before. In order to prevent this unique cause for a potentially dangerous situation, an additional "Conflicting ATC Clearances safety net" was created. This safety net detects if clearances given to aircraft or vehicles could lead to an unsafe situation.

2 Concept

2.1 Background

The "Single European Sky Air Traffic Management Research" (SESAR) programme is one of the most ambitious research and development projects ever launched by the European Union. The programme is the technological and operational dimension of the Single European Sky (SES) initiative to meet future capacity and air safety needs, i.e. an improvement of safety by a factor of 10 [5]. In this context runway incursions shall be reduced. They are defined by International Civil Aviation Organization (ICAO) as "any occurrences 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" [6].

The "Conflicting ATC Clearances safety net" concept as well as the prototypes used for validation were developed under the SESAR programme and co-financed by the European Community and EUROCONTROL. Work on the report of the final validation exercise finished at the end of February 2013, therefore it should be stressed that the source material for the results published in this paper has not been approved by the SESAR Joint Undertaking (SJU) yet. The sole responsibility of this paper lies with the authors. The SJU and its founding members are not responsible for any use that may be made of the information contained herein.

2.2 The "Conflicting ATC Clearances Safety Net" Concept

Currently the only safety net available to Tower Runway Controllers is the Runway Incursion Monitoring System (RIMS). It uses Advanced Surface Movement Guidance and Control System (A-SMGCS) Surveillance data to detect dangerous situations within the Runway Protection Area. Detections and subsequent alerts to controllers are provided at the very last moment and require immediate reaction.

The new "Conflicting ATC Clearances safety net" will not replace the existing RIMS but is intended as an additional layer of safety. It will detect conflicting ATC clearances much earlier – when the controller inputs clearances into the Electronic Flight Strips (EFS), which are already in operational use in many control towers. To do so, it will perform crosschecks with the clearances input on the EFS, and in most cases the aircraft position, to see if the given inputs violate the rules and procedures at the concerned airport, which could lead to a hazardous situation [7]. In the introductory example at Zurich airport, a conflicting "land vs. take-off" alert would have been given.

2.3 Recommendations from Real Time Simulation

A first prototype had already been successfully tested in a SESAR real time simulation exercise [8] with three air traffic control officers (ATCOs) in 2011. It was recommended that the detection of take-off versus line-up and line-up versus take-off should be fine-tuned so that the system takes into account the line-up point of the taxiing aircraft and not the actual position of the aircraft. This would prevent a so-called nuisance alert that is triggered when the aircraft that was due to line-up would be still taxiing on the taxiway parallel to the runway but is in front of the aircraft taking off, but the line-up point is behind the aircraft taking off.

Furthermore it was recommended to make the safety net more proactive instead of reactive. A "what-if tool" would be capable to highlight potential conflicting ATC clearances before these clearances are actually given. This would eliminate alerts and therefore the need for the ATCO to revise clearances.

2.4 Description of DFS's Prototype

The prototype to support the final validation was developed by DFS based on the flight data processing system (FDPS) *SHOWTIME* including electronic flight strips, and on the surveillance data processing system (SDPS) *PHOENIX*. For a detailed description of the prototype's detection logic for conflicting ATC clearances, please refer to [9]. The present section briefly summarizes some aspects of the prototype, focusing mainly on its human machine interface (HMI).

Conflicting ATC clearance alerts are displayed both in the FDPS HMI (Figure 1) and the SDPS HMI (Figure 2, left) for both the tower runway and ground controller. As can be seen in the figures, the type of conflict is displayed both on the flight strip and on the SDPS target label. An alert may be acknowledged by clicking on the "ACK" part of the strip on the right; this makes the alert display less obnoxious, but does not suppress it completely.

Clearances are entered into the electronic flight strips using a mouse. In particular, the next clearance (according to standard procedure) can be entered by clicking on the part of the strip that displays the currently active clearance (the square symbols on the very left in Figure 1). Taking back an entered clearance is possible via a menu, or – more quickly – using a special undo button.

Fig. 1. Conflicting take-off vs. land Clearance ("TOF/LND") in SHOWTIME

In developing the prototype, recommendations from the previous real time simulation (cf. section 2.3) were taken into account. In particular, the route-based conflicting clearance detection mechanism [9] helps in avoiding certain nuisance that occurred in the real time simulation (e.g. clearances that would be identified as conflicting clearances although the trajectories would never cross each other due to the positions or cleared routes). The prototype generates the needed ground routes automatically for all aircraft with a flight plan. If necessary this plan can be changed manually by the ATCO.

The core detection logic uses routes as inputs and – roughly speaking – checks whether the cleared routes of two mobiles overlap somewhere on a runway. An example is shown in Figure 2: The system identified the clearances line-up vs. land as conflicting, because the aircraft's routes overlap on the runway. The conflict disappears as soon as the landing aircraft passes the runway entry of the second aircraft.

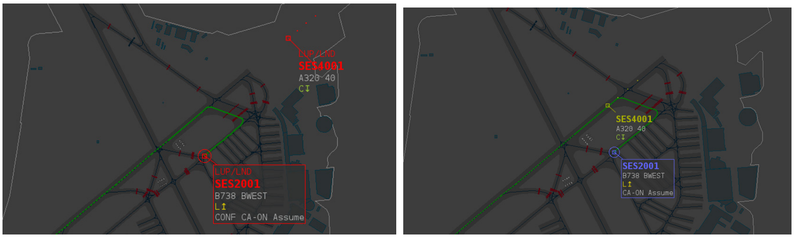

Fig. 2. Conflicting line-up vs. land ("LUP/LND") clearance in PHOENIX (left), neutralized after SES4001 passed the entryway of SES2001

Fig. 3. Predictive conflict indication: two possible conflicting clearances indicated by a red dot in the flight strips UAE25 and DLH1MA

Furthermore a **predictive indication** is introduced as well. It is integrated on the left side of the flight strip. If the next clearance (according to standard procedures) would currently cause a clearance conflict, this is indicated by a little red dot. In contrast, a green dot indicates that giving this next clearance would currently not cause a clearance conflict. For example as shown in Figure 3, giving a line-up clearance to UAE25 or to DLH1MA would create a clearance conflict, whereas giving the clearance to GEC9834 would not.

2.5 Validation Objectives for Shadow Mode Trials

First of all, the operational feasibility in terms of fulfillment of operational requirements (as stated in the Operational Services and Environmental Description (OSED)

[7]) had to be checked, mainly by controllers' feedback on the usability of the different alerts and the HMI design.

Secondly operational improvements in terms of safety had to be studied. It was crucial that the new safety net detected all conflicting situations. Furthermore the safety net should allow the controller to solve detected situations timely. In addition to that the false alert rate had to be acceptable for the controller. Finally it should be tested if some detections were considered as nuisance alerts by the controllers.

3 Method

The shadow mode trials were performed with different controller teams each day at the airport environment in Hamburg between the 26th and 30th November 2012. A controller team consisted of a Ground and Runway controller.

3.1 Sample

In total eleven Tower Controllers took part in the study. Six were active Hamburg controllers, one was recently retired in 2011. Additional one ATCO each came from the airports in Hamburg Finkenwerder, Leipzig (both Germany), Klagenfurt (Austria) and Lamezia Terme (Italy). Eight of them were male, three were female. Their average age was 35.5 years (standard deviation: 7.3 years). For the six active Hamburg controllers the mean reported experience was 6.3 years (standard deviation: 4.7 years).

3.2 Shadow Mode Environment

The exercise was located outside the control tower environment to not interfere or disturb the active controllers and pilots at the time. All data was copied and re-routed to a separate, temporary control room set up for the duration of the exercise.

3.3 Traffic

Real life traffic of the Hamburg Airport was used. Additional synthetic traffic was produced to create pre-conditions for conflicting clearances. ATCOs were informed that these synthetic targets could be injected to increase the number of sufficient critical situations in the trials.

3.4 Task

Due to the nature of a shadow mode trial both ATCOs of a team had to act as if they were in charge but without any intervention to the real traffic. One of the two ATCOs started as tower runway controller, assisted by a technical supporter from DFS on his left, and the validation supervisor on his right. The following clearances of the tower controller were part of the exercise: line-up, take-off, land and cross runway.

Any combination of these clearances as defined in [7] shall trigger an alarm. The other ATCO had to act as a ground controller, dealing with all other clearances. Together with the co-validation supervisor they created potential conflicting situations for the Runway Controller.

The ATCO was briefed to make an input to the electronic flight strip (EFS) for an aircraft in accordance to a clearance by the real operational ATCO in the Hamburg control tower. The validation supervisor identified a second aircraft and asked the ATCO in the validation scenario to give now a pre-defined conflicting ATC clearance. For example, the ATCO made a take-off clearance input on the EFS for an aircraft. After that he gave – on order of the validation supervisor – a cross clearance to another aircraft. This resulted in a "take-off vs. cross" conflict.

The first part of each day was dedicated to brief both ATCOs on the scope and objectives of the shadow mode trials and to train them on the equipment and environment. Most of them already had a pre-training on DFS's FDPS PHOENIX and DFS's SDPS SHOWTIME the week before as SHOWTIME was not in operational use at Hamburg tower resp. PHOENIX is used in another version and configuration.

3.5 Scenarios

Three shadow mode trials lasting seventy minutes each were performed during the day. After 35 minutes ATCOs were told to switch roles (from tower to ground controller and vice versa). The first of the three shadow mode trials focused on scenarios with the first clearance being given was "land". The second shadow mode trial took into account scenarios with the first clearance being given was "line-up" or "take-off". The third and final shadow mode trial dealt mainly with cross scenarios and any other conflicting clearance which had not been tested before or which was regarded as particularly interesting.

3.6 Measurements

To check if the operational requirements of the OSED [7] were fulfilled a Post Trials Questionnaire was tailor-made [10] to capture ATCOs' feedback and comments. Each ATCO had to complete the questionnaire in an excel spreadsheet after the last of the three shadow mode trials. Controllers were asked how far they could agree to or not by choosing answers amongst six categories ranging from 1 (strongly disagree) to 6 (strongly agree).

Mean values (M) and standard deviations (SD) were calculated to describe the result. Furthermore, by use of a binomial test [11] for a single sample size, each item was proven for its statistical significance with an expected mean value = 3.5, test ratio: .50 and alpha = 0.05.

Furthermore the triggering of the correct type of alert and the amount of false alerts was measured by observations of experts.

4 Results

4.1 Operational Feasibility

ATCOs agreed in the Post Trials Questionnaire that they appreciate the conflict information (M=4.7 on a six point Likert scale, SD=0.9, N=10, p=0.02). In the following further results from the questionnaire are reported [10], arranged for different types of alerts:

Detailed feedback for conflicting clearances alerts including a **landing aircraft** was given by the ATCOs. The alert for conflicting clearances with two landing aircraft was rated as usable (M=4.9, SD= 0.7, N=10, p=0.00), especially when two aircraft received landing clearances on the same runway. The alert in case of an aircraft cleared to land and another aircraft being cleared for line-up was rated as usable as well (M=5.3, SD=0.6, N=11, p=0.00), especially when the aircraft receiving the line-up clearance was in front of the aircraft receiving the landing clearance on the same runway. The alert was rated as particularly usable when the aircraft receiving the clearances were on the opposite ends of the same runway. The alert for the conflicting clearances "land vs. take-off" (M=5.1, SD=0.6, N=10, p=0.00) was usable for the ATCOs as well. Notable situations to be mentioned here are two aircraft on the same runway; respectively two aircraft at opposite ends of the same runway. ATCOs also agreed that "land vs. cross" alerts were usable (M=4.7, SD=1.2, N=11, p=0.01). Of particular importance are situations when an aircraft receiving the cross clearance was in front of the aircraft receiving the landing clearance on the same runway.

Further positive results were gained for alerts in case of conflicting clearances including a **line-up clearance**. Alerts for two aircraft being cleared for line-up were usable according to the ATCOs (M=5.3, SD=0.5, N=6, p=0.03) especially when both aircraft were on the same or adjacent holding points on the same runway when multiple line-up was not authorized. Furthermore the alert was rated as usable when holding points were opposite on the same runway. An alert for "line-up vs. take-off" was also rated as usable (M=4.5, SD=1.0, N=10, p=0.02), especially when the aircraft receiving the line-up clearance was in front of the aircraft receiving the take-off clearance on the same runway. Furthermore the alert is usable when both aircraft were on the opposite ends of the same runway. The alert "line-up vs. cross" was usable as well (M=4.7, SD=1.1, N=10, p=0.02), for example when holding points were opposing on the same runway.

ATCOs also agreed on the usability of alerts in case of conflicting clearances including an **aircraft being cleared for take-off**. An alert for two aircraft receiving take-off clearances was rated as usable (M=4.9, SD=0.7, N=10, p=0.02), especially for two aircraft on the same runway or at opposite ends of the runway. Usable were also alerts with cleared aircraft on different but intersecting runways when aircraft trajectories were converging. The alert "take-off vs. cross" was usable as well (M=5.2, SD=0.4, N=10, p=0.00), especially when an aircraft receiving the cross clearance was in front of the aircraft receiving the take-off clearance on the same runway.

In conclusion ATCOs agreed that the alerts for conflicting clearances with two aircraft **cleared for cross** were usable as well (M=4.8, SD=1.1, N=11, p=0.01) especially when holding points were opposing on the same runway.

ATCOs gave positive **feedback for the HMI** design aspects. They agreed that the configuration of the alert window was fine with them regarding size (M=4.7, SD=0.6, N=11, p=0.01), the use of the alert color "red" (M=4.9, SD=0.8, N=11, p=0.01), and contrast (M=4.8, SD=0.4, N=11, p=0.00). Furthermore audio alarms were rated as usable (M=4.8, SD=0.4, N=10, p=0.00).

4.2 Operational Improvements in Terms of Safety

Detection of Conflicting Situations. Based on observation by experts the correct type of alert was triggered in each case. In detail, the following alerts were triggered successfully during the week of shadow mode testing: 55 land vs. land; 55 land vs. line-up; 96 land vs. take-off; 25 land vs. cross; 35 line-up vs. line-up; 27 line-up vs. take-off; 18 line-up vs. cross; 39 take-off vs. take-off; 25 take-off vs. cross; and 4 cross vs. cross [10].

In addition all ATCOs emphasized that no alerts were missing in the different trials. It could be shown that multiple alerts with more than two aircraft can be displayed comprehensibly. ATCOs state that the alert indication for these rare events can be improved [10].

Timely Detection of Alerts. There is no doubt among the ATCOs that the alerts are generally displayed in time (M=5.0 on a six point Likert scale, SD=0.5, N=9, p=0.00) [10].

Acceptability of False Alert Rate. Based on observation by experts no alerts were given by the system in case that no conflict existed. Therefore no false alerts can be reported [10].

Absence of Nuisance Alerts. ATCOs were asked if alerts were given in situations where the alert is not necessary according to (local) procedures. ATCOs agreed in the Post Trials Questionnaire that the number of nuisance alerts was acceptable (M=4.8 on a six point Likert scale, SD=1.2, N=8, p=0.07 indicating a statistically significant trend). Furthermore the number of alerts that were displayed "too early" was sufficiently low (M=5.3, SD=0.5, N=6, p=0.03) [10].

ATCOs reported that two "line-up vs. cross" alerts were not necessary because the breath of these particular two taxiways allows a simultaneous line-up and cross of two aircraft.

5 Discussion

Overall the validation can be considered as very successful. DFS had provided a well working safety net [9] which was updated and fine-tuned according to the previous validation results of a real time simulation [8] and the updated Operational Services and Environment Description documentation for the safety net [7]. The technical feasibility of the safety net within a real airport environment could be shown. Response of the new safety net was faster than required. The display of alerts simultaneously on SDPS and FDPS and the use of an audio alert were appreciated by the ATCOs [10].

ATCOs' feedback as given in the questionnaires and debriefing was very positive regarding the new safety net. According to the ATCOs and the observers every expected alert was generated and displayed on time by the system. No false alerts were observed during the trials. Operational improvements in terms of safety were indicated by the ATCOs in their comments and in the questionnaire results. Especially the added value of a predictive information tool contributed to this result. It was especially appreciated by the ATCOs because it reduces the number of situations in which the controller would have to *react* on an already given conflicting clearance to a minimum. The implementation of the safety net is capable to assist the ATCOs to perform their tasks more safely while maintaining the efficiency of the airport operations.

The concept in general was considered to be a useful predictive safety support tool that would work in conjunction with additional safety nets (e.g. RIMS).

In the next step the use of the underlying routing function as part of the concept will be discussed because its added value to suppress nuisance alerts was shown in the Hamburg shadow mode trials.

Moreover the interaction of different safety nets should be studied, namely the new developments for Conflicting ATC Clearances plus an additional Conformance Monitoring tool and RIMS which is already in operational use at several airports [10]. Firstly the priority of alerts has to be identified. Secondly it has to be clarified which type of alert should be triggered at which time. In this context it is necessary to discuss if a simultaneous display of different alerts is required or if one safety net should be capable to overwrite alerts given by another safety net. For example a RIMS alert should be given more importance than a conflicting clearance alert. Results from exercises with the simultaneous use of these three safety nets do not exist to give indications in this context by now [10].

Furthermore the necessity of additional real time simulations was stressed by the validation team, ATCOs and observers. They should involve the above mentioned safety nets, and include visual flight rules traffic and helicopters to test more complex situations (e.g. traffic without flight plans). This will certainly increase workload for the controller and probably create more safety critical situations. Conflicting *taxi* clearances could be tested in this environment as well [10].

In the validation exercise conflicting ATC clearances were provoked on purpose to test the concept. However, in the real operational environment the new safety net acts as a kind of watchdog in the background, visible only in the rare occasion of a clearance conflict. It would be a revealing test to let the system run silently and unattendedly in shadow mode linked to the EFS inputs of the real operational tower controllers. This would allow one to measure how often conflicting clearance alerts occur in practice with real controllers acting normally (the goal being that this happens almost never).

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