A New Safety Net for Tower Runway Controllers:

Preliminary Results from SESAR Exercise at Hamburg Airport in Detection of Conflicting ATC Clearances

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Abstract – **One of the most serious safety concerns in air traffic control are runway incursions. A runway incursion is 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" [1]. Traditional Advanced Surface Movement Guidance and Control Systems (A-SMGCS) level 2 safety systems detect runway incursions and potential collisions. The subsequent alerts to controllers often require immediate reaction. A new, additional safety net for tower runway controllers was developed to provide longer reaction times for certain kinds of imminent runway incursions. This new safety net detects if controllers give a clearance to an aircraft or vehicle contradictory to another clearance already given to another mobile. The new safety net, developed in context of SESAR, was tested in a shadow mode validation exercise at the operational environment of Hamburg Airport (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 defined conflicts.**

A data logging was made to measure reaction time of the developed Conflicting Air Traffic Control Clearances System (CATC), in interaction with the electronic flight strips (EFS) system.

Keywords: ATC Clearances, Runway Controller, Runway Incursions, Hamburg Airport

I. Introduction

Chicago Midway International Airport, December 1st 2011, runways in use are 31C for take-off and landing and runway 22L for take-off. There are two air traffic controllers, one is handling the regular traffic, a second is plugged in as "ground control 2" monitoring the tower frequency and working a VIP arrival checklist.

The tower runway controllers know that a VIP arrival is planned for later the day, which would effectively shut down the airport. This creates a lot of pressure to get as many departures and arrivals through as possible. For this reason the tower runway controllers decide to open runway 31R as an additional departure runway. Figure 1 shows the runways in use at Chicago Midway Airport.

It is 09:06 in the morning. A Boeing 737 of Southwest Airlines flight SWA844 gets the landing clearance for runway 31C. During the landing the first officer of SWA844 observes a Learjet 45 lining up on runway 31R.

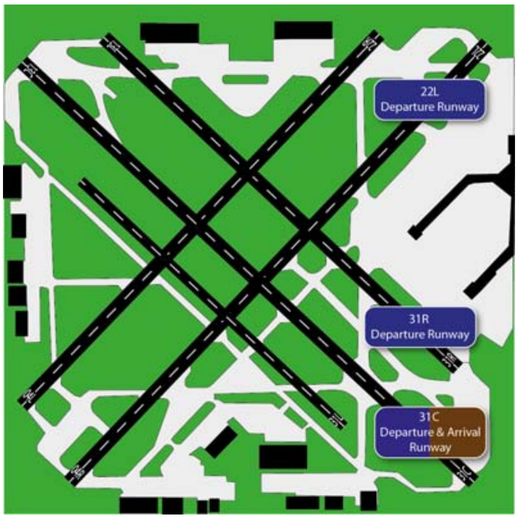

Figure 1: Runways in Use at Chicago Midway Airport

After the landing of SWA844 the tower runway controller gives take-off clearance to the Learjet on runway 31R. After that he gives SWA844 the instruction "*vacate runway 31C via taxiway Bravo, cross runway 31R and contact ground"*. The monitoring tower runway controller recognizes the conflict of the two instructions and queries his colleague whether he would give SWA844 an instruction to hold short of runway 31R on taxiway November. The runway controller does not answer his colleague. The monitoring controller points out for a second time that there is a conflict between SWA844 and the Learjet 45; however he receives no reply by his colleague. In the meantime SWA844 is taxiing at high speed on taxiway Bravo. At 09:08 the pilot of SWA844 calls the tower and advises that *"we have a plane taking off from 31R and you cleared us to cross runway 31R"* The runway controller responds *"SWA844 cross 31R, contact ground"*. "*Okay if you just copied you cleared us to cross a runway where there is a plane taking-off*" respond the cockpit crew of SWA844. The tower runway controller does not cancel the take-off nor issue an instruction to SWA844 to hold short of runway 31R on November. At this moment the first officer of SWA844 spots the Learjet which is taking-off from runway 31R and yells to the captain to stop. The SWA844 Boeing stops just short of the runway edge. At this moment the Learjet overflies the Boeing with a vertical separation of 62 feet/ 19 meters and a lateral separation of 267 feet / 81 meters. [2]; [3]. Figure 2 illustrates the runway incursion at Chicago Midway Airport.

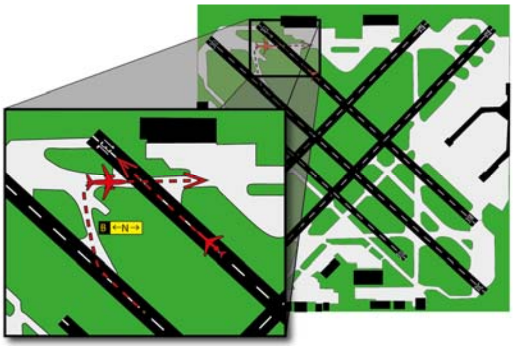

Figure 2: Runway incursion at Chicago Midway Airport

This incident illustrates the risk of conflicting air traffic control (ATC) clearances and their potential consequences.

Another pair of conflicting ATC clearances was given on May 17th 2013 at Hartford airport (Connecticut, USA). In this case simultaneous clearances for take-off and landing on crossing runways were given. In both cases (Chicago and Hartford), fatal collisions could be prevented.

Unfortunately, this was not always so. On February 1st 1991 in Los Angeles conflicting ATC clearances led to a collision between two aircraft where 34 people lost their lives [4].

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 tower runway controllers [5] but it can be presumed that conflicting clearances were given before. In order to prevent this cause for a potentially dangerous situation, an additional "Conflicting ATC Clearances Safety Net" (CATC) was created. This safety net detects if clearances given to aircraft or vehicles could lead to a runway incursion.

II. CONCEPT

A. *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 [6]. In this context runway incursions shall be reduced.

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.

The sole responsibility of this paper however 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.

B. *The Conflicting ATC Clearances Safety Net Concept*

Currently the only safety net available to tower runway controllers to avoid runway incursions 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 often provided at the very last moment and require immediate reaction.

The new CATC Safety Net will not replace the existing RIMS but is intended as an additional layer of safety. It will give tower runway controller more time to react by detecting conflicting ATC clearances much earlier – typically at the moment when the tower runway 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 previous clearances input on the EFS, and in most cases the aircraft position, to check whether one of the situations described in the subsequent paragraphs occurs which could lead to a runway incursion or other hazardous situation [7].

Below we define the types of "conflicting clearances". Our definition follows the one in [9], which in turn is based on the one in [7]. We consider 4 types of runway related ATC clearances: Line Up (LUP), Cross (CRS), Take-Off (TOF) and Land (LND). Based on these four clearances we define the following conflicting clearance situations:

LUP/LUP: two aircraft are cleared to line up from opposing runway entries on the same end of a runway; or: two aircraft are cleared to line up on opposite ends of the same runway; or: two aircraft are cleared to line up on the same or adjacent runway entries on the same runway, and multiple line-up is not authorized.

LUP/CRS: one aircraft is cleared to line up and another mobile is cleared to cross the same runway from an opposing runway entry.

LUP/TOF: one aircraft is cleared to line up and another is cleared to take-off on the same runway, and the runway entry of the aircraft lining up is in front of the position of the aircraft taking off.

LUP/LND: one aircraft is cleared to line up and another is cleared to land on the same runway, and the runway entry of the aircraft lining up is in front of the position of the landing aircraft, and the landing aircraft is not expected to vacate the runway before the line up point.

CRS/CRS: two mobiles are cleared to cross the runway from opposing runway entries.

CRS/TOF: one mobile is cleared to cross and another is cleared to take-off on the same runway, and the runway entry point of the crossing mobile is in front of the position of the aircraft taking off.

CRS/LND: one mobile is cleared to cross and another aircraft is cleared to land on the same runway, and the entry point of the crossing mobile is in front of the position of the landing aircraft, and the landing aircraft is not expected to vacate the runway before crossing point.

TOF/TOF: two aircraft are cleared for take-off on the same runway or on dependent runways.

TOF/LND: one aircraft is cleared to take-off and another aircraft is cleared to land on the same runway or on dependent runways.

LND/LND: two aircraft are cleared for land on the same runway or on dependent runways.

A CATC system provides an alert to the responsible tower runway controller whenever it detects one of these conflicts. In the introductory example at Chicago Airport, a CRS/TOF conflicting alert would have been given.

Furthermore, definitions of alert types were made [10]:

False Alert: an alert is given but no conflict exists. No alert should be indicated in this case.

Wrong Alert: an alert is given and a conflict exists (e.g. LUP/LUP) but a wrong type of alert is indicated (e.g. LUP/TOF). The correct type of conflict should be indicated instead (e.g. LUP/LUP).

Nuisance Alerts: in contrast to false alerts and wrong alerts, there is no objective definition for "nuisance alerts", but we use this name to label alerts which are not false alerts, but which at least one tower runway controller in the validation subjectively considered this alert as a nuisance.

C. *Recommendations from Real Time Simulation*

A first CATC prototype had already been successfully tested in a SESAR real time simulation exercise [8] with three tower runway controllers from the airports Paris Charles de Gaulle (France) and Leipzig (Germany) in 2011. As a result of this exercise, the definition of the LUP/TOF conflict was changed: previously, the situation had been considered to be a conflict if the position of the lining up aircraft was in front of the taking-off aircraft, as opposed to its runway entry being in front of the taking off aircraft. This lead to nuisance alerts in situations when the aircraft that was due to line up would be still taxiing on the taxiway parallel to the runway but was in front of the aircraft taking off, while the planned line up point was behind the aircraft taking-off.

Furthermore, the real time simulations lead to the recommendation 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 some alerts and therefore the need for the tower runway controller to revise clearances.

D. *Description of DFS's Prototype*

The prototype that supported the final validation was developed by DFS Deutsche Flugsicherung GmbH. It is based on the flight data processing system (FDPS) *SHOWTIME* and on the surveillance data processing system (SDPS) *PHOENIX*. In contrast to other CATC implementations, the prototype employs a novel detection logic based on *ground routes:* essentially, a conflict is detected by noting that the cleared parts of two routes overlap somewhere on a runway. See [9] for more details on this approach.

Detected conflicts lead to alerts that are displayed both in the FDPS HMI (

Figure 3) and in the SDPS HMI (Figure 4) for as long as the conflict persists. When a new alert occurs, this event is also accompanied by an audible beep.

Figure 3: TOF/LND alert in FDPS

The tower runway controller may *acknowledge* an active alert by clicking on the "ACK" button the very right of a flight strip. Acknowledged alerts continue to be displayed, but become less obtrusive.

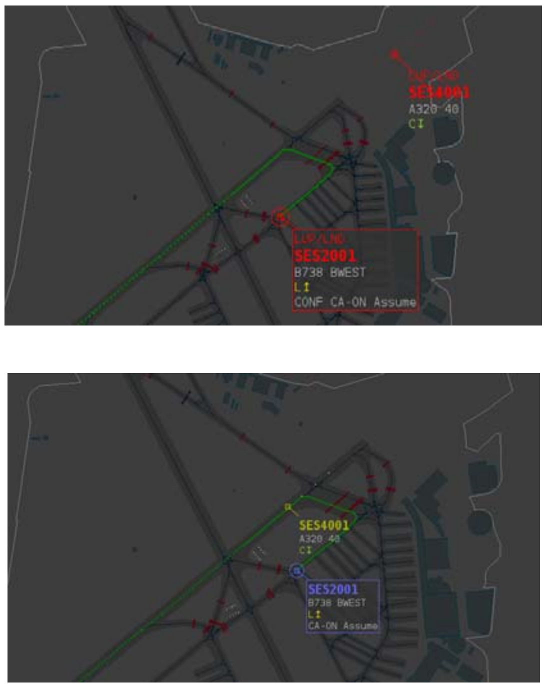

Figure 4: LUP/LND alert in SDPS display (first image), neutralized after SES4001 passes the runway entry of SES2001 (second image)

Tower runway controllers enter relevant information such as holding points, assigned thresholds and clearances via the FDPS HMI. For example, the typical "next" clearance according to standard procedures at the airport can be entered by clicking on the square at the very left of a flight strip.

Following a recommendation that resulted from the real time simulation (see Section 2.3), the prototype includes a predictive indication of conflicts in addition to the regular alerting mechanism. The system continuously checks for every active mobile whether entering the typical next clearance (according to standard procedures) would, at this point in time, cause a clearance conflict or not.

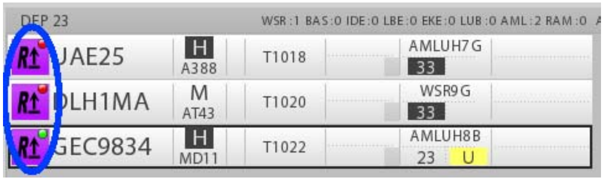

Figure 5: Predictive conflict indication: two possible clearance conflicts indicated by red dots in the flight strips of UAE25 and DLH1MA

The result is shown as a little red or green dot in the flight strip. For example, in Figure 5, the system indicates that giving a LUP clearance to UAE25 or to DLH1MA would currently create a clearance conflict, whereas giving a LUP clearance to GEC9834 would not.

E. 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. Also, it was crucial that the new safety net detected all defined conflicting situations. Furthermore the safety net should allow the controller to solve detected situations timely. In addition to that the false alert rate and also the nuisance alert rate had to be acceptable for the controller.

Furthermore, in this paper we consider in detail one of the objectives, derived by SESAR P16.06.01 and SESAR P06.07.01 on the basis of [12] and [13], which validates if the CATC system is able to provide alerts to the tower runway controller in not more than 1 second following the reception of the conflicting clearance from the EFS system.

III. Method

A. General Description of the Trials

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

In total eleven tower controllers took part in the study. Six were active Hamburg controllers, one had recently retired in 2011. Additional controllers 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. For the six active Hamburg controllers the mean reported experience was 6.3 years.

B. Shadow Mode Environment

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

C. Traffic

Real live traffic of Hamburg Airport was used. Additional synthetic traffic was produced to create preconditions for conflicting clearances in case the live traffic did not allow for a CATC situation. The participating controllers were informed that these synthetic targets could be injected to increase the number of critical situations in the trials.

D. Task

Due to the nature of a shadow mode trial both controllers of a team had to act as if they were in charge but without any intervention to the real traffic. One of the two controllers started as tower runway controller, assisted by a technical supporter from DFS on his left, and the validation supervisor from DLR on his right. The other controller had to act as a ground controller, dealing with all other clearances. Together with the validation co-supervisor they created potential conflicting situations for the tower runway controller.

The inherent problem of the validation exercise was that the controllers had to be forced to produce conflicting ATC clearances situations to test the concept. The tower runway controller was briefed to make an input to the EFS for an aircraft in accordance to a clearance by the real operational tower runway controller in the control tower. The validation supervisor identified a second aircraft and asked the tower runway controller in the validation scenario to give now a pre-defined conflicting ATC clearance. For example, the tower runway controller made a TOF clearance input on the EFS for an aircraft. After that he gave – on order of the validation supervisor – a CRS clearance to another aircraft on the same runway in front of the taking-off aircraft. This resulted in a TOF/CRS conflict.

The first part of each day was dedicated to brief both controllers on the scope and objectives of the shadow mode trials and to train them on the equipment and environment. Most of them already had an additional pretraining the week before.

E. Scenarios

Every day, three shadow mode trials lasting seventy minutes each were performed. After 35 minutes controllers were told to switch roles (from tower to ground controller and vice versa). The first of the three trials focused on scenarios with the first clearance being "LND". The second trial took into account scenarios with the first clearance being "LUP" or "TOF". The third and final trial dealt mainly with CRS scenarios and any other conflicting clearance situation which had not been tested before or which was regarded as particularly interesting by the participating controllers.

F. *Data Logging and Measurements*

Data logging was made to check if the objective and the resulting requirements were fulfilled. To this end, the message-oriented middleware of the DFS prototype had been wiretapped such that all messages throughout the trials were sorted (with respect to their origin), time stamped, and written to disk. These messages carried information about:

- flight plans,
- flight plan changes,
- selections, i.e., a mouse click on a specific target,
- CATC alerts,
- CATC alert acknowledgements (cf. chapter 2.4).

Furthermore, tailor made questionnaires had been prepared to capture controllers‘ feedback and comments. Each controller had to complete the questionnaire in an Excel spreadsheet after the last of the three shadow mode trials on each day. Controllers were asked how far they could agree to each proposition by choosing answers amongst six categories ranging from 1 (strongly disagree) to 6 (strongly agree) on a Likert scale. Mean values (M) and standard deviations (SD) were calculated to describe the result. Furthermore, by use of a binomial test [14] for a single sample size, each item was proven for its statistical significance by following conditions:

Expected mean value = 3.5
Test ratio: 0.50
Alpha = 0.05
Probability (p) values are classified as follows:

p<0.01: the agreement with a statement has been highly significantly unambiguous because the p-value is equal or less than the critical error probability which is 0.01.

p<0.05: the agreement with a statement has been significantly unambiguous because the p-value is equal or less than the critical error probability which is 0.05.

p<0.10: the agreement with a statement has at least a significantly unambiguous trend because the p- value is equal or less than 0.10. More tests are needed to clarify if this trend is really unambiguous significant.

Furthermore, the questionnaires asked whether the correct type of alerts had been triggered and to what amount false and nuisance alerts had been observed.

The complete results of the final debriefing questionnaire including comments can be found in the SESAR Validation Report [10].

IV. RESULTS

A. *Operational Feasibility*

The tower runway controllers 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). Furthermore, the tower runway controllers gave positive feedback for the HMI design aspects. They agreed that the configuration of the alert indicating 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). Further, audio alarms were rated as usable (M=4.8, SD=0.4, N=10, p=0.00) by the controllers.

Detailed feedback for conflicting clearances alerts regarding operational feasibility is provided in [10] and [11].

B. *Operational Improvements*

B.I *Operational Improvements in Terms of Safety*

B.I.I *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 exercise: 55 LND/LND; 55 LUP/LND; 96 TOF/LND; 25 CRS/LND; 35 LUP/LUP; 27 LUP/TOF; 18 LUP/CRS; 39 TOF/TOF; 25 CRS/TOF; and 4 CRS/CRS [10].

In addition all controllers highlighted that no alerts were missing in the different trials.

Furthermore it could be shown that multiple alerts with more than two aircraft can be displayed comprehensibly.

B.I.II *Timely Detection of Alerts*

Based on observation by the expert team, on the controllers’ statements during the debriefing session and the results in the questionnaires, it can be said 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].

B.I.III *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].

B.I.IV *Absence of Nuisance Alerts*

The controllers were asked if the CATC system gave alerts in situations where the alert is not necessary, for instance according to local procedures.

The controllers 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].

The controllers of Hamburg airport reported that two LUP/CRS alerts were not necessary in some cases because the width of these particular two taxiways allows a simultaneous line up and cross of two aircraft depending on aircraft size.

B.II Validation of Average Time of Alerts' Provisions

The average provision time of an alert was calculated with the average time between a change in the flight plan and the time when the alert message occurred. In this case a flight plan change means when the second clearance was given. The system logged this time only in seconds not in milliseconds. During the validation exercise we had 379 alerts (cf. chapter B.I.I).

In 61.18% of all cases the alert occurred within the same second in which the conflicting clearance was given which means that the time between the flight plan change and the alert was somewhere between 0 seconds and 1 second.

In 38.03% of all cases the alert occurred within two consecutive seconds which means that the time between the flight plan change and the alert was somewhere between 0 seconds and 2 seconds. It is also possible that the value could be less than 1 second[1].

In only 0.79% the alert needed more than two consecutive seconds which means that the time was somewhere between 1 second and 3 seconds[1].

This result was also supported by observations through DLR experts. The observation and the data logging revealed that the most of the average provision of alerts took no longer than one second.

Furthermore, this topic was discussed with controllers. They gave a positive feedback about this topic during the discussion in debriefing sessions and within the questionnaires. The result of controller questioning about the average provision of alerts was a positive feedback with a mean=4.0 on a 6-point Likert scale (SD=1.5, N=6) [10].

V. DISCUSSION

Overall the validation can be considered as very successful. The technical feasibility of the safety net within a real airport environment could be shown. The display of alerts simultaneously on SDPS and FDPS and the use of an audio alert were appreciated by the controllers [10].

Even though, for obvious reasons, the experimental setup on site at Hamburg Airport did not allow for real-time interaction with aerodrome traffic, the trial was able to demonstrate the potential of an additional safety net of this kind.

The controllers' feedback given in the questionnaires and debriefing sessions was very positive regarding the new safety net. Every expected alert was generated and displayed by the system. During the exercise no false alert occurred. This is an important result, because few false alerts within a period of time could lead to total distrust, followed by ignorance of the controllers, thus making the entire safety net void.

Furthermore, false alert events are noted yet more intensely. The workflow would be interrupted, actions might be taken possibly even creating new and additional risks, as no conflict existed in the beginning – a result that is not acceptable and thus is strongly remembered by the user.

It therefore is crucial to allow for individual configuration, decreasing nuisance alerts and to invest into the elimination of false alerts before introducing a safety net of any kind.

According to the controllers and observers and after evaluating of the data logging the alerts occurred in an acceptable time.

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 could be discussed as a part of the next OSED. This function is an added value to suppress nuisance alerts this was also shown in the Hamburg shadow mode trials. Furthermore the necessity of additional real time simulations was stressed by the validation team, controllers 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].

A new objective concerning the acknowledgement of alerts should be derived. This new objective could validate in which situations the controller acknowledges an alert, to adapt the safety net on local procedures.

Furthermore, data logging in future validations should use milliseconds in order to validate the reaction times of the system much more precisely.

In the validation exercise conflicting ATC clearances were caused on purpose in order to test the concept. However, in the real operational environment the new safety net would act as a kind of watchdog in the background, and would be visible only in the rare occasion of a clearance conflict. It would be a revealing test to let the system run silently and unattendedly by the controller 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.

In summary, the implementation of the safety net is capable to assist the controllers to perform their tasks even more safely while maintaining the efficiency of the airport operations.

In combination with other safety tools in use and under development, decreasing the risk of potential conflicting clearances is one step in the effort to maintain and increase safety in air traffic despite continuously increasing traffic numbers and growing demand especially at international airports as bottlenecks in the air transport system.

[1] The reason for this inaccurate information is the lack of milliseconds during the data logging.

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