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Enhanced Virtual Block Control for Milan Malpensa Airport in Low Visibility

J. Teutsch and A. Postma-Kurlanc

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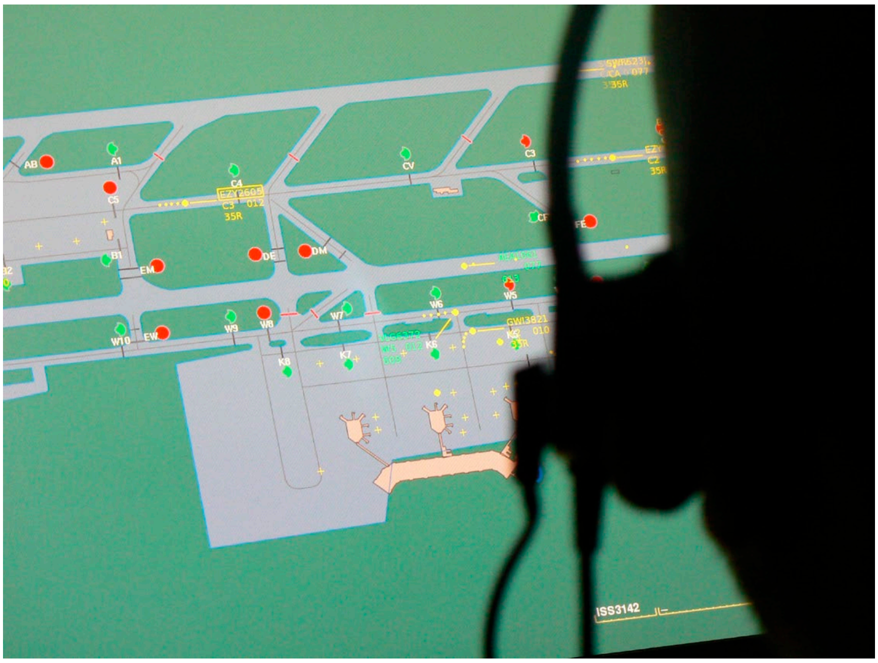
Executive summary

Enhanced Virtual Block Control for Milan Malpensa Airport in Low Visibility



Tower Controller Working Position during Milan Malpensa Simulations

Problem area
The Virtual Block Control concept makes use of virtual stop bar positions on a controller display and aims at reducing the size of control blocks that are used under low visibility conditions to achieve sufficient spacing between taxiing aircraft.
Within the SESAR Programme, Virtual Block Control was chosen as an operational concept for improving weather resilience at airports as part of the conceptual step towards time-based operations.

Concept feasibility and expected performance were validated on the NARSIM Tower platform which realistically simulated a working environment for Milan-Malpensa Airport (LIMC). This airport was chosen as its layout was very complex allowing for implementation of a much more mature concept of use as compared to earlier evaluations at Rotterdam Airport (EHRD).

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This report is based on a presentation held at ICNS 2014, Herndon (VA), U.S.A., April 08, 2014.

Description of work
Experiments were partially carried out in connection with an Alenia Regional Aircraft Flight Simulator in order to investigate the expected advantages of displaying virtual stop bar positions and statuses via data link on a moving map display in the cockpit. Thus, the SESAR validation led to more generally applicable results in terms of operational improvements.

An extensive preparation phase with controllers from Milan-Malpensa Airport already resulted in an unprecedented detailing of the concept in terms of positioning of virtual stop bars, definitions of types of stop bars and virtual stop bars and their representation on the display. The concept was also extended by adding functionality to administer the clearance limits and efficiently enter that information via the HMI. The alerting concept was refined by detailing requirements for visual and aural presentation of an alert. All this led to a very dedicated and highly refined implementation of Virtual Block Control for an airport with long parallel taxiway stretches and merging taxiway traffic flows.
In its final set-up, the new system incorporated Virtual Block Control, alerting for unauthorised block boundary crossings, a Watch Dog alerting concept for monitoring aircraft that are supposed to hold position and a clearance limit administration for all controllers.

Results and conclusions
Analysis results had a focus on operational feasibility aspects. However, capacity, efficiency and safety trends that could be extracted from the data were also further investigated. Regarding feasibility of the concept, overall scores obtained presented a very positive picture of the operations with the new functionality.
System usability, automation trust, situational awareness and teamwork aspects all scored significantly higher than in the reference scenarios. Mental workload scored significantly lower than in the reference scenarios. Both the operational improvements and the alerting concept were evaluated in more detail and reached very positive scores.
Controllers easily accepted the new system functionality and were often missing these tools as helpful means to maintain situational awareness and safety of operations in the reference scenarios. The Watch Dog functionality was highly appreciated and it was used in various situations to maintain a safe traffic flow without focusing too much on a single problem. The clearance limits on the labels supported silent co-ordination between different positions and increased the general situational awareness (this is also supported by high teamwork scores).
Observations made in a cockpit simulator with a moving map display including virtual stop bar positions and alerting for block boundary crossings, resulted in the same conclusions regarding operational feasibility aspects and operational improvements for the flight crew.
By comparing results for different arrival capacities, statements about efficiency of operations could be made. One of the foremost conclusions is probably that the efficiency gains that are observed at lower capacity values (current capacity and up to 20% more traffic) seem to level out at higher capacities (around 30% more traffic). Interestingly, this effect was not reflected in questionnaires. This could mean that workload and safety perception in itself was probably not directly related to the actual throughput or capacity values, but rather to the level of support that the system was providing.

Applicability
It was recommended that future activities should also be looking at the use of Virtual Block Control under even more realistic conditions, e.g. in shadow-mode trials.

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ENHANCED VIRTUAL BLOCK CONTROL FOR MILAN MALPENSA AIRPORT IN LOW VISIBILITY

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Abstract

The Virtual Block Control concept makes use of virtual stop bar positions on a controller display and aims at reducing the size of control blocks that are used under low visibility conditions to achieve sufficient spacing between taxiing aircraft. The concept was evaluated in the past as part of a EUROCONTROL initiative in combination with different safety nets for minimum spacing, block boundary crossings and runway entry on the NARSIM Tower simulation platform of the National Aerospace Laboratory of the Netherlands, NLR (Figure 1). The airport chosen at the time was Rotterdam Airport (EHRD). While this airport proved to be ideal for demonstration and evaluation purposes, the simplicity of its layout did not allow drawing conclusions on achievable performance improvements in more complex environments [1].

Within the Single European Sky ATM Research Programme, Virtual Block Control was chosen as an operational concept for improving weather resilience at airports as part of the conceptual step towards time-based operations. Concept feasibility and expected performance were validated on the NARSIM Tower platform which realistically simulated a working environment for Milan-Malpensa Airport (LIMC). This airport was chosen as its layout was very complex allowing for implementation of a much more mature concept of use as compared to the earlier evaluations.

In its final set-up, the new system incorporated Virtual Block Control, alerting for unauthorized block boundary crossings, a Watch Dog alerting concept for monitoring aircraft that are supposed to hold position and a clearance limit administration for all controller positions in the simulation. Regarding feasibility of the concept, overall scores obtained presented a very positive picture of the operations with the new functionalities.

Controllers easily accepted the new system functionality and were frequently missing these tools as helpful means to maintain situational awareness and safety of operations in the reference situation that reflected currently applied operational procedures. Observations made in an Alenia Regional Aircraft flight simulator with a moving map display including virtual stop bar positions and alerting for block boundary crossings resulted in similar conclusions regarding operational feasibility aspects and operational improvements for the flight crew.

By comparing results for different arrival capacities, statements about efficiency of operations could be made. The new system functionality allowed for working with up to 20% more traffic under low visibility conditions leading to clear efficiency gains. At higher capacity values of about 30% more traffic than in the current situation, the efficiency gains seemed to level out. Still better results were obtained for mental workload, teamwork aspects and situational awareness.

Figure 1. NARSIM Tower Facility at NLR

Introduction

The ATC operational concept of Virtual Block Control (VBC) describes specific airport ground control procedures for operations under low visibility conditions. The concept aims to achieve increased efficiency, situational awareness of all actors and safety of operations by means of enhanced block control which adds virtual stop bar positions to the Human-Machine Interface (HMI) of both ground and runway controllers and, if equipment is present, to the navigation display of pilots. Virtual stop bars do not exist on the airport surface but are merely displayed on a surveillance or navigation display for easy reference. Air traffic controllers guide the aircraft in sequence from one virtual stop bar to the next in analogy of the block control procedure. Alerting functions for minimum spacing, for unauthorized block boundary crossing and for unauthorized runway entry can be combined with VBC for additional safety and to eliminate the need for an additional buffer block, as recommended by ICAO [2].

When the Single European Sky ATM Research (SESAR) Programme started its development phase, it defined a project for improved weather resilience (P06.08.07) as part of the airport work package (WP6). This project was detailed later to look at improved technology and operational processes for use during low visibility conditions, and VBC was suggested as the operational concept for achieving operational benefits.

After careful evaluation of both the taxiway conflict alerting and the VBC concept, the SESAR-Joint Undertaking (SESAR-JU) approved a validation activity (with reference EXE-06.08.07-VP-635) for VBC at Milan Malpensa Airport (LIMC). The layout of the airport was considered appropriate for testing the concept due to several long taxi stretches that run parallel to the runway system and have numerous connection nodes to the apron areas, thus offering possibilities to reduce taxiway segment sizes. Furthermore, Milan Malpensa Airport already had hold lights installed at a large number of clearly defined intermediate holding positions. This allowed the operational concept to be extended to non-data link equipped aircraft, in which pilots would need to be able to detect a visual reference point for a virtual stop bar on the airport surface.

The validation exercise (carried out in late 2012 and early 2013) was performed at a function level, meaning that only a particular functionality aspect of a system was looked at, namely the VBC concept which is enabled by the display of virtual stop bars on a Traffic Situation Display[1] (TSD) at the Controller Working Position (CWP) and, for a single flight, on the navigation display of a flight simulator. The main objective of the exercise was thus to validate the operational feasibility of the novel concept and the associated operational procedures for Milan Malpensa Airport.

Operational Concept

The VBC concept, although generally being usable under all weather conditions, was conceived for use in Visibility Condition 3 (as defined in the ICAO A-SMGCS Manual, [3]) with less than 400m RVR. On most airports, this means that the controller allows only one aircraft or vehicle to be present within one segment of a taxiway (or block) at a time. Taxiway segments or blocks must be clearly defined and identifiable, so that stop bars usually offer the only possibility to implement control blocks.

When applying the VBC concept to control operations, the TSD of ground and runway controllers is enhanced with the so-called virtual stop bars (VSB). These additional stop bars are introduced for controller reference but do not exist on the airport surface. The concept requires both the existing real stop bars and the additional virtual stop bars to be managed from the same display (TSD) so that practically there would be no difference in working with one or the other type of taxiway segment boundary (see Figure 2).

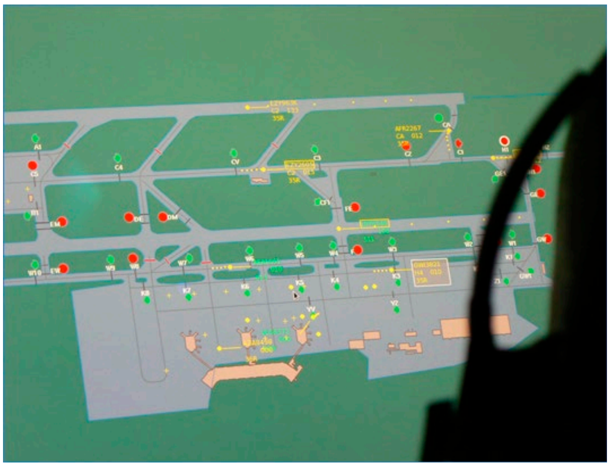

Figure 2. Ground Controller Display with VBC

[1] The TSD was assumed to be showing surveillance information from the available radar sources (SMR and MLAT).

In its most advanced state the concept would include an additional support tool in the cockpit, showing pilots the exact positions of the VSBs on a moving map display, thereby allowing them to taxi without further visual reference for such a position (see also Figure 3). VSB positions and states would be transmitted to the aircraft systems via data link. For the simulations, it was assumed that a fixed number of aircraft would be data link equipped with a navigation display being capable of presenting VSB positions and states. Equipped aircraft were mainly introduced to evaluate the work of controllers and pilots with VSB positions that had no visual references on the airport surface. In order to validate performance aspects of the concept for mostly unequipped aircraft, though, it was necessary to have visual references in place indicating the VSB positions. At Milan Malpensa Airport a large number of Intermediate Holding Positions (IHP) were already available which all had transversal yellow lights as indicators in addition to lighted signs and ground markings.

Figure 3. Navigation Display with VBC

The VSB system was supported by two alerting features on the controller side, namely the stop bar violation alerting, which gives an acoustic and visual alert in case of unauthorized crossing of (virtual) stop bars, and a so-called Watch Dog tool, which places a circular area around an aircraft that can be activated and will generate an alarm once the aircraft starts moving again. In that way, the controller would not miss a violation of an aircraft that had been given the instruction to hold position.

Another feature that was elaborated was the switching of stop bars and VSBs with automatic input of clearance limits into the aircraft labels on the TSD. This feature was expected to facilitate system input and to enhance situational awareness as it combined the two functions of switching a (virtual) stop bar and entering clearance information into the aircraft label.

Implementation Decisions

Human Machine Interface

Most VSBs were located at the existing IHPs on the airfield and were set to green (unlit) by default. They had to be switched manually. In that way, it was possible to clear the first aircraft directly to a position close to the departure runway and then gradually build up traffic flows in the movement area, manually switching (virtual) stop bars to clear aircraft to the desired positions.

Stop bars and VSBs at critical bottlenecks as well as all runway protecting stop bars were red (lit) by default. When switched to green (unlit) they automatically switched back to red (lit) when either the aircraft had passed the location or 30 seconds after they had been switched to green (unlit).

Some of the runway protecting stop bars (no-entry lights) could not be switched (in accordance with current procedures) and stayed red (lit), while others could be switched. The latter had the symbol of a circle attached to their position so they could be switched in the same way as the VSBs.

Generally, the following interface elements were displayed during the simulations:

- Stop bars (physically existing on the airport surface)

    - Stop bars for runway protection (switchable, non-switchable)
    - Stop bars at critical IHPs (lit by default)
- Virtual stop bars (only visible on the controller display and to the cockpit crew of an aircraft equipped with data link and VBC on an aircraft moving map display)
    - VSBs at critical IHPs (lit by default)
    - Manually switchable VSBs (initially green, i.e. unlit)

Figure 4 shows the different types of stop bars and VSBs for a small part of the West apron:

- Runway protection stop bars that are red (lit) by default but are switchable: EM, EW, DE, DM
- Switchable VSBs that are initially green (unlit): B1, W10, W9, W7, K8 and K7
- Always lit VSBs (red): W8
- Runway protection stop bars (no-entry lights) that cannot be switched: red lines near W8/W7

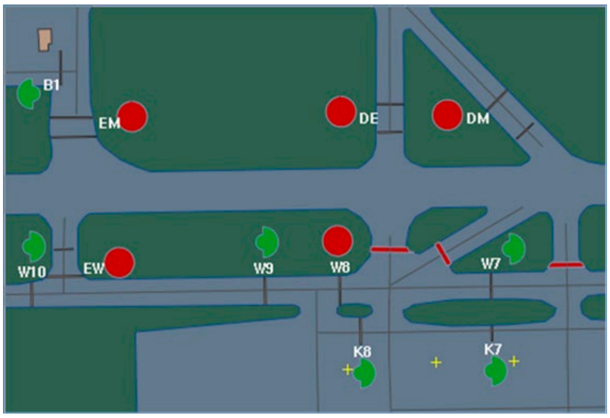

Figure 4. Different Types of Stop Bars

Clearance Automation

All aircraft with a clearance limit available in the system (selected and unselected label) showed that clearance limit in the label. In order to increase situational awareness, the symbol at the actual position of the clearance limit was highlighted (white outline) as soon as a label with clearance limit was selected. When clearing an aircraft to a stop bar or VSB beyond the current clearance limit, that clearance limit disappeared from the label and was replaced by the new clearance limit (cf. Figure 5 with a change from W6 to W5).

All clearance limits could be cancelled with the help of a context menu for the clearance limit field. When activating the context menu, it was possible to remove the clearance limit from the label and at the same time break the correlation between the aircraft and the clearance limit position, meaning that the symbol would not be highlighted anymore when selecting the label.

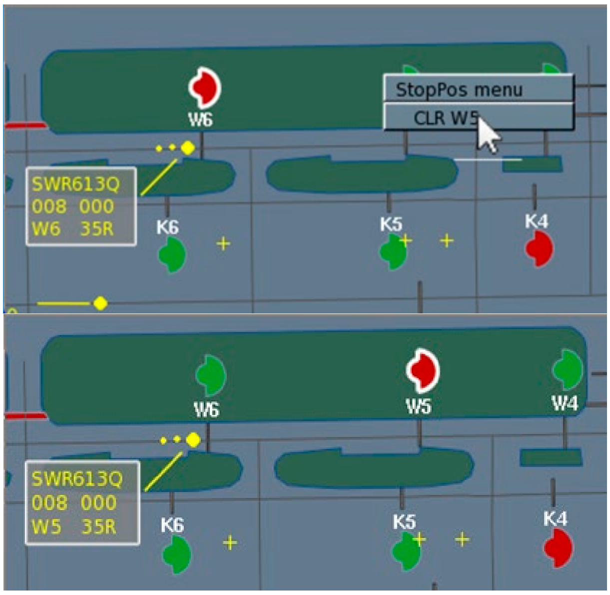

Figure 5. Example for Clearance Automation

Alerting Features

Three different alerting features were provided together with VBC.

The most plausible feature checked for unauthorized crossings of stop bars and VSBs. In such a case, the label background would turn red and semi-transparent, no matter if the label was selected or not (see Figure 6). At the same time a speed vector was shown originating from the position indicator and pointing in the direction of movement, with the length of the speed vector giving an indication of the actual speed. The symbol of the concerned stop bar or VSB would have a thick red outline. The stop bar violation audio signal repeated three times (triple chime) and the visual representation would appear for

30 seconds. The controller had the possibility to acknowledge the fact that a stop bar was violated by left-clicking on the label when it was red. The label change and all other visual representations of the alert would then turn back to normal.

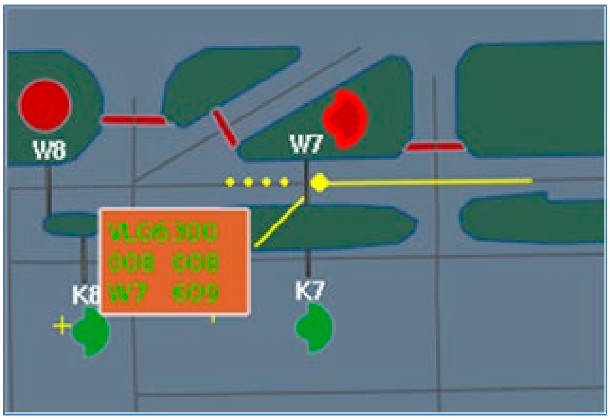

Figure 6. Unauthorized Stop Bar Crossing

The second feature was simply a special variation of the unauthorized crossing alert. It concerned the crossing of runway protection stop bars. In case of a violation, the same visual cues as before were given and a voice alert would indicate the position of the incursion.

Finally, the so-called Watch Dog tool was implemented (cf. Figure 7). The Watch Dog alerted the controller in case an aircraft that was supposed to hold its position started to move unexpectedly. Thus, the tool would perform some of the monitoring activity that is usually done by the controller, e.g. when a stop bar violation occurred.

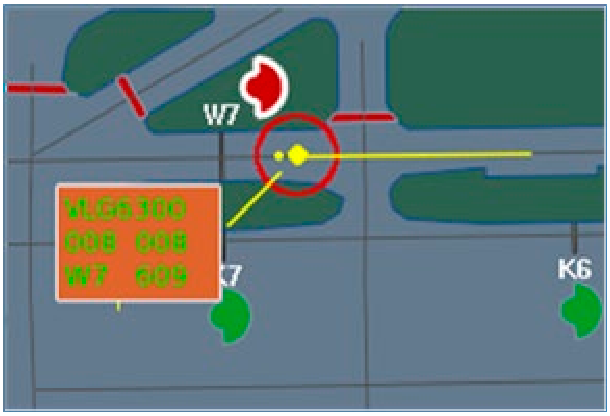

Figure 7. Watch Dog Alert

For activation of the Watch Dog (when the aircraft is not moving), the controller left-clicked the aircraft radar blip symbol. A yellow circle was then shown around the blip. A violation or unauthorized movement was indicated in the same way as a stop bar or VSB violation. Additionally, the color of the circle switched to red.

Exercise Preparation and Set-up

In order to bring forward the concept of Virtual Block Control, human-in-the-loop real-time simulation exercises were defined that allowed for validation of operational feasibility of the concept as well as a first evaluation of the key performance areas (KPA) Capacity, Efficiency, and Safety. The exercises involved four air traffic controllers from ENAV, two runway controllers (one for each runway) and two ground controllers (one for each apron area). Five Dutch pseudo-pilots managed traffic using a dedicated HMI to realistically simulate taxi speeds as a function of RVR.

Since the aim of the project was to improve operations under low visibility conditions, the procedures described in the Italian AIP for low visibility operations (Low Visibility Procedures Chart AD-2-LIMC-2-7 [4]) were taken as a reference. That meant that RWY 35L was used for arrivals only and that RWY 35R was used for departures only. Furthermore, a number of standard taxi routes were defined in the AIP to get from Apron North and West to RWY 35R and vice versa from RWY 35L to the stands and gates at Apron North and West (see also Appendix I).

For the assessment of the mentioned KPAs, two types of scenarios were defined. In the so-called reference scenario, current Milan-Malpensa operations under low visibility conditions were applied, meaning that the TSD could not be used for control (only for reference), VBC and alerting features were not available, and one aircraft was taxiing at a time within a block. Blocks were separated by real stop bars. Flight strips were used to capture clearance information. Due to the given circumstances the chosen traffic situation was expected to lead to a certain amount of departure delay. The reference scenario was run three times with different traffic samples.

So-called solution scenarios with VBC elements in use (virtual stop bars plus alerting features) were run several times to reduce biases and to get a good indication of the achievable performance. In order to obtain relevant data that is comparable with the data of the reference situation, several solution scenarios were run per reference scenario with comparable traffic samples.

Apart from assessing the nominal control work for validation of feasibility and performance, non-nominal situations were defined that allowed making a first assessment of safety-related incidents. They covered the following topics:

- Aircraft crosses lit stop bar swiftly (could include a situation in which the aircraft is fixed by the Watch Dog tool and then violates the controller instruction to hold position)
- Navigation error (deviation from route or clearance)
- Aircraft are too close because of loss of visual reference of preceding aircraft (longitudinal spacing)
- Aborted take-off with aircraft needing to return to the stand
- Loss of communication and subsequent guidance by follow-me car (for arrivals blocking certain runway exits)
- Closure of parts of the taxiway due to blocking aircraft with a malfunction

The non-nominal situations were elicited during the last 15 minutes of a simulation run in order not to disturb the performance measurements during the first hour of the simulations and covered the special topics mentioned above. Non-nominal situations were tested in both the reference and the solution scenarios.

Special flights carried out by a flight simulator from Alenia as part of the validation activities were considered not suitable for obtaining performance-related information. Therefore, operational feasibility on the pilot side was validated in a different scenario. This scenario was shorter and included many nominal and non-nominal situations in order to assess pilot reactions.

The non-nominal situations that could only be tested with the flight simulator connected were:

- Mismatch of virtual stop bar positions between controller and pilot display
- Failure of the CPDLC connection (and subsequent problems of identifying active VSBs and their positions, which are the clearance limit)

In general, the exercises had the following objectives:

1. Validate operational feasibility of VBC during low visibility conditions for the ground controller and for the pilot by obtaining positive results for operational feasibility from a set of standard questionnaires.
2. Evaluate validation scenarios in terms of trends for Capacity and Efficiency by comparing results from solution and reference scenarios and by gathering controller feedback.
3. Evaluate validation scenarios in terms of trends for Safety by obtaining positive results from a set of questionnaires and from interviews addressing specific non-nominal and safety relevant events at the end of each simulation scenario.

In order to assess operational feasibility, it was necessary to gather subjective feedback from operational experts in the form of questionnaires and interviews. To this end, controllers filled in a number of custom-made questionnaires (specifically addressing concept and tool features) and standard questionnaires (e.g. from the Solutions for Human Automation Partnership in European ATM initiative of EUROCONTROL, SHAPE) concerning:

- System Usability Rating
- System Functionality
- Situational Awareness (SHAPE)
- Automation Trust Index (SHAPE)
- Teamwork (SHAPE)
- Impact on Mental Workload (SHAPE)

The pilot filled in the following questionnaires:

- System Usability Rating

- System Functionality
- Automation Trust Index (SHAPE)
- Workload Assessment (NASA-TLX)

For controllers, the scores obtained from the questionnaires led to different mean values for simulation scenarios with (solution scenario) and without the new functionality implemented (reference scenario). The mean values were compared through hypothesis testing. Interviews had to ensure that the questions were interpreted correctly by the controllers but also by the observers and the validation team. On the cockpit side scores were only obtained for the simulation runs with the new functionality and only represented the opinion of one pilot in a cockpit simulator.

Capacity was used as a control variable. It changed throughout the different phases of the simulation run, meaning that inbound capacity was gradually increased. This was achieved operationally by small changes in the applicable RVR condition. Efficiency could then be assessed in each of the phases of a simulation run in terms of R/T usage and taxi-out times for both reference and solution scenarios. By comparing the two types of scenarios, it was possible to determine whether efficiency gains could be expected.

Safety was investigated by assessing subjective controller ratings from questionnaires and by having a detailed look at the operational impact of induced non-nominal situations at the end of both reference and solution scenario simulation runs.

Validation Results and Conclusions

The operational input given by the Milan-Malpensa controllers during the preparation phase proved to be very valuable and led to an unprecedented detailing of the concept in terms of positioning of VSBs, types of stop bars and VSBs and their representation on the display. The alerting concept was refined by detailing requirements for visual and aural presentation of an alert. All this led to a very dedicated and highly refined implementation of VBC.

The whole process also led to recommendations regarding the structuring of the implementation work for a VBC system at airports comparable with Milan-Malpensa.

The results focused on feasibility aspects, but capacity, efficiency and safety trends that could be extracted from the data logged and gathered were also investigated.

In general, questionnaires showed very positive feedback on the concept from the controllers (see also Figure 8). It should be noted that the controllers participating in the exercise were not directly involved in the preparation activities and thus only knew about the concept details through a briefing by the colleagues that were involved and by training on the NARSIM-Tower platform. This means that they did not judge their own conceptual work but rather the work of operational experts that very well knew about their daily work and possible operational constraints. Without going into the details of each question asked, the overall scores obtained presented a very positive picture of the operations with the new functionality (VBC and Watch Dog plus alerting concept and clearance limit administration)[2]:

- System Usability: 4.65 (Solution) versus 4.34 (Reference) on a scale from 1 to 5
- Automation Trust: 5.34 (Solution) versus 4.71 (Reference) on a scale from 0 to 6
- Situational Awareness: 5.04 (Solution) versus 4.32 (Reference) on a scale from 0 to 6
- Mental Workload: 0.86 (Solution) versus 1.97 (Reference) on a scale from 0 to 6
- Teamwork Aspects: 5.54 (Solution) versus 4.53 (Reference) on a scale from 0 to 6

Apart from these aspects, the operational improvements were assessed in a single questionnaire with a mix of safety, HMI and efficiency related questions (cf. the split results following the Overall Improvement bar in Figure 8). The alerting concept was assessed in a dedicated questionnaire as well. Since none of the operational improvements were available in the reference scenario, the values

[2] It should be noted that, for all scores, the probability that the mean values for reference and solution scenarios were the same was clearly less than 5%.

obtained only concerned the solution scenarios. These results were also very encouraging:

- (Overall) Operational Improvement: 4.98 on a scale from 1 to 6
- Alerting Concept: 5.13 on a scale from 1 to 6

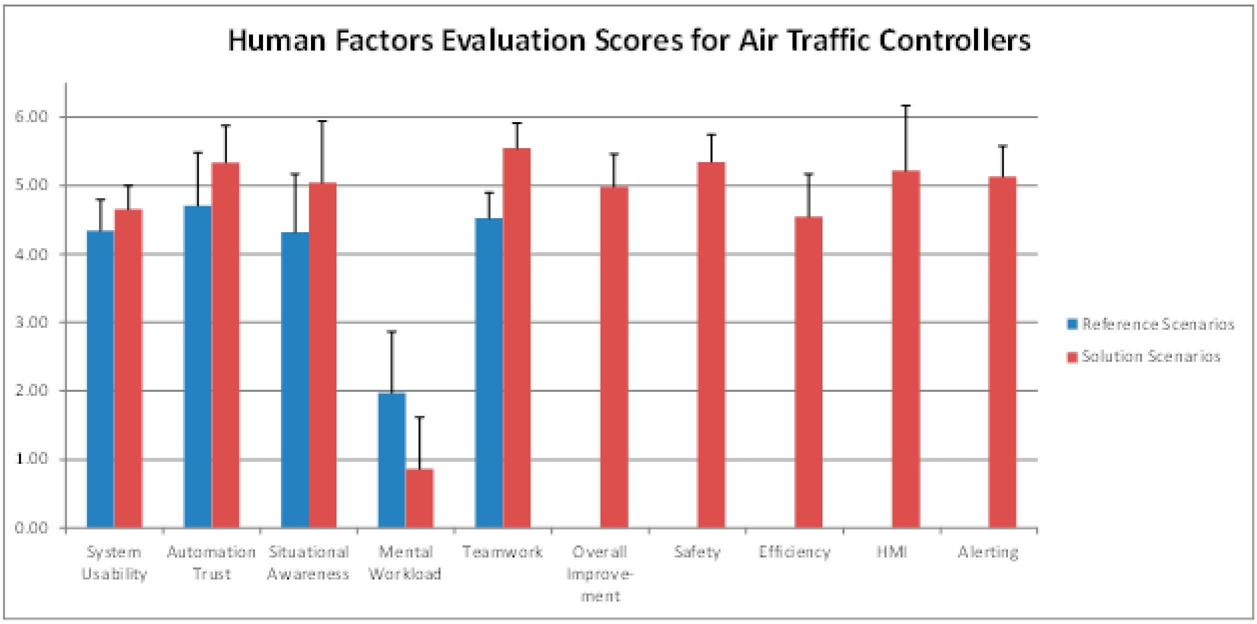

Figure 8. Overview of Human Factors Results

Other safety aspects than mentioned above (contributing factors from the SHAPE questionnaires and safety related operational improvement questions) were assessed by introducing non-nominal situations at the end of each simulation run, and assess these situations by comparing observer remarks made by operational experts with the controllers' own assessment of the situations.

Apart from the result that the safety contribution of the system was rated very high (5.35 on a scale from 1 to 6), this process led to additional conclusions regarding the execution of the controllers' work. Controllers easily accepted the new system functionality and were often missing these tools as helpful means to maintain situational awareness and safety of operations in the reference scenarios. The Watch Dog functionality was highly appreciated and it was used in various situations to maintain a safe traffic flow without focusing too much on a single problem. The clearance limits on the labels supported silent co-ordination between different positions and increased the general situational awareness (this was also supported by the high teamwork scores).

Capacity and efficiency were evaluated in a much different manner. As explained above, capacity values changed throughout the different phases of a simulation run by increasing inbound capacity. Efficiency could then be assessed by analyzing R/T usage and taxi-out times (cf. Figure 9 and Figure 10). During the simulation sessions it was found that the capacity value could in fact be increased beyond which was deemed currently possible, without having a very negative impact on workload or safety perception. The original simulations started with a capacity of about 40 movements per hour, and capacity increased up to 49 movements per hour. An unplanned reference and solution scenario with higher capacities that was added upon request of controllers remained more or less constant at 52 movements per hour.

The most important conclusion would be that the system allowed for working with up to 20% more traffic under low visibility conditions leading to average efficiency gains of more than 13% in R/T communication and about 8% in taxi-out time. At higher capacity values (30% more traffic) the efficiency gains seemed to level out (no gains or losses). Still better results were obtained for mental workload, teamwork aspects and situational awareness. Based on the controller interviews, this was due to the supporting new system functionality.

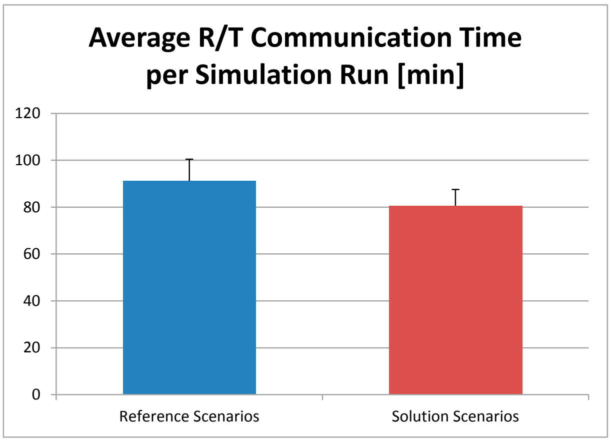

Figure 9. R/T Efficiency Results

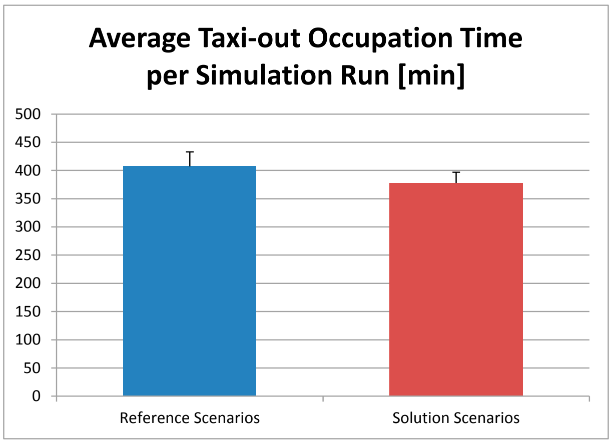

Figure 10. Taxi-out Efficiency Results

From the aircraft point of view the results focused on feasibility aspects related to the cockpit integration of a VSB application into the Airport Moving Map (AMM). Due to the availability of just one pilot assessor, the collected results were mainly qualitative and did not allow statistical considerations. However, the pilot feedback on the use of the application compared with current low visibility procedures was very positive. The VSB application on the AMM was found to be very useful and easy to manage, significantly improving pilot situational awareness in low visibility conditions. Pilot workload was rated low (34 on a scale from 0 to 100). The pilot judged that, when properly using the assessed VSB application, the aircraft should be able to taxi safely and with a performance much closer to good visibility conditions than with the currently applied low visibility procedures.

Recommendations

The exercise preparation process had the largest impact on the final operational concept and the eventual system implementation. This led to a number of important recommendations that were considered when carrying out the simulations:

- Operational experts with a detailed knowledge of the airport low visibility operations and operational constraints must be involved in the detailed concept development and prototype implementation process from the beginning.
- VSB positions will depend on the availability of visual reference points on the airport surface for aircraft without data link and an AMM.
- Larger blocks without intermediate holding positions should be reduced by placing VSBs without visual reference at strategically important locations (e.g. before taxiway crossings).
- Different types of stop bars and VSB should be implemented depending on the layout of the airport and the operational rules.
- The alerting concept should integrate seamlessly with existing alerting tools, such as Runway Incursion Alerting, Taxiway Conflict Alerting, Restricted Area Intrusion Alerting and Clearance Deviation Alerting.
- Controller input should be reduced to a minimum, which in this project led to the development of a clearance limit administration for the aircraft label that is directly linked with the chosen stop bar

or VSB position and will also trigger the selected VSB to be automatically lit.

- Building on the previous recommendation: the correlation between the selected aircraft label and the respective clearance limit should be visible on the controller display.
- When establishing traffic flows it is important to consider that aircraft following another aircraft should generally never be cleared to a stop bar or VSB position that lies beyond the current position of a preceding aircraft (exceptions are particular occasions in which a pilot reports having the preceding traffic in sight or a controller constantly monitors the taxiing progress of the pair).

All other recommendations were a direct result of the exercise and therefore focus at possible future development and integration with other SESAR systems or activities:

- Training VBC operations is paramount to a successful use of the concept.
- Controllers considered the new system functionality as highly usable and intuitive improving situational awareness, teamwork aspects, and automation trust. Mental workload impact was considered very low. This means that the new system functionality should be seen as a very efficient safety net in the first place, that allows controllers to focus on a more structured way of controlling the traffic flow on an airport in low visibility.
- Efficiency or capacity gains are not only due to reduced block sizes but are also a secondary effect of the more structured and system-supported approach to controlling the aircraft.
- Hand-over positions or responsibility areas must be clearly defined to avoid controllers switching the same stop bar or VSBs.
- R/T instructions might be slightly different in contents but general phraseology does not change.
- The Watch Dog should be used whenever a situation occurs in which an aircraft needs to be monitored, but the controller also needs to focus on other traffic at the same time.
- Clearing an aircraft to a position beyond the current position of a preceding aircraft will cause an alert in the current system when the preceding aircraft crosses the point associated with the clearance limit of the trailing aircraft. This essentially means that the two aircraft are moving in one large block. How to resolve this issue needs further investigation as it will lead to a more complex system logic.
- Future activities should also look at the use of VBC under even more realistic conditions, e.g. in shadow-mode trials.

Following the coupled simulations (NARSIM Tower and Alenia Regional Aircraft Flight Simulator), the following recommendations were issued by the pilot:

- Since the pilot trust in automation is considered to be essential for a successful use of the application, reliable monitoring must be provided in order to alert the flight crew in case of data transmission failure or the reception of incorrect data.
- The possibility to improve the application by means of a taxi guidance tool integrated with the data link transmission of the taxi instructions (in this way reducing R/T, which will be maintained as back-up solution) should be considered.
- Dedicated procedures will have to be shared between aircraft and ATC in order to manage data transmission failures. Basically, procedures should require to complete the last cleared movement and then wait for further ATC instructions, or to immediately stop any movement.

Outlook

Conclusions and recommendations from the Virtual Block Control simulations of Milan-Malpensa Airport on the NLR NARSIM Tower validation platform pointed at two different ways in which the development of VBC could be continued.

On the one hand, the system could be brought to a higher maturity level (Validation Phases V2+ or V3, as described in the E-OCVM, [5]) for Milan-Malpensa airport by further discussing efficiency aspects (mainly related to operations on the North apron, as analysis of the results revealed) and building a final prototype for validation of the benefits in terms of capacity and efficiency, and perhaps with less focus on the already successfully assessed advantages for safety. In that case, a recommendation would be to take sufficient time for training controllers on the use of the system, especially ground controllers and the controller for RWY 35R (with the task to merge traffic flows). Furthermore, there should be at least two different controller teams with changing roles for Apron North and West in order to further reduce biases and increase both quality and significance of the validation results.

On the other hand, shadow-mode operations could be considered at Milan-Malpensa airport. Such an activity could be seen as a V3+ or V4 activity (as described in the E-OCVM, [5]) where an industrial prototype is used in either passive or active shadow-mode. In that case, the AMM and data link connection should be working on at least one test aircraft in order to make a meaningful assessment of VSB positions without visual reference on the airport surface.

Generally, it is observed that a current lack of harmonization of airport low visibility procedures may lead to highly customized operational solutions and support systems for low visibility conditions. While this paper presented a low-cost solution based on virtual stop bars enhancing, in particular, the air-traffic controller side of operations, there are also solutions using the airfield ground lighting system for guidance purposes (the so-called follow-the-greens concept). In the end, implementation of such systems may differ depending on local conditions, such as the availability of required ground lighting, local regulations for spacing of aircraft on the ground, and the interpretation of ICAO manuals and guidelines. The latter issue certainly requires a harmonization effort in the future.

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Appendix I

Low Visibility Procedures Chart for Milan-Malpensa Airport (LIMC)

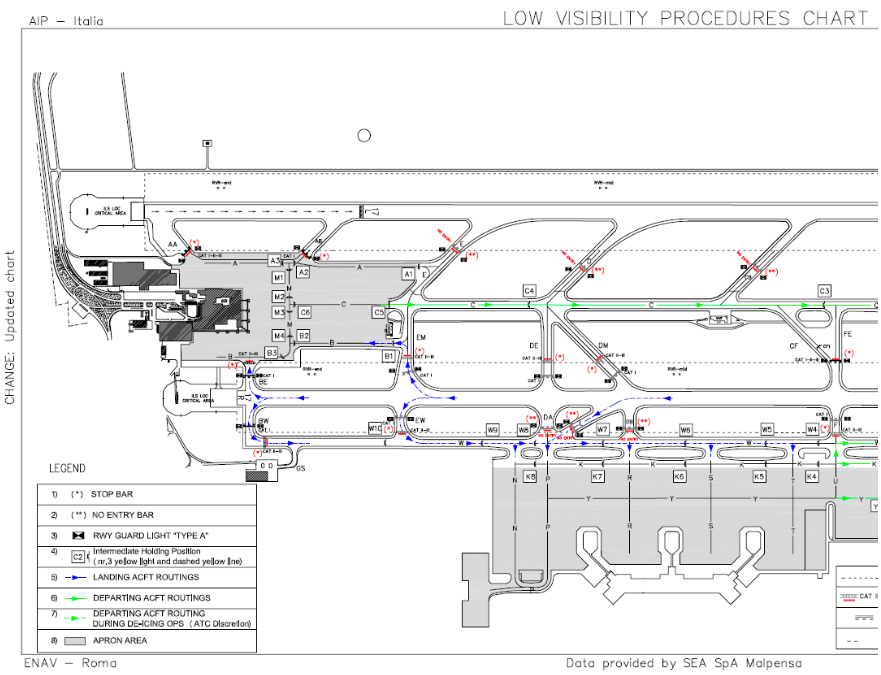

Figure 11. AIP Detail with Apron North on the Left (Source: AIP Italy)

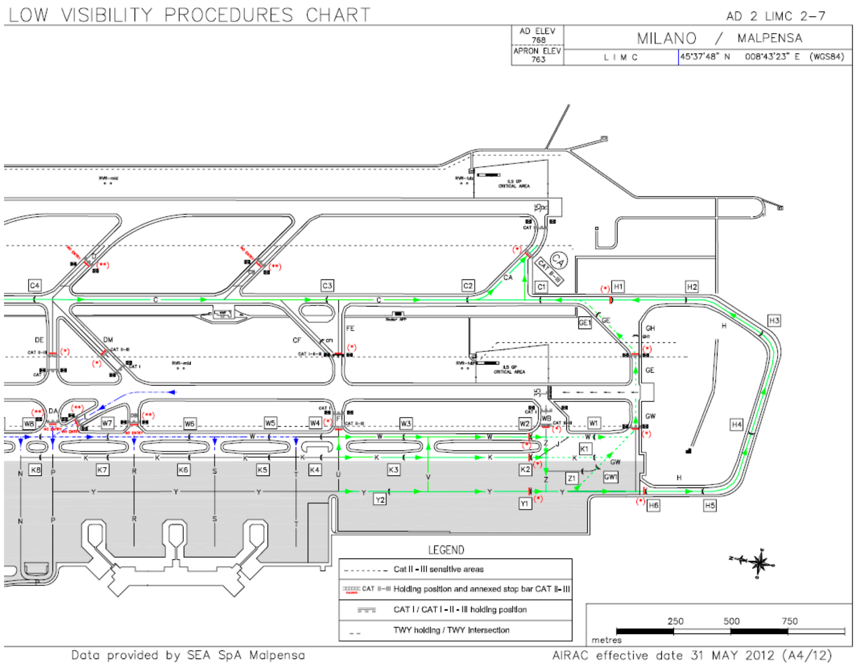

Figure 12. AIP Detail with Apron West at the Bottom (Source: AIP Italy)

Abbreviation List

AIP	Aeronautical Information Publication
AMM	Airport/Aircraft Moving Map
ATC	Air Traffic Control
ATM	Air Traffic Management
CPDLC	Controller-Pilot Data Link Communications
CWP	Controller Working Position
ENAV	The Italian Company for Air Navigation Services
E-OCVM	European Operational Concept Validation Methodology
HMI	Human-Machine Interface
ICAO	International Civil Aviation Organization
IHP	Intermediate Holding Position
KPA	Key Performance Area
LIMC	Milan Malpensa Airport (ICAO code)
LVNL	Luchtverkeersleiding Nederland
MLAT	Multilateration
NARSIM	NLR ATC Research Simulator
NASA-TLX	NASA Task Load Index
NLR	Nationaal Lucht- en Ruimtevaartlaboratorium
R/T	Radio Telephony
RVR	Runway Visual Range
RWY	Runway
SESAR	Single European Sky ATM Research
SESAR-JU	SESAR Joint Undertaking
SHAPE	Solutions for Human Automation Partnership in European ATM
SMR	Surface Movement Radar
TSD	Traffic Situation Display
VBC	Virtual Block Control
VSB	Virtual Stop Bar

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