Studying the Impacts of the reduction of Minimum Radar Separation on Approach and Tower ATCOs using EUROCONTROL Real Time Simulators

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One of the main reason of the long waiting on holding of aircrafts approaching big airport is the lack of capcity due to the runway utilization constraints for separation. To increase the runway throughput different solutions are studied under the SESAR2020 EnhAnced Runway THrouput (EARTH) project [1] such as pair wise separation (PWS), wether dependent separation (WDS), Increase Glide Slope (IGS) to Second Runway Aiming Point, prediction of runway occupancy time (ROT) and Reduction of the Minimum Radar Separation (MRS) based on the required Surveillance Performance (RSP).

To validate the different concepts and the impacts of the different solutions on Air Traffic Controllers (ATCOs), EUROCONTROL airport team developed a real time simulator tool called LORD (Leading Optimised Runway Delivery tool) integrated to its real time simulators for Approach and Airport.

In this paper we present the solution consisting on reducing the current minimum radar separation , we detail the results of the real time simulation conducted on the approach and Tower environment of Vienna (Austria) with the participations of their Air Trffic Controllers, we discuss the impacts of the reduction on the Air Traffic Controller Workload and Situation Awareness and we provide the limitation and constraints to apply a reduction of the MRS.

Keywords: EARTH, PWS, MRS, ROT, Air Traffic Controller Workload and Situation Awareness.

I. Introduction

The EUROPEAN Aviation in 2040 Report [2] states that "in the fastest growing scenario, 3.7 million flights will be lost due to airport capciy shortfall in 2040. The main reason for that is the congested big airport across ECAC.

The capcity of an airport is linked to two main factors : number of Gates/parking and runway throuput. If the first factor is related to the airport infrastructure, the second factor is related mainly to three constraints: Wake Vortex Separation, Runway Occupancy time and Minimum Radar Separation.

The SESAR2020 EnhAnced Runway Throughput project cover the three subjects and in this paper we focus on the Real Time Simulation (RTS) conducted on Vienna airport environment to study the using of the LORD to support the reduction of the minimum radar separation (MRS) to 2NM. Vienna Controllers are already using a reduced MRS to 2.5 NM in specific conditions. The results are compared to two scenarios : 2.5 NM MRS without LORD Tool and 2 NM MRS without the using of the tool. The same controllers are involved in the evaluation of the three scenarios, different measurements are conducted to collect the impact of each scenario on the situational awareness of the controllers and workload, in addition to different KPI such as the number of Go around per scenario.

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II. Background

The ICAO standard Document 4444 [3] sets the operational requirements for the reduced runway separation minima which may be applied at an aerodrome. Each minimum is determined for each separate runway. The separation to be applied shall in no case be less than specified minima for a landing aircraft detailed also in the document, the Technical feasibility and impacts of Reducing Standard Separation Minima in final approach [4] provide the details of minima and the required surveillance performance developed in the context of the SESAR2020 EARTH project. From a theoretical perespective it is possible to reduce the MRS to 2NM based on the defined RSP but from a practical one, this is has a different impacts on safety and human performance. In This paper, we describe the experiements that took place in EUROCONTROL Bretigny Sur Orge in June and October 2018, first to evaluate the impacts of the reductions of MRS without using a tool, in a second step we use the tool supporting the reduction of the MRS in a s imilar environment as today in Vienna airport and finally we study the impacts of the reduction to 2NM using the LORD tool [].

III. Leading Optimised Runway Delivery tool

The LORD tool is an Air Traffic Control support tool to enable consistent and efficient delivery of the required separation or spacing between arrival pairs on final approach to the runway landing threshold. It consists of Target Distance Indicators which provide an indication of the required spacing/separation minima per aircraft pair (Final Target Distance (FTD) indicator) on the final approach down to the runway threshold together with an indication of the compression due to aircraft decelerating for landing (the Initial Target Distance (ITD) indicator).

The Target Distance Indicators takes into consideration operational constraints such as the Wake Turbulence Separation (WT), Minimum Radar Separation (MRS) and Runway Occupancy Time (ROT) for each aircraft pair. The Final Target Indicator presents the most constraining spacing / separation to the controllers on the final approach with the associated compression.

Figure 1 below shows the system layout for the platform and the LORD tool integration which is used in the real time simulation.

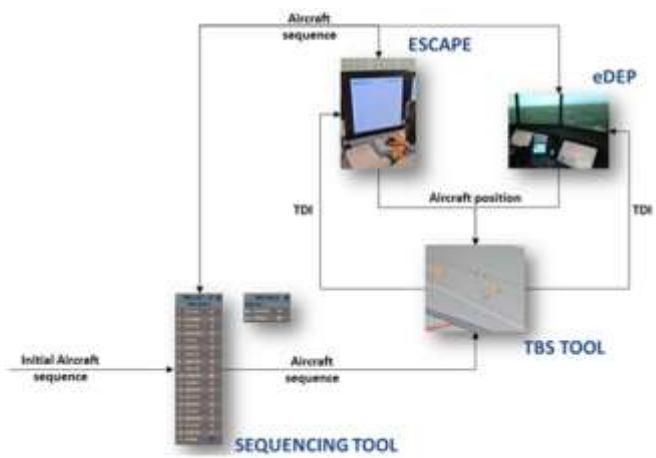

Figure 1: LORD Integration in EUROCONTROL Plateforms

LORD tool is integrated into both the EUROCONTROL ESCAPE and eDEP integrated tower working position platforms. It has aircraft pair separations, speed profiles and wind profiles input so that the Target Distance Indicators (TDIs) can be computed for display on the approach and tower positions.

The initial sequence is provided to the platform based upon the order of the predicted landing times in the simulator. In an operational environment it is likely this would be provided by an AMAN. The Sequencing Tool includes a HMI which is displayed on the Approach working positions which allows tactical modifications to be made to the sequence by the controllers. Sequence modifications are then fed back into the Separation Delivery Tool allowing for Target Distance Indicators (TDIs) updates to be displayed.

The LORD tool computes TDIs for each following aircraft of an aircraft pair based on the minimum separation/spacing required per aircraft pair whether its due wake vortex reasons or minimum radar separation, minimum runway occupancy time (ROT).

The TDIs consist of a Final Target Distance indicator (FTD) and an Initial Target Distance indicator (ITD). The FTD calculation represents the minimum required separation or spacing depending on the most constraining factor (e.g. WT separation, MRS or ROT to be applied at the point of separation delivery (in this case the runway threshold)).

The ITD calculation includes the additional buffer required on top of the FTD to take into account the effect of compression due to aircraft deceleration to landing stabilisation speed in order to meet the FTD at the separation delivery point.

In the final approach position the most relevant indicator is the ITD as it displays the spacing required on the final approach to ensure the separation minimum is not infringed at the separation delivery point. Therefore, the ITD only is permanently displayed on the final approach CWP HMI.

However, the final approach controller can display the FTD associated with each aircraft on selection. Furthermore, if an aircraft passes the ITD (i.e. infringement of the initial target distance to be applied), the FTD is automatically displayed so the controller can judge what action needs to be taken to avoid a subsequent "infringement" of the final target distance.

To prevent an infringement scenario where there is little or no predicted compression, the FTD is also automatically displayed if the aircraft passes a predefined distance from the FTD (a distance of 0.3Nm from the FTD was implemented in the simulation).

The relevant TDI for the tower controller is the FTD as it displays the separation minimum to be delivered at the separation delivery point that shall not be infringed; therefore the FTD only is constantly displayed on the tower runway CWP HMI. The ITD is still available and can be displayed on selection on a 'need to know basis'.

In addition, three alerts have been introduced; a sequencing alert, speed conformance alert and catch-up alert. The alerts were implemented as follows:

• The sequencing alert is triggered for aircraft when the lead aircraft as defined in the sequencing tool is behind follower aircraft (per aircraft pair) on the final approach.

• The catch-up alert is triggered when there is a 12kt difference between the calculated speed of the ITD and the speed of the follower aircraft (this 12kt difference is only relevant when lead is before the deceleration fix, as due to the compression effect the ITD is faster than its leader following the deceleration fix as it is merging into the FTD) plus a catch-up time limit of 60 seconds (i.e. the minimum time allowed for a follower aircraft to infringe the initial target distance).

• The speed conformance alert is triggered when an aircraft exceeds 160knots plus 20knots (i.e. 180knots) within the last 10NM from the threshold.

IV. Experimental Setup

A. Simulation Plateforms

The simulation platforms being used in the RTS are stated below:

- the EUROCONTROL eDEP Integrated Tower Controller Working Position including the 3D external view was used to simulate the tower runway position for RWY34 at Vienna. The tower runway controller handles only arrivals in segregated mode runway operations. Controllers were required to input all aircraft clearances /instructions and sequence changes directly into the system via the ITWP HMI- The tower runway position is also manned by one pseudo-pilot. The ground position is fully automated.
- The EUROCONTROL ESCAPE platform simulates the Vienna final approach controller working position. Arrival traffic for the final approach executive controller is delivered by a feed sector (representing the initial approach or final approach planner position as called in Vienna).

Controllers were required to input all aircraft clearances /instructions and sequence changes directly into the system via the CWP HMI- i.e. there were no paper strips. The final approach controller working positions are each manned by three pseudo pilots. The controllers communicate with the pseudo pilots using a headset and microphone.

For the final approach controller positions there are three pseudo-pilot positions; their role is to input the aircraft clearances/instructions given by the controllers into the system so that the aircraft flies in accordance with the controller instructions.

B. Simulation Environment

The operational environment used for the simulation was based on the Vienna environment, detailed information n the simulation Environment is provide in the SESAR Solution PJ02-03: Validation Plan [6].

1. Airport information

Vienna airport has two runways (see Figure 1): Runway 16/34 and Runway 11/29, for this simulation we considered only Runway 34 in segregated mode : no departure on runway 34, we considered High Intensity Runway Operations (HIRO) and no visual separations are allowed.

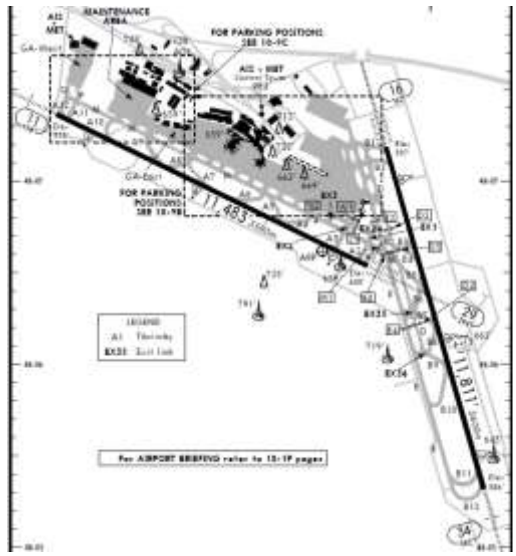

Figure 2: Vienna Airport AIP

2. Airspace information

All of the arrivals will fly an ILS approach following the STARs. For Vienna scenario only two STARs will be used; BALAD3N and MABOD4N/NERDU4N (see Figure 3: Simulated STARs (RNAV transitions)). Aircraft are generated following the STARs path at 3000 feet with speed of 220 knots and turned on base and final leg based on required spacing computed by the LORDtool and displayed in the form of TDI. Figure 4 below shows the ILS approach procedure for RWY34.

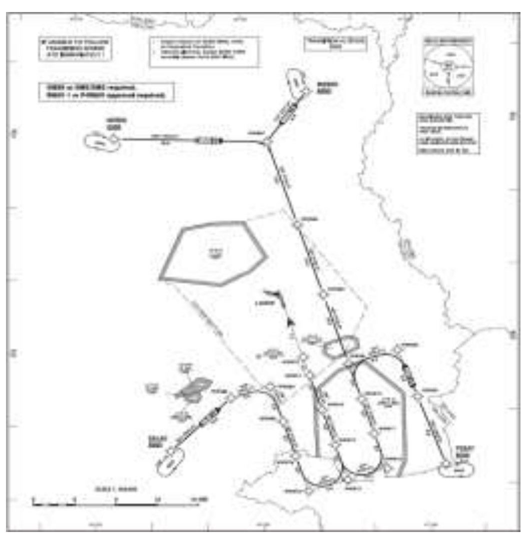

Figure 3: Simulated STARs (RNAV transitions)

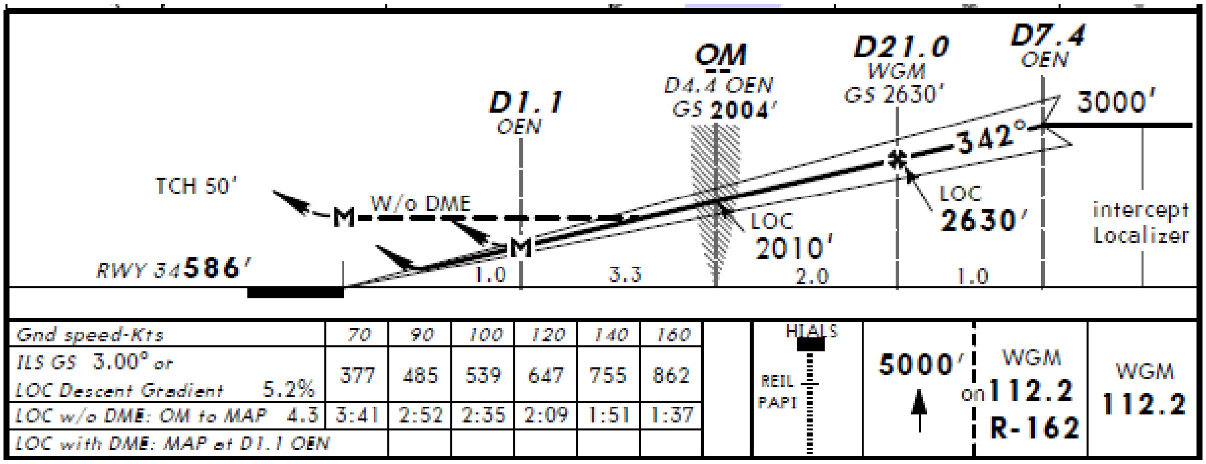

Figure 4: ILS approach procedure for Runway 34 at Vienna

3. Traffic information

The traffic samples used in the RTS were based on real flight data taken from the morning traffic from Vienna (August 2015) which have been adapted so that they have a mix that corresponds to an extrapolation of what the traffic is expected to be at Vienna Airport in the next 5 years. Furthermore, the timings of the arriving aircraft have been modified to ensure the high traffic density is maintained throughout the simulation exercise.

The traffic are realistic in terms of aircraft types, call sign and traffic mix compared to Vienna traffic. The traffic sample has included the following mix of the aircraft type categories.

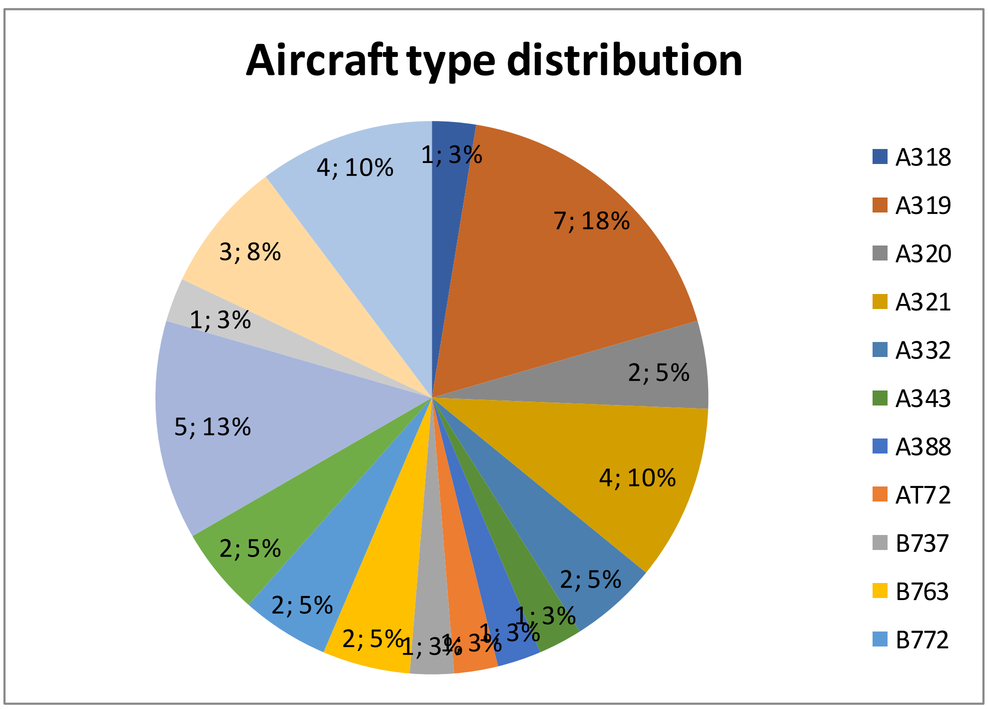

Figure 5: Aircraft Type Distribution

In order to reduce familiarisation effect, the traffic sample has been replicated with different callsigns (airline and callsign) for each aircraft. Since the aircraft speed behaviour is only affected by the aircraft type and not by the airline, the two samples can be considered identical in terms of traffic demands and pressure. Hence the two traffic samples are matched as far as is possible and comparisons can be made between different experimental conditions which can be considered independent of the traffic sample.

Traffic samples was tested and adapted as necessary during acceptance tests and prototyping sessions to ensure that they are appropriate.

The following wind profile will be used in the measured exercises of the simulation as described below:

Table 1: Wind profile

LEVEL Feet MSL	WIND HEADING	WIND SPEED Knots	WIND SPEED m/s	Crosswind Component Knots	Headwind Component Knots
000-3500	320	20	10,28	6,8	18,8
3500-5500	310	30	15,42	15	26
5500-RFL 400	300	45	23,13	28,9	34,5

The same wind is applied in all runs. The wind remainq constant throughout each exercise, so there will be no wind variation during an exercise.

Both the platform and the LORD Tool will use the same wind profiles hence that no wind errors are being simulated.

For the arriving aircraft speed profiles were used in the LORD tool and the simulation platform to calculate TDIs. True air speed (TAS) profiles on approach has been analysed to create modelled profiles which are split by aircraft type and wind band. The simulation platform used speed profiles which are split by aircraft type, wind band to simulate variability.

The model used is outlined in the figure below and is described using four parameters:

- The glide speed VGLIDE maintained down to the deceleration fix;
- The deceleration fix, defined as a certain distance from the threshold;
- The stabilisation fix, defined as a certain distance from the threshold;
- The final approach speed VAPP reached and maintained by the aircraft from the stabilisation fix to touchdown.

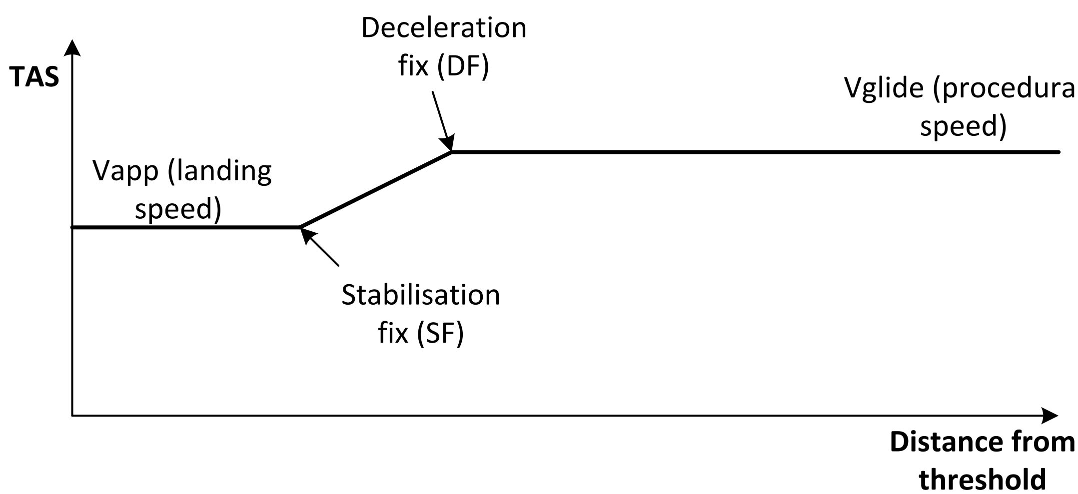

Figure 6: Aircraft speed profile model

C. Real Time Simulation for MRS Reduction without using LORD Tool

An evaluation of the impacts of the MRS reduction to 2NM without using any tool took place in Bretigny sur Orge in June 2018, involving ATCOs from Vienna Airport and Approach using the Vienna Environment under under very strong traffic pressure conditions and challenging wind conditions. The purpose of this first validation was was to assess the feasibility of operation of an MRS value reduced to 2.0 NM instead of the current 2.5 NM. To do so, six runs were conducted: two with MRS set at 2.5 NM and four with MRS set at 2.0 NM. two of those runs were considered as reference runs with MRS set at 2.5 NM (ICAO, Distance Based Separation DBS), whereas the others were based on the project solution of 2NM MRS without tool (ICAO DBS, reduction of MRS at 2.0 NM for all M-M pairs)

The six runs of interest were conducted with two traffic samples with the same aircraft type statistics, but with different callsigns in order to minimise the training effect throughout the exercises. Both samples were only made of arriving aircraft (i.e., no departures were simulated).

In order to maximise the number of potentially MRS separated pairs, the main wake turbulence category represented in the traffic samples was the MEDIUM category.

Finally, the approach context was challenging in terms of traffic pressure as the wind conditions presented a strong reduction of headwind component near the ground (going from 35 kts at 5500 ft to 19 kts at ground level).

Table 2: Traffic samples

ICAO WTC	RECAT LOWW WTC	Arr
A380-800	A380-800	1
Heavy	Heavy (except B76X/B75X/A310)	3
	B76X/B75X/A310	1
Medium	A320/B737NG	18
	Medium (except A320/B737NG)	16
Light	Light	2

For all runs, the MRS value is fixed at either 2.0 or 2.5 NM but ATCO added buffers during the different runs as hereafter:

- For runs 1, 3, 5 and 6, the approach controllers said they added 0.5 NM of buffer compared to the separation minima on the aimed separation to deliver.
- For run 4, the controller said he added 0.2 NM of buffer compared to the separation minima on the aimed separation to deliver.
- For run 2, the controller said he added 0.3 NM of buffer compared to the separation minima on the aimed separation to deliver.

D. Real Time Simulation for MRS Reduction using LORD Tool

The Real Time Simulation assessed the application of 2NM MRS on the final approach with time based pairwise wake turbulence separations based on static aircraft characteristics for arriving aircraft (static Pair Wise Separations:PWS)

Time based PWS is the efficient aircraft type pairwise wake separation rules for final approach consisting of both the time based 96 x 96 aircraft type based pairwise wake separation minima and the time based 20-CAT wake category based wake separation minima for arrival pairs involving other aircraft types.

Two degraded modes were tested : lost of the tool and worng aircraft type.

Both objective and subjective data were collected during the RTS for each measured sector. The objective data consists of system performance data recordings whilst the subjective data were obtained via post exercise questionnaires, ISA recordings, debriefs as well as expert observations.

The objective data obtained from system recordings is quantitative data only. The subjective data obtained during the real time simulation can be quantitative or qualitative.

V. Real Time Simulation Results

A. Real Time Simulation for MRS Reduction without using LORD Tool

The NASA TLX Scale was used to assess the controllers' perceived workload. The NASA-TLX encompasses three dimensions related to the demand imposed on the subject (Mental, Physical and Temporal Demands) as well as three dimensions showing the level of interaction of the subject with the task (Effort, Performance and Frustration).

The degree to which each of the six factors contributes to workload is evaluated from the ATCO`s perspective, giving a more detailed insight into the factors contributing to the mental spare capacity while completing a task. The ATCOs had to rate their answers, using a Likert Scale from 1 (Extremely Low) to 10 (Extremely High).

Due to small amount of the data, the NASA TLX overall workload score was calculated per exercise and per controller for the approach positions. In the second step, the individual dimensions that comprise the NASA-TLX rating scale were assessed separately for each exercise.

The following figure presents the overall NASA TLX mean workload scores for each controller in the approach positions.

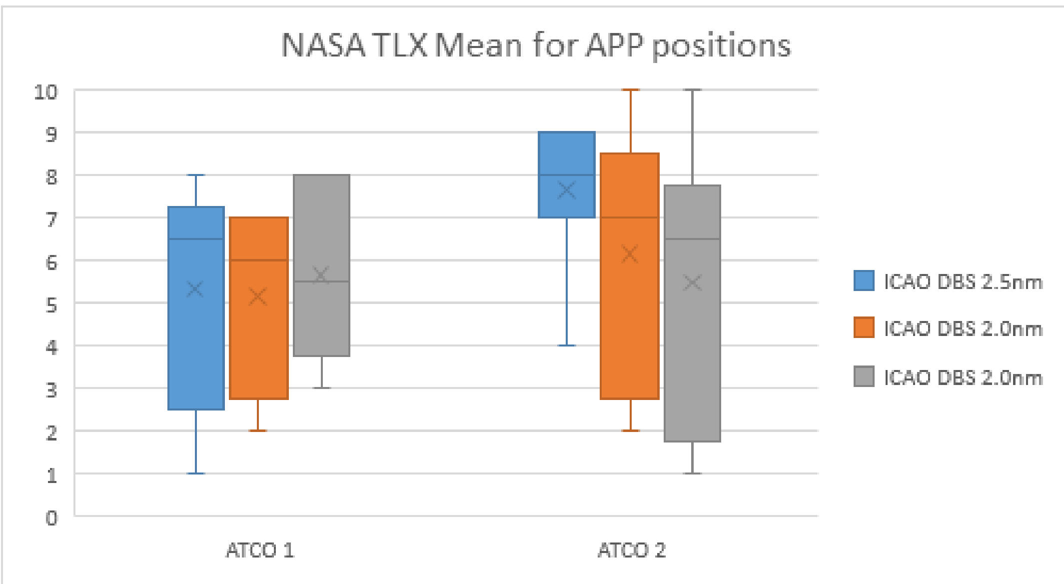

Figure 7: NASA TLX overall workload score means for ATCO 1 and ATCO 2

For ATCO 1, the NASA TLX mean overall rating scores were: 5.33 in Reference (exercise run 1) against 5.1 (exercise run 3) and 5.6 (exercise 5) in the solution scenario. Therefore, no difference was found between the subjective workload scores obtained in the reference and solution scenarios for ATCO 1. However, the task load results show that in the reference scenario the number of aircraft handled per hour was slightly less than in the two solutions scenarios (36.3a/c per hour in Reference (exercise run 3) compared to 39.2 a/c per hour (exercise run 1) and 40.2 a/c per hour (exercise 5).

For ATCO 2, the overall NASA TLX rating score means were 7.6 in reference scenario (exercise run 4) against 6.1 and 5.5 in solution scenarios (exercise run 2 and exercise run 6 respectively). These results shows reduction of workload experienced associated with the solution scenarios where 2.0NM MRS was applied between M-M pairs on the final approach compared to the reference scenario.

Furthermore, the task load results show that more aircraft were handled per hour in the solution scenarios than the reference scenarios (35.1 a/c per hour in the Reference scenario (exercise run 4) compared to 40.5 a/c per hour (exercise run 2) and 40.2 a/c per hour (exercise 6) in the solution scenarios.

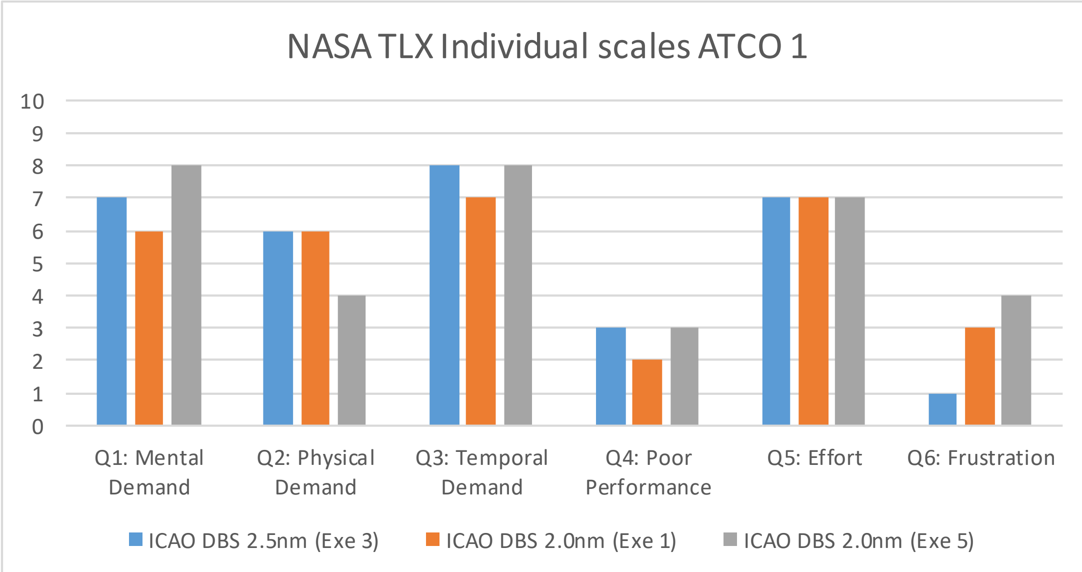

Figure 8 NASA TLX ratings for the individual dimensions for ATCO 1

The analysis of individual scales showed that ATCO 1 rated similarly his Mental Demand, Temporal demand, Performance and Effort in both conditions. However, the Frustration was higher in solution scenario to compare to the reference.

According to Figure 9, ATCO 2 rated his Mental, Physical, and Temporal demand as well as Frustration lower in Solution scenario. Additionally he rated his performance higher in Solution indicating positive impact of the concept on his performance. The Effort was rated slightly higher.

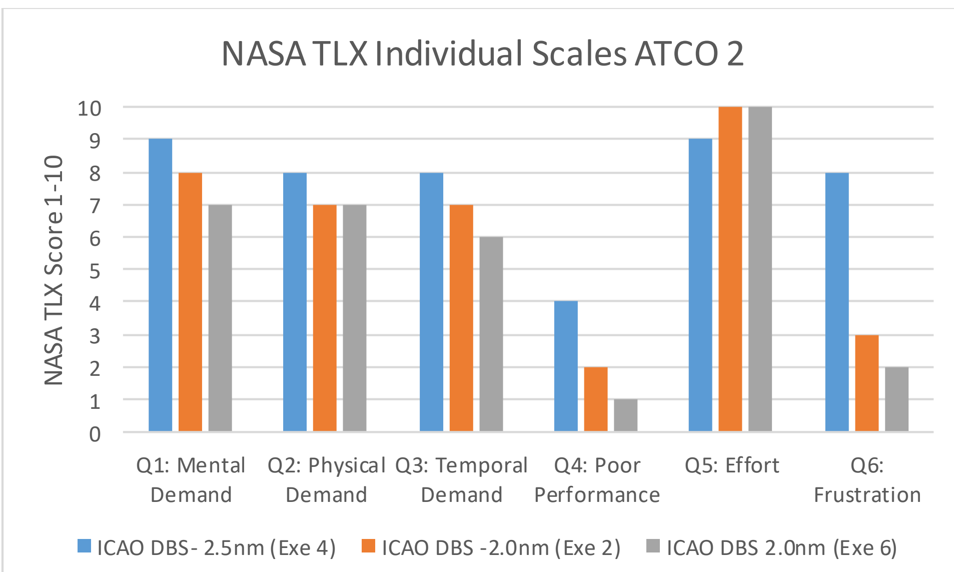

Figure 9 NASA TLX ratings for the individual dimensions for ATCO 1

During the simulation exercises it was observed that when 2.0NM MRS was applied between the M-M aircraft pairs the final was much shorter with aircraft intercepting the final approach around 15-20NM from the runway threshold during the exercise run. In the exercises with 2.5NM MRS between M-M pairs the aircraft were intercepting much further out from the runway threshold at about 20-25NM for ATCO2 and up to 30NM away from the runway threshold for ATCO1 for a period of 30-40 minutes during the exercise. The length of the final being worked by the final approach is used in operations an indication of taskload / workload of the final approach controller: The longer the final being worked by controllers higher the work load / taskload. Therefore, being able to apply 2.0NM MRS between M-M pairs was observed to significantly reduce length of final being worked in the peak traffic period being simulated. As the controllers reported in the debriefs this explains why the workload was perceived to be the same or less with the final approach controllers when applying 2.0NM MRS between M-M pairs compared to 2.5NM MRS even though more aircraft were handled per hour in the solution scenarios compared to the reference scenarios. Being able to apply 2NM between M-M MRS pairs gave them 'more space' on the final approach.

Only one ATCO (ATCO 3) performed at the TWR position, thus the results has been grouped per scenario: two reference exercises against four solution exercises. The overall workload score rating mean for the reference scenario was 1 and for the Solution scenario was 1.04. Thus, no difference was found for Tower position in terms of the subjective workload experienced in the reference scenarios and solution scenarios, as measured by the NASA-TLX workload rating scale. Although it should be noted that as with the approach controller more aircraft were handled per hour in the solution scenarios compared to the reference scenarios.

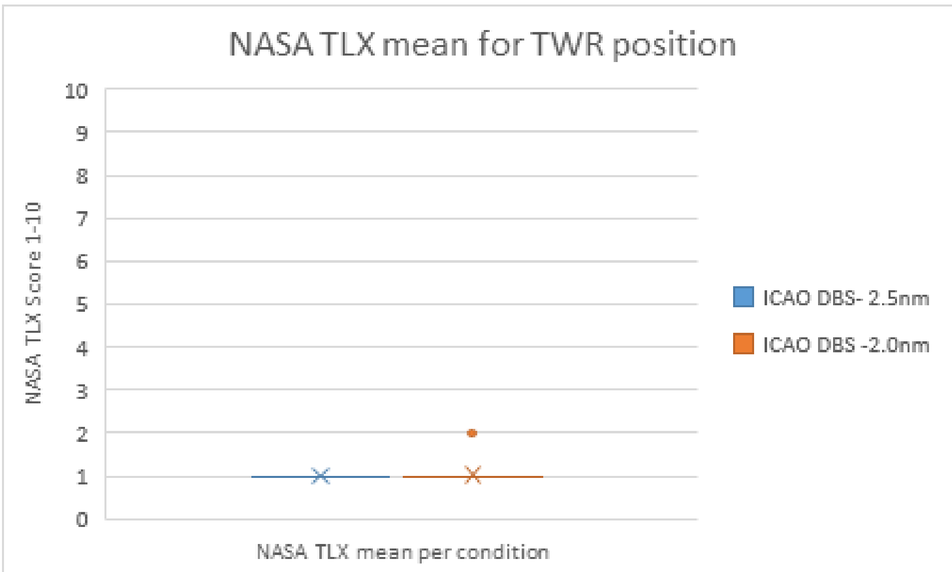

Figure 10 overall NASA TLX rating score means for TWR position.

It should be noted that the NASA-TLX overall mean rating scores are very low due to the fact that the tower position in the real time simulation is performing only a sub-set of tasks usually performed in the tower runway position in live operations.

The Results on the operational feasibility and acceptability of 2.0NM MRS between Medium-Medium pairs only with Distance Based ICAO separation scheme and no controller support tool in specific wind conditions showed the concept did not have a negative impact on safety or human performance and so could be considered operationally feasible. However, the Vienna controllers were concerned about the fact that this reduction of MRS from 2.5 NM to 2 NM on final approach was dependant on specific wind conditions and so could not be applied at all times. The controller felt that the opportunity to apply the reduction under IMC under specific wind conditions would be limited in Vienna.

Controllers reported that working with a conditional application based on weather conditions could lead to confusion and error – especially in the Vienna environment where other weather conditional procedures are applied (visual separations in VMC). Therefore, if a reduced MRS of 2NM was to be applied under DB ICAO M-M pairs in Vienna a tool, such as the LORD tool, would be needed

B. Real Time Simulation for MRS Reduction using LORD Tool

Controllers subjective workload was assessed using three different but complementary measures; The Bedford scale, NASA-TLX and ISA workload ratings. Objective task load measures relating to the number of aircraft on frequency, percentage of R/T occupancy and number of instructions were used to further complement and interpret the subjective workload measures obtained. Additional feedback from the post exercise questions and debriefs has been captured.

The Bedford workload scale: The Bedford Scale was used to identify the ATCOs perceived spare mental capacity during each exercise run. The scale encompasses a hierarchical decision tree that guides the ATCO through a ten-point rating scale (1=low, workload insignificant and 10=high, task abandoned), where each point is accompanied by a descriptor of the associated level of workload.

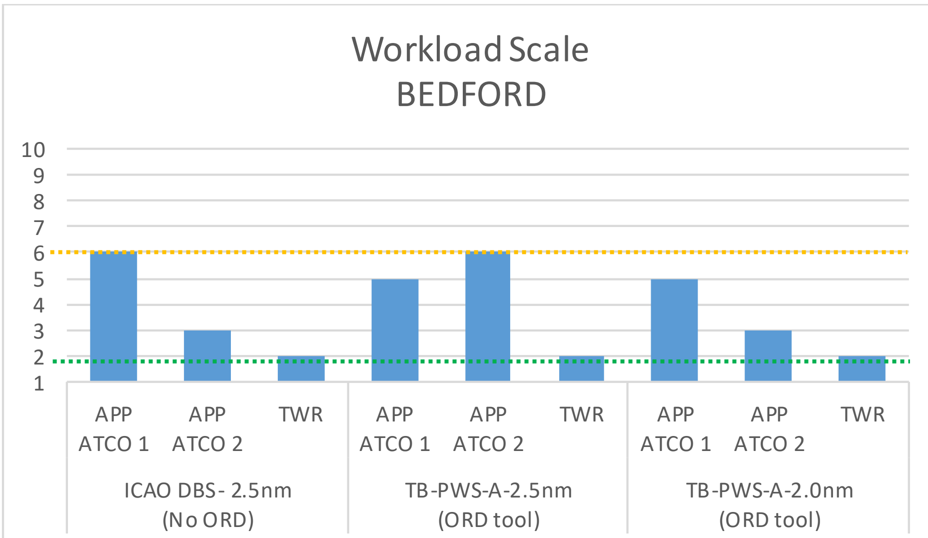

Figure 11[1] Bedford Workload Scale mean ratings for App and TWR controllers

The mean Bedford Workload scale ratings obtained in the Reference 1 (ICAO DBS with 2.5NM MRS) for the APP position was 4.5, indicating that the overall level of workload was generally "tolerable". For the Reference 2 (TB-PWS-A 2.5NM MRS with the LORD tool), the overall level of workload was 5.5, indicating a higher overall level of workload than in the Reference 1, identified nonetheless as being "tolerable".

In the Solution (TB-PWS-A with 2.0NM MRS and the LORD tool), the APP mean workload score was identified as being tolerable as well, with a score of 4, a slightly lower overall level of workload as compared to the Reference 1 and Reference 2 runs.

The further analysis showed that APP ATCO 1 reported to experience a ''tolerable'' level of workload in all scenarios scoring workload on the Bedford scale to be ''6 - little spare capacity '' under Reference 1 (ICAO DBS) and ''5- reduced spare capacity'' in both the Reference 2 (TB PWS 2.5NM MRS with LORD tool) and Solution (TB-PWS-A with 2.0NM MRS).

However, APP ATCO2 reported workload on the Bedford scale to be "3 - enough spare capacity for all desirable additional tasks", indicating a "satisfactory" level of workload, in the Reference 1 (DBS ICAO and 2.5NM MRS) and Solution (TB-PWS-A with 2.0NM MRS and the LORD tool) and '"6- "little spare capacity'' in the Reference 2 (TB PWS with 2.5NM MRS and the LORD tool) indicating tolerable workload.

When questioned in the debrief ATCO 2 mentioned that the increase in workload in the Reference 2 run was attributed to the fact that one of the a/c had to be instructed to reduce the speed to 150kt early on the final approach, which caused a domino effect behind the aircraft. As a result, more speed instructions and enhanced monitoring were required, which explains ATCO2 perceiving to have less spare mental capacity in this run.

[1] The green horizontal marker indicates the "satisfactory" answers, while the orange horizontal marker indicates the "tolerable" responses

Under all three scenarios, the TWR ATCO has perceived to have an "insignificant" level of workload, with a score of "1" in all exercise runs.

The mean NASA TLX score obtained under the Reference 1 scenario (ICAO DBS and 2.5NM MRS) for the APP position was 5.83.

Under the Reference 2 (TB-PWS-A 2.5NM MRS with the LORD tool), the mean workload results for the APP position was 5, indicating a slightly lower level of workload as compared to the Reference 1.

For the Solution scenario (TB-PWS-A 2.0nm MRS with the LORD tool), the mean workload score for the APP position was 4.16 indicating a slightly lower level of workload as compared to the Reference 1 and Reference 2.

For ATCO1 the NASA TLX overall mean ratings was 5 for Reference 1 (ICAO DBS), 3.8 for Reference 2 (TB-PWS-A 2.5nm MRS with the LORD tool) and 3.3 for the Solution (TB-PWS-A 2.0NM MRS with the LORD tool).

For ATCO2 the NASA TLX overall mean ratings was 6.66 for Reference1 (ICAO DBS), 6.1 for Reference 2 (TB-PWS-A 2.5nm MRS with the LORD tool) and 5 for Solution (TB-PWS-A 2nm MRS with the LORD tool).

The NASA TLX overall workload ratings indicate that workload was highest in the DB ICAO exercise runs and lowest in the solution scenario TB PWS 2Nm MRS with the LORD tool exercise runs for both APP ATCO1 and ATCO2.

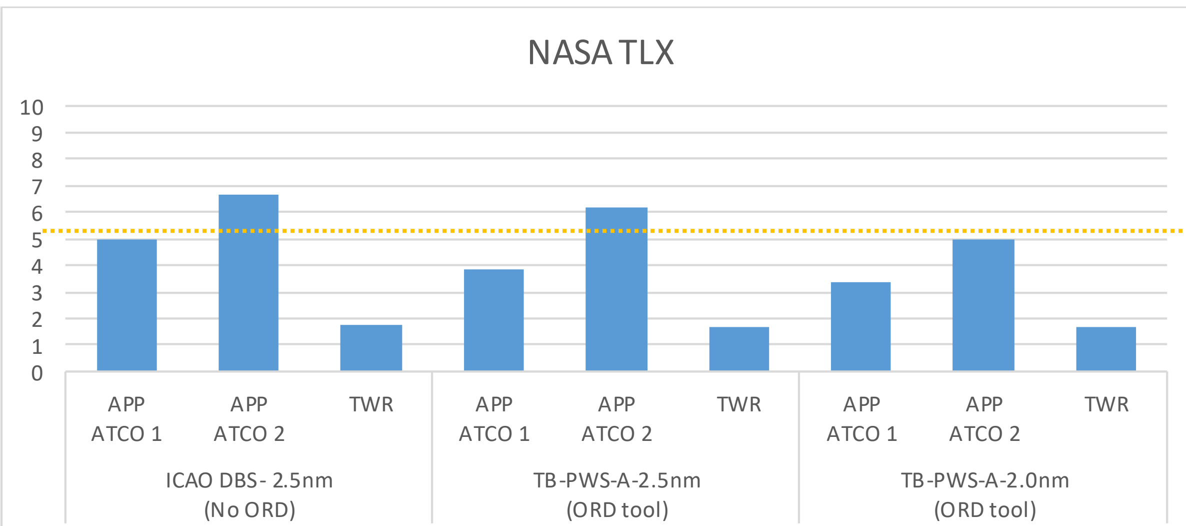

Figure 12[1] NASA TLX mean ratings for APP and TWR controllers.

In the debriefs the approach controllers report that the LORD tool helps to reduce their workload as they no longer have to calculate the separations and required spacing on aircraft interception themselves as they are displayed on the final approach with the ITD.

In addition, the controllers also reported that being able to apply a MRS up to 2NM gave them 'more space on the final approach''. This meant that under high traffic conditions the length of the final approach was ''reduced'' i.e. aircraft were able to intercept at around 15NM from the runway threshold. Whilst when the MRS was 2.5NM with TB PWS-A and the LORD tool the aircraft were intercepting further out on the final approach at 25-30NM from the runway threshold. This means that with 2.0NM MRS the approach controllers had to 'work' each aircraft for a shorter time. Furthermore, the controllers reported that when they had to intercept the final approach further out at 25-30NM from the runway threshold it created less manageable traffic patterns.

Similarly as with the Bedford scale, no significant differences were found for the tower position with means 1.75 for Reference 1 (ICAO DBS) and 1.66 equally for Reference 2 (TB-PWS-A 2.5nm MRS with the LORD tool) and Solution runs (TB-PWS-A 2.Onm MRS with the LORD tool).

[1] The orange horizontal line indicates the "medium" threshold.

The NASA TLX rating scores for each individual scale are presented in Figure 13 NASA TLX Individual scales ratings.

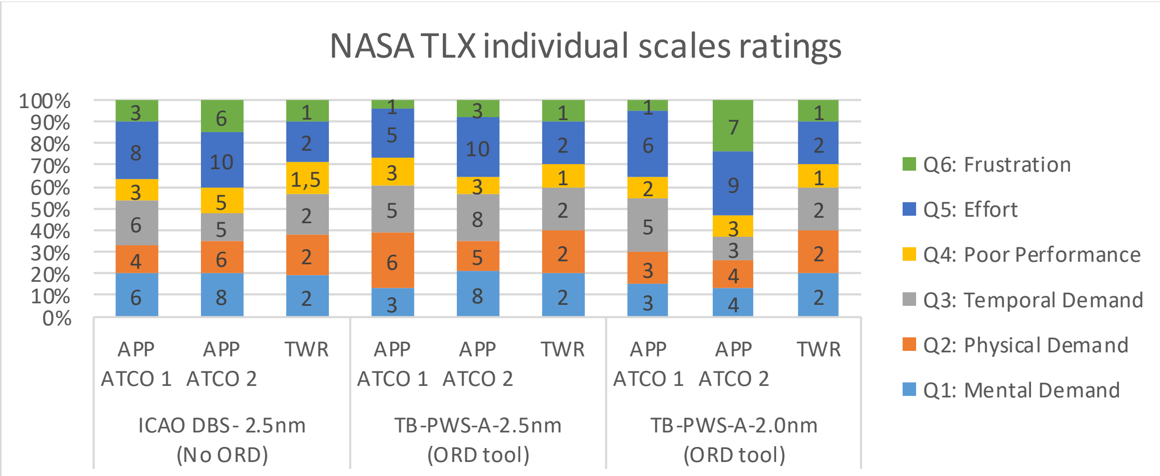

Figure 13 NASA TLX Individual scales ratings

ISA rating scale: The ISA, Instantaneous self-assessment workload scale was used with a time interval every 3 minutes during the simulation exercise time. The controllers assessed their workload based on a 5 point scale: Very low (1), Low (2), Fair (3), High (4) and Very high (5). The measurements coming from exercise start and exercise end when there were less than 4 aircraft have been disregarded from the analysis.

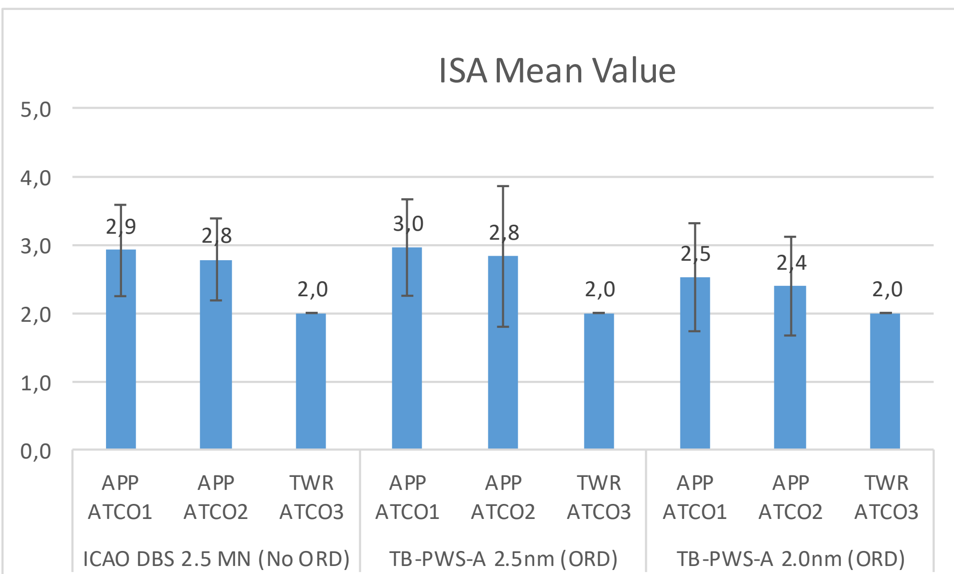

Figure 14: ISA mean value for APP and TWR positions

The ISA mean value ratings shows that no difference could be found between the mean values comparing Reference 1 (ICAO DBS & 2.5NM MRS) and Reference 2 (TB-PWS-A 2.5NM MRS with the LORD tool) with mean ISA ratings of 2.9 against 3.0 for ATCO1 and 2.8 for both conditions for ATCO2.

Comparing Reference 2 (TB-PWS-A 2.5NM MRS with the LORD tool) against Solution (TB-PWS-A 2.NM MRS with the LORD tool), the ISA ratings showed there to be a reduction of workload with the Solution for both approach ATCOs, (reduction from 3.0 to 2.5 for ATCO1 and reduction from 2.8 to 2.4 for ATCO2).

The TWR controller mean ISA rating rated was 2.0 in all there scenarios.

Again, the subjective ISA workload ratings are particularly interesting when combined with the task load ratings such as the RT occupancy, and runway throughput. The runway throughput with the TB PWS concept with both 2.5NM and 2.0NM MRS and LORD tool showed significant increase of 2 ac/h for ATCO1 and 3.2 ac/h for ATCO2 for the first landing throughput metric (including go-rounds) and 5.7 ac/h for ATCO1 and 6.5 ac/h for ATCO2 for the second landing throughput metric (the gaps and go-arounds are removed from the analysis).

Considering the ISA ratings, together with RT Occupancy and runway throughput, it is interesting to observe, that although the objective task load, in terms of number of aircraft handled per hour has increased in Reference 2 and Solution scenarios, the controllers perceived workload was reported to decrease, and RT Occupancy stayed the same or decreased.

The ISA results demonstrate that the main benefit in workload reduction can be gained with application of TB-PWS-A 2.0NM MRS and the LORD tool for APP positions even though more aircraft are handled per hour compared to ICAO DBS with 2NM MRS and TB PWS-A 2.5NM MRS with the LORD tool. These results are consistent with Bedford and NASA TLX results.

Despite the objective results indicating that the RT occupancy did not increase with the solution scenario, during the RTS, the controller expressed their concerns about the risk of increasing RT occupancy due to increased throughput. Few mitigations have been proposed such as silent transfer to APP sector, data link for transfers, or shortening of some clearances.

It has also been observed that due to high workload, the controller was working according to a different sequence than that given by the LORD tool. In the current implementation, the APP ATCO arrival sequence alert triggers only when the follower is already aligned on the centreline, which is too late. In case of high workload, the APP ATCO might find it too demanding to monitor the arrival sequence (which is vital information for the LORD separation delivery tool) which might cause the controller to not detect a wrong order in the sequence without the alert).

For approach controllers the reference 1 with ICAO DBS was considered more demanding than working with the tool.

In summary, The controllers report that the changes to roles, tasks and procedures under 2NM MRS as tested in all measured positions (final approach and tower runway controller positions) are usable /acceptable with the LORD tool; The controllers further stated that the reduction of MRS on the final approach to 2NM with a tool such as the LORD tool (with ROT constraints as well as MRS & WT) would be acceptable for any separation scheme applied whether conditional on weather or not. In addition, they added that such a tool was essential under separations schemes which increased the complexity of the approach and tower controllers work such as TBS, PWS and WDS with 2NM MRS. With 2NM MRS it became even more important that pilots adhere to controller speed instructions on the final approach and respond promptly to controller instructions. Failure to respond in a timely manner may lead to separation infringements which may have more serious consequences as the margins for error under 2NM MRS were reduced.

The controllers also recommended that consideration should be given to reducing the MRS from 3NM to 2.5NM on the baseleg due to the fact that margins for error were reduced on the baseleg due to the reduction to 2NM MRS on the final approach and this increased their levels are stress.

The workload results obtained from ISA ratings, the Bedford scale and the NASA TLX demonstrate that when working with 2NM MRS workload was acceptable for both the approach and tower runway controllers.

Furthermore, the results indicate that a workload reduction can be gained with application of TB-PWS-A 2.0nm MRS and the LORD tool for Approach controller positions even though more aircraft are handled per hour compared to ICAO DBS 2.5NM MRS and TB PWS-A 2.5NM MRS with the LORDtool.

In the debriefs the approach controllers reported that the LORD helps to reduce their workload as they no longer have to calculate the separations and required spacing on aircraft interception themselves as they are displayed on the final approach with the ITD indicator.

Others results of the real time simulation can be found in the SESAR Solution PJ02-03: Validation Results [7]

VI. Conclusion

The Vienna Simulation showed the importance of using a support tool to Controller when reducing MRS to 2NM, the controller acceptability of the concept depends on this. The main advantage of the tool is the reducing of the mental workload of the controller as he doesn't need to add additional buffer impacting the runway throughput. The simulation showed that by adding simple display on the HMI, the reduction is possible without any impact on controller workload and safety.

For implementation, incremental steps can be proposed, first by introducing the tool with the current sepration scheme, the controller doesn't have to change his methods of work, he has an additional HMI feature and the seprations remain the same only Final Target Distance is then displayed. In a second step, an Initial Target Distance is displayed to show the controller the compression and the position where to put the aircraft, in this step a decrease of the mental workload will be noticed in a final step a change of the sepration scheme can be applied.

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