VIRTUAL BLOCK CONTROL & SEPARATION BUBBLES INCREASING TAXIWAY THROUGHPUT IN LOW VISIBILITY CONDITIONS

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Abstract

A study on the concepts of Virtual Blocks with Separation Bubbles as safety net showed a significant increase in taxiway throughput in low visibility conditions when compared to current procedures. Virtual Blocks and their bars are operated as real taxiway stop bars but do not require expensive infrastructure. Separation Bubbles surround aircraft as protected zones to warn controllers for loss of separation. Controllers found the combination of Virtual Blocks and Separation Bubbles an appropriate tool for operations in low visibility. Pilots could easily hold in front of Virtual Bars and never violated a Virtual Bar. They preferred to have Virtual Bars visualized by intermediate holding lights, as these were best detectable for them in low visibility. Virtual Blocks supported by intermediate holding lights and used in combination with Separation Bubbles are thus considered feasible simple and low-cost additions to present day tower operations with automated Surveillance and Identification.

1 Introduction

Under contract of EUROCONTROL, AT-One carried out research activities between 2007 and 2009 on the selection and evaluation of candidate concepts for advanced Air Traffic Control tower operations under Low Visibility Conditions [1]. In the study it was assumed that the tower was equipped with the surveillance and identification functions of an Advanced Surface Movement Guidance and Control System (A-SMGCS) [2][3]. AT-One is the alliance for research in Air Traffic Management of the National Aerospace Laboratory (NLR) of the Netherlands and the German Aerospace Center (DLR).

This paper gives an overview over the activities and presents the results and derived recommendations from the feasibility study of five concepts to improve capacity with A-SMGCS procedures in Visibility Condition Three (VC3)[1] and a follow on study on the two most promising concepts [4]: Virtual Blocks and Separation Bubbles. It briefly presents the concepts developed in the first study and the results from the workshops. It describes in more detail the concepts of Virtual Block Control and Separation Bubbles in their prototyping state. Furthermore, the paper gives a short introduction to the setup of the tower and cockpit simulations to test controller and pilot acceptance. The main results of these are presented. Finally, the paper presents in detail the recommendations derived from the results and from interviews with controllers and pilots.

2 Background and concepts

2.1 Visibility conditions

In Visibility Condition 1 pilots are able to taxi and to avoid collision with other traffic on taxiways and at intersections by visual reference, and personnel of control units are able to exercise control over all traffic on the basis of visual surveillance.

Visibility Condition 2 allows pilots to taxi and to avoid collision with other traffic on taxiways and at intersections by visual reference, but visibility is insufficient for personnel of control units to exercise control over all traffic on the basis of visual surveillance.

Visibility Condition 3 (VC3) is sufficient for the pilot to taxi but insufficient for the pilot to avoid collision with other traffic on taxiways and at intersections by visual reference, and insufficient for personnel of control units to exercise control over all traffic on the basis of visual surveillance. For taxiing, this is normally taken as visibilities equivalent to a Runway Visibility Range (RVR) of less than 400 m but more than 75 m.

Visibility Condition 4 (VC4) is insufficient for the pilot to taxi by visual guidance only. This is normally taken as a RVR of 75 m or less. Criteria for determining the transition between visibility conditions are a function of local aerodrome and traffic characteristics.

2.2 Feasibility study

A first feasibility study on airport operations in VC3 was carried out in 2007 [1], aiming to increase airport throughput and efficiency making smart and low cost use of A-SMGCS level I without endangering safety. Five candidate concepts were developed and presented in dedicated workshops with Air Navigation Service Providers (ANSP) from two medium to large airports as well as pilots. The concepts were:

- Multiple Line-up (ML): ANSPs considered the possibility of using ML for take-off during low visibility conditions based on the procedure to check all aircraft positions using A-SMGCS level I (surveillance and identification). ML could perhaps provide more capacity in mixed mode and VC 3.

- Virtual Block Control (VB): The HMI of the Tower Controller could be enhanced with Virtual Stop Bars (not really existing on the surface). Aircraft can be controlled in sequence from Virtual Bar to Virtual Bar on the controller screen similar to the Block Control procedure. This would require hold commands to the pilots to stop at the right places.

- Convoy Operations (CO): Aircraft taxiing to the same destination are brought in visual contact with preceding aircraft by the controller, so close that pilots see the preceding aircraft while in VC3. The controller instructs the leading pilot, while other aircraft are instructed to follow. Speed should be low to avoid collisions.

- Parallel Push Backs: Aircraft parked close to each other could perform coordinated push back movements. Responsibility for separation is delegated to the push back operators on the apron.

- Separation Bubbles: The positions of aircraft and vehicles as surveyed and identified by A-SMGCS can be predicted taking into account their speed and the local airport geometry (bubbles). When the bubble touch an alert is generated for the controller to avoid collisions.

Two of the candidate concepts emerged from this first study as the most promising solutions – the concept of Virtual Block Control (VB) and the concept of Separation Bubbles (SB). The other three concepts were judged too dangerous or too limited in their application. The VB and SB concepts were further evaluated and validated in a follow-up study [8] in real-time tower and cockpit simulations with active ground controllers and airline pilots involved.

2.3 Virtual Block and Separation Bubble Concepts

When in low visibility pilots are not able to see and avoid other traffic on the movement area (VC3), responsibility to provide safe separation is shifted to the Ground Controller and taxiway throughput and capacity decrease considerably. When applying Virtual Block Control, Virtual Stop Bars are presented on the traffic situation display in the tower for controller reference but do not exist on the airport surface [Fig.1].

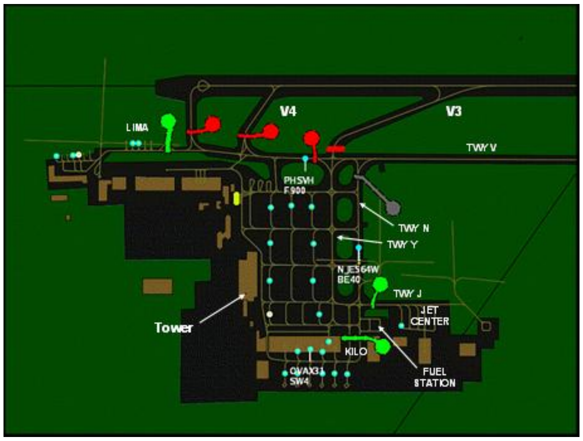


Fig. 1. Tower Controller radar screen with Virtual Bars (Green for pass, red for hold and grey for deactivated)

Thus, the concept aims to reduce block sizes by providing additional Virtual Bars thereby increasing the number of blocks and thus improving taxiing throughput. It avoids the expensive installation of real stop bars and cockpit moving map situation displays. As pilots cannot observe Virtual Bars on the taxiways, solutions were sought, found and tested to preserve their situation awareness. Virtual Bars can be placed at places that pilots can easily recognise, like crossings and intersections. Alternatively Virtual Bar locations can be marked by intermediate holding lights, painted lines or by a sign aside of the taxiway, all according to ICAO specifications [6]. Virtual Blocks were proposed in the context of the EMMA project [2] but not further elaborated. The pilot perspective of taxiing in the transition area between Visibility Condition 2 to 3 was investigated in [5]. This study with real time cockpit simulations did not investigate the boundary between Visibility Conditions 3 and 4.

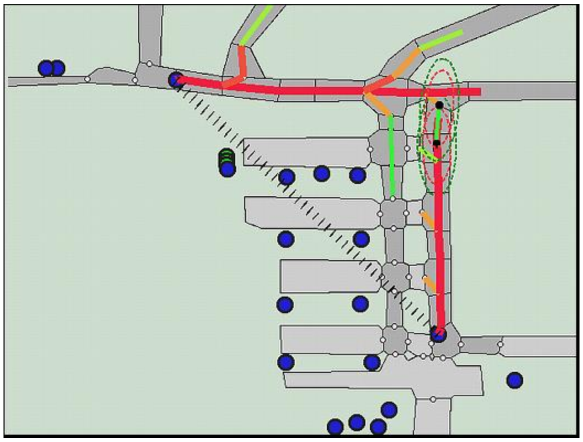


Fig. 2.a. Visualisation of the Separation Bubble algorithm with trajectory prediction of all theoretically possible routes. Blue dots are aircraft. Right:

Fig. 2.b. Separation Bubble alert corresponding to the situation depicted in Fig. 2.a. The table specifies which aircraft cause the alarm.

The basic idea of Separation Bubbles as safety net is to create an artificial bubble around all taxiing aircraft and vehicles the size of which primarily depends on speed and taxiway layout [Fig.2.a]. These bubbles can function as a buffer zone to prevent collisions with other aircraft and vehicles on taxiways by giving a preventive alert to the ground controller in case two or more bubbles touch. Both concepts are depicted in Fig. 2.b. The Separation Bubbles are normally not visible for the controller. Only when separation distance is expected to be violated, an alarm pops up on the traffic situation display [Fig.2.b]. A lot of off-line tuning was spent to obtain realistic alerting (not too much false alerts, but never miss one). The apron area (Fig. 1), however, was still a difficult area with too many false alerts.

3 Tower control operational study

The operational tower control trials with VB and SB were carried out in the NLR ATC Research Simulator for Tower Operations (NARSIM-Tower) in Amsterdam in December 2008. The main purpose of the study was to gather controller usability and operational improvement information. Rotterdam Airport was chosen for the real time simulations because of its simple lay-out with one runway, one long taxiway and compact apron structure being representative for many other airports. Two controllers from Rotterdam and two from another European airport took part in the simulations in two separated teams. The Rotterdam controllers performed a pre-evaluation of the tools and they trained the controllers from the other airport. Controllers indicated where extra Virtual Bars should be created including one Virtual Bar called Spot 1 along the long taxiway. This Spot 1 got an extra sign aside of the taxiway in the visual.

Two baseline scenarios were agreed with the controllers for reference purposes. One baseline was identical to the existing low visibility procedure at Rotterdam airport (Procedure Control, no Surface Movement Radar (SMR) and only one aircraft moving at a time). As controllers judged this too conservative a second baseline was created with SMR supported control and as much aircraft as controllers would allow in VC3.

Thereafter they applied Virtual Block Control and Separation Bubbles as safety net to aircraft in several advanced scenarios during about 6 hours of testing in total per controller team. Each scenario contained about 30 aircraft movements per hour. The scenarios were repeated randomly to obtain a good indication of controller acceptance and achievable capacity and efficiency. Fig. 3 gives an impression of the tower controller working position during the trials. The tools were evaluated separately and in combination.

The simulated aircraft were controlled by pseudo pilots following predefined scenarios, communicating with the controllers and having their own observation screen to conduct safe taxi operations.

Fig. 3 Tower Controller Working Position in NARSIM during Tower Trials.

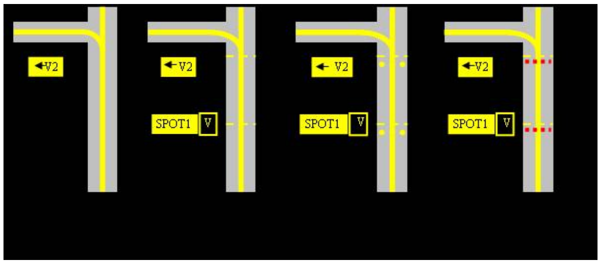
4 Cockpit operational study

The cockpit trials were carried out in the Generic Cockpit Simulator (GECO) of DLR in Braunschweig in May 2009. GECO is a fixed based flight simulator with a 180° collimated visual system. Four pilots from major German airlines taxied in two groups of two on the simulated Rotterdam airport while Virtual Blocks and Separation Bubbles were operated by a pseudo-controller. The trials simulated taxi operations in VC3 up to the boundary of VC4, as a continuation of the Eurocontrol-Airbus study in VC3 [8]. Fig. 4 is a picture taken in the cockpit with taxiway centre lights and -in this test case- Intermediate Holding Lights just visible in VC3.

Fig. 4. GECO Approaching Intermediate Holding Lights.

Pilots were first asked to indicate to which visibility they could taxi safely, separating their aircraft from other and being able to hold in time in front of their cleared-to position. The pilots judged a visibility distance of 30 meters RVR to be the lowest limit possible. The cockpit study was performed for two pilots at an RVR of 30 meters. As this is well below the VC4 threshold, the other two pilots taxied at this threshold being a RVR of 75 meters.

Different kinds of visualisation for Virtual Bars were investigated [Fig.5 left to right]: no extra lines or signs, extra lines, extra intermediate holding lights and lines, and a situation with red stop bars for reference purpose.



No markings Extra lines Lines and lights Stop bars

Fig. 5. Various types of supporting markings and lights for intermediate holding.

GECO was connected to a local copy of the NARSIM tower simulator, providing the same air traffic control simulation facility including the VB and SB tools and real stop bar control if part of the scenario. Separation bubble conflicts were created by intentional errors of the pseudo controller. Pilots changed roles in the GECO during the test runs. The focus was on the GECO pilot position awareness, their capability to hold in time in front of the cleared-to position, their preferences for extra signs for VB and their judgment of VB and SB during taxi operations.

The study applied briefings, questionnaires and debriefings to gather pilots and controllers responses. They provided input to Eurocontrol SHAPE [[7] (Solutions for Human-Automation Partnerships in European ATM) questionnaires on automation impact, on mental workload, situational awareness and automation trust. The tower controllers participated to four training and familiarisation runs and eight runs of about one hour with the VB and SB tools intermixed with three baseline runs. The cockpit crews spent one hour for familiarisation and about one hour to find the lowest visibility threshold for taxi operations. They performed 14 taxi runs of about half an hour.

5 Results and discussion

5.1 Tower Control aspects

System usability for VB and SB scores were generally high [Fig. 6] on a scale of 0 (no use) to 6 (very useful). The situational awareness was high and the experienced mental work load low. VB scored higher in automation trust than SB. In spite of the low statistics, these evaluation results indicate that the VB and SB tools can be used in low visibility tower control.

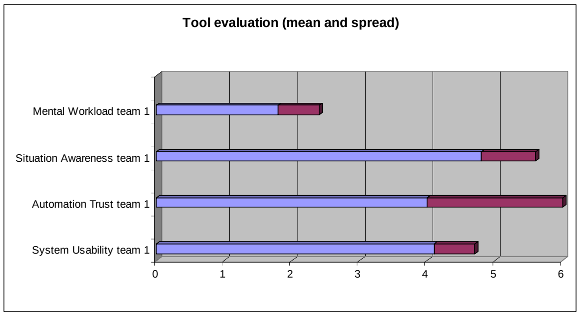


Fig.6. Controller evaluation results of the prototype Virtual Blocks and Separation Bubbles.

Controllers felt extra supported by SB when operating the VB. The SB tool monitored the traffic, giving controllers more time for other tasks. The VB were operated by the controllers as real stop bars giving more possibilities for Block Control, thus more holding positions and throughput. The SB acted as a safety net. The controllers expressed that a real clearance limit (cleared-to position) is mandatory in the Procedural Control. This means that virtual bar positions shall be correlated to real existing land marks on the field, such as intersections and intermediate holding points. This reduces the flexible location of VB but is required for safety reasons in case of communication failure. The results of the evaluation test were used to optimise the tools and conditions for the tool validation.

The combination of SB and VB was tested in validation runs to get a good observation of achievable capacity and efficiency in VC3. The situation without tools, with controllers following ICAO regulations with only one aircraft taxiing at a time and no SMR, was compared with controllers following own intuition and using the tools and the SMR. The evaluation results (Fig. 6) were even improved during the validation which is attributed to a general learning effect. The operational improvement due to the tools was logged not to impair safety (5.2), to enable more traffic (4.9), not to increase the average stop time (3.9), to increase throughput (4.2) and to reduce human error (5.1). The judgement scaling comes from a scale of 0 (no agreement) to 6 (complete agreement). The lower value for average stopping time indicates that controllers expect a negative effect on efficiency when using more stop bars. The SB alerting performance was judged to identify conflicts in time (4.3), to present conflict information unambiguous (4.8), to provide sufficiently low false alarms (4.2) and to provide useful alerts on taxiways (4.9). Controllers did not prefer alerting during better visibility and did not prefer two stages, i.e. warnings followed by an alert. There was clear preference for as few alerts as possible and only in low visibility operations. The number of radio – telephony calls did not differ between operations.

The average throughput in VC3 was 11 aircraft per hour without SMR and tools, and 29 with the SMR, VB and SB. This is a clear demonstration of capacity gain using labelled SMR and the tools. It could not be concluded from the study what the contribution was of the tools to this capacity gain.

5.2 Flight Crew aspects

As stated earlier the VB positions were chosen at intersections, crossings and at a place named SPOT1 indicated by a sign along the taxiway. Average taxi speed was 11.5 kts independent of the additional visualisation of VB. Lowest speed was 8.8 kts and highest 14.2 kts. Stopping distances varied from 47.6 meter in front of the VB position to 0.5 meter passed, which was not counted as a violation but within the safety margin. Pilots never crossed an active VB. Pilots never got lost on the movement area.

Pilots answered dedicated questionnaires on a scale ranging from 1 representing complete rejection to 10 full acceptance.

The acceptance of VB and SB was tested for four conditions: without any position indication, with intermediate holding lines, with intermediate holding lights and with stop bars [Fig. 7 Left part]. Position awareness where to stop is reflected in the right part of the same.

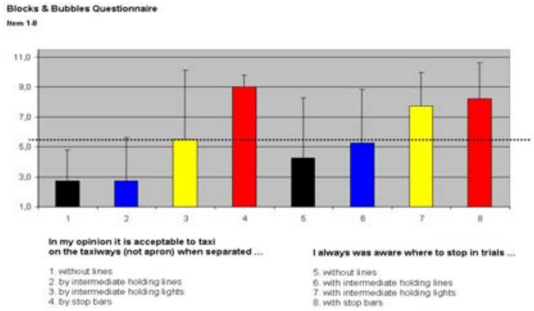


Fig. 7. Pilot acceptance (Left) and position awareness (Right) for four VB visualisations

Pilots were on average less willing to accept taxi operations with SB as safety net. There were also large differences in the crew responses reflected by the high standard deviations. This can be attributed to different pilot awareness of the reasons to hold.

A VB without any additional land mark was not acceptable for the pilots. The first crew adhered to real stop bars for safety reason. They argued that a real stop bar is the only means to cross check with the radio clearance. The second crew shared this opinion, but accepted intermediate holding lights also. If combined with intermediate holding lights both VB and SB were judged feasible by the pilots. One pilot was used to stop when instructed, no matter where, as he occasionally experiences such instructions already today. For him the introduction of VB and SB would not make any difference.

The reported situation awareness (SA), when holding in front of a VB, was at medium level (4) on the Situation Awareness Rating Technique index, ranging from -5 to +13. SA was judged high enough in case of bubble alerts.

The pilot workload was measured via NASA-TLX ratings [8]. None of the experimental conditions was perceived to cause high pilot work load. As expected, mental wok load for situations with painted lines or without any position mark was higher.

6 Conclusions

The tower simulations revealed that in Visibility Condition 3 a combination of labelled Surface Movement Radar with Virtual Block Control and Separation Bubbles as safety net leads to a significant increase in throughput when compared to current procedures without automation support. Reported capacity increases from 10 to 29 aircraft movements per hour for the single runway airport as simulated in the study. The extra holding positions created by the Virtual Bars allowed for more traffic moving in the manoeuvring area

While Virtual Stop Bars could be created everywhere, both controllers and pilots preferred easily recognisable places like taxiway crossing, intersections and apron exits. If there are too much VBs, it will cause administrative delay.

Controllers found the combination of Virtual Blocks and Separation Bubbles an appropriate tool for operations in low visibility. The tools gave them a feeling of safety and reduced their perceived workload. This effect is attributed to a task shift as Separation Bubbles take over partially the monitoring tasks of the controller.

Overall the VB offered the controllers a more structured and safe working method in low visibility. SB should be used as extra safety net allowing Procedural Control with VB and more throughput. The SB alerts cause a slightly higher controller workload, but this is compensated by the take over of monitoring tasks.

The implementation of SB needs dedicated tuning for the local conditions in order to reduce the nuisance alarms. Aprons and the expected surveillance position noise are probably difficult spots for SB application.

The controllers recommended further development in combination with electronic flight strip (EFS) operations. EFS could carry input fields for controller clearances. Or use could be made of clearance inputs in the label.

This would allow an automated cross check of traffic situation and clearances.

Pilots taxied during low visibility conditions down to 30 meters RVR. They could easily hold in front of Virtual Bars and never violated a Virtual Bar. As the commonly accepted boundary between VC3 and VC4 is 75 meters, this visibility was taken in the second part of the cockpit trials.

Two out of four pilots said to stuck to real, remotely controlled stop bars. They argued that real bars are the only means to separate aircraft safely in VC3. The two other pilots did not support that opinion.

Pilots preferred to have Virtual Bars visualised by Intermediate Holding Lights, as these were best detectable for them in low visibility. Virtual Blocks supported by intermediate holding lights and used in combination with Separation Bubbles are thus considered feasible, simple and low-cost additions to A-SMGCS Surveillance, that are expected to increase airport throughput in a safe way.

The study revealed interesting discussions among controllers on safety and tower control in Visibility Condition 3. With automation support from labelled Surface Movement Radar and the additional Virtual Bars and Separation Bubbles this study concludes that there is a possibility to allow for more traffic in VC3 than present rules and ICAO recommendations permit.

An in depth safety assessment is recommended before in field prototyping can commence. Especially the aspect of communication failures and the clearance limit when applying Virtual Block and Procedural Control in low visibility should get proper attention

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