

Validation of the Runway Utilisation concept

A case study for Vienna airport

Catherine Chalon Morgan & Mohamed Ellejmi

EUROCONTROL

Brétigny, France

catherine.chalon-morgan@eurocontrol.int &
mohamed.ellejmi@eurocontrol.int

Floris Herrema & Ricky Curran

Technical University of Delft

Delft, Netherlands

f.f.herrema@tudelft.nl & r.curran@tudelft.nl

Abstract — Runway utilisation is a function of actual yearly runway throughput and annual capacity. The runway utilisation use case is part of work being conducted by the H2020 project SafeClouds. Within SafeClouds we have built a machine learning algorithm that support the tower ATCO during high intensity runway operations by making predictions based on historical observations of runway traffic. The runway utilisation tool includes a Gradient Boosting algorithm that provides runway occupancy time and runway exit predictions for Vienna airport. The tool is able to show predicted alerting issues and support decisions. The real-time simulation reported in this paper is part of the first runway utilisation validation process to investigate how the knowledge gained from a Gradient Boosting algorithm can be applied in the operational environment to support the tower runway controllers in their work.

Keywords—component; runway occupancy time, runway exit utilised, gradient boosting

I. INTRODUCTION

Many of today's hub airports are at times unable to handle planned air traffic demand. Despite being saturated, some airports have political and environmental challenges associated with any further physical airport development. In view of expected further growth in air traffic demand, there is a clear need for safety and runway capacity improvements in an environmentally responsible manner. In order to enhance existing runway throughput, technology and procedures have enabled in certain circumstances reductions in legacy separation standards. Since demand for air traffic movements is continuously increasing, all stakeholders of the aviation system aim at a maximum utilisation for the given infrastructure, in particular the airport runways. A high number of runway movements entails the realisation of minimum separation standards between arrival and departing aircraft. With a view to avoiding accidents or risks of incidents, airline operators and Air Traffic Controllers (ATCOs) are moving toward proactive risk management which aims to identify and predict risk precursors and to mitigate the associated risks. The identification of risks that precede the anomaly and have some correlation to the occurrence of the anomaly, called precursors. In this context, Arrival Runway Occupancy Time (AROT) is one major impact factor, which normally cannot be adapted or

regulated in any manner. In fact, it depends highly on the runway exit an aircraft utilises after the landing roll out. Landing or departing aircraft that follow a landing aircraft can only use the runway if that runway has been vacated. If a landing aircraft misses a planned or foreseen exit or for whatever reason increases its AROT during the rollout phase, a tightly sequenced following aircraft will have to perform a missed approach and go around. These disturbances in the arrival/departure sequence will result in delayed operations for the scheduled movements. Due to the uncertainty surrounding AROT times, spacing buffers are routinely applied by ATCO so that separation standards are never infringed. Furthermore, the variation in the application of these buffers is down to the weather of the day, notably winds and precipitation but moreover the experience level of the controller and even if the aircraft is considered a locally based aircraft or airline. Thus, it is of major importance to identify precursors for the probability of missed runway exits and landings with increased AROT. With our contribution, we provide a validation of the Machine Learning (ML) Runway Utilisation (RU) algorithm developed in the H2020 project SafeClouds¹. The RU tool is capable to predict the runway exit utilised (Nrex) and AROT based on actual movements at airports. Currently, there is no supplementary operational system that assists the Arrival Manager (AMAN) and Departure Manager (DMAN) on predicted runway exits and AROT. AMAN systems provide an automated sequencing support for approach and runway ATCOs, whilst continuously optimising arrival traffic sequences and runway slot times for landing aircraft. This is accomplished by a more efficient and predictable arrival management process that can assist in reducing low-level holdings and tactical intervention by the ATCO. AMAN takes into account the locally defined maximum landing rate (capacity), the required separation for aircraft in the touchdown zone (safety) and additional operational criteria. DMAN is an advanced controller tool for optimising runway throughput. To achieve optimal use of runway capacity and airspace capacity in the Terminal Management Area (TMA), a DMAN assists the ATCO in managing departure traffic by providing optimised take-off sequences in considering departure trajectories. AMAN and DMANs are essential controller tools that provide guidance and

¹ www.safecLOUDS.eu (H2020) project

as such ensure the best use of the available runway capacity (i.e. maximum throughput). An additional support tool providing real time AROT and Nrex alerts would be an advantage if not a necessity in a future environment of High Intensity Runway Operations (HIRO) where the associated risk of a loss of separation between aircraft in time and/or distance has a direct impact on incident and accident avoidance. A Real-Time simulation (RTS) should give insight into the risk mitigation.

A. Related work

For the literature we focus on the work to be performed on runway capacity enhancements and methods to predict and validate exit usage and AROT. In the context of efficient runway operations, the AROT is an important driver. AROT along with the runway exit utilised is key in quantifying actual throughput and thus generating predictions with respect to a runway utilisation indicator. For certain predictions ML techniques can be used. Previous studies have explored and applied ML techniques using radar and A-SMGCS data, but the prediction and validation of the Nrex along with the observation of related precursors are not well developed. A statistical analysis of the final approach and AROT is done by [1] using data from the Detroit multilateration surveillance system. A study on surveillance data highlighting benefits and including different sources of information to improve capacity and safety is conducted [2]. Several operational factors and their impact were analysed in [3]. In [4], a model to predict the landing performance of airplanes is developed with a focus on locating high-speed exits. This model was based on empirical heuristics, which were derived from field observations, as a different mix of aircraft and different environmental conditions at airports will result in specific approaches for runway exit designs. In [5, 6], a model for optimally tailored runway and exit layouts is proposed whereas [7] provides the airport taxiway structure and links it to the runway exit choice process. The runway utilisation depends on the runway used as well as several additional factors (e.g. number of arrivals and departures or runway configurations, efficiency of taxi operations) [8]. Furthermore, efficient airside operations will depend on a balanced consideration of capacity/demand management [9], aircraft/runway scheduling [10], taxiway planning/ground movements [11] and gate assignment [12], which clearly emphasise the demand for efficient runway exit selection for landing aircraft. In this context, [13] provides an operable calculation method to manage the runway exit availability considering uncertain exit usage and exit times. In [14], an analysis method for medium-speed manoeuvres and more specifically, runway exit manoeuvres is presented. A Monte Carlo simulation algorithm and empirical heuristics derived from field observations were used in [15] to estimate landing-roll trajectories and to predict aircraft landing performance on runways in order to locate high-speed exits. In [16] an application was designed that relates to the optimisation of runway exits based on assessment of runway conditions and

aircraft-based braking capability, with the aim of selecting the best runway exit to optimise runway throughput.

II. VALIDATION METHODOLOGY

A. RTS objectives

This RTS is a V1² validation activity to investigate how the knowledge gained from the ML RU tool can be applied in the operational environment and support the tower runway controllers in their work. There were three main objectives of the RTS:

- **Operational Needs**

To gain feedback from controllers in terms of whether such a controller support tool based on ML and enhanced prediction of RU meets controllers' operational needs.

- **Operational feasibility & acceptability**

To assess the operational feasibility and acceptability of a controller support tool based on ML and enhanced predictions of RU.

- **Controller requirements**

To assess the requirements of the controllers with regards to controller support tool based on ML RU predictions (e.g. AROT and Nrex), for example, in terms of information requirements, timeliness of information, accuracy/reliability of predicted information.

B. RTS scope

Based on the findings in [17] an initial prototype controller support tool was developed to inform controllers in advance of the predicted AROT and/ or Nrex for each aircraft, i.e. the ML RU controller support tool. The prototype was used to provide controllers with a possible example of how the enhanced predictions of runway utilisation gained from ML could be applied in the operational environment to support their work. The simulation was conducted using the EUROCONTROL RTS Early Demonstration & Evaluation Platform (eDEP) platform with integrated Tower Working Position (iTWP) and a 3D external view. The RU ML support tool prototype for predicting AROT and Nrex was integrated into the EUROCONTROL eDEP iTWP [18]. The simulation was based on the Vienna approach / tower environment using Runway 34 (RWY34) in segregated arrival mode only. Two controllers from the Vienna Tower participated in the simulation.

C. Solution description

Within this study we are validating an algorithm that would support the tower ATCO during HIRO by making predictions relating to AROT and / or Nrex based on historical observations of runway traffic. The predictions are produced at 2NM upstream from the runway threshold. The Vienna controllers chose the 2NM since this enables tactical operational tools to be supplied with real time data and provide **additional information or warning to the tower controllers** if

² V1 identifies the operational and technical solutions for meeting the target performance identified in Section II.A.

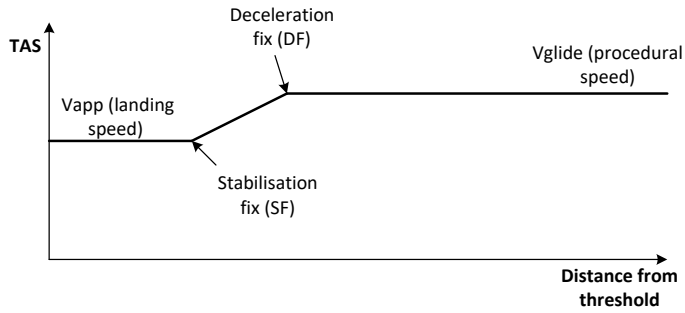


Figure 2. Aircraft speed profile model for arrivals

E. Separation Scheme

The wake turbulence separation scheme was the current wake turbulence separation scheme used in the Vienna approach and tower environment, i.e. Distance Based ICAO wake turbulence separation scheme without any support tool under visual meteorological conditions (VMC). In VMC in Vienna visual separations are often applied therefore, minimum radar separation pairs may be delivered under 2.5NM under visual separation rules.

F. Arrival Runway Occupancy Time

The average predicted AROT is highlighted in Table 3.

TABLE III. AVERAGE AROT IN THE SAFEClouds RTS

	Traffic sample 1	Traffic sample 2
Super Heavy	76 seconds	79 seconds
Heavy	65 seconds	68 seconds
Medium	55 seconds	56 seconds
Light	49 seconds	50 seconds

In each exercise, a number of non-procedural exits were simulated. A non-procedural exit refers to when a flight vacates the runway at an exit further along than the Aeronautical Information Publication (AIP) intended one. The number of non-procedural exits that occurred in each measured exercise run was about 15% of the total landing aircraft. Table 4 shows the procedural exit and non-procedural for Heavy, Medium and Light aircraft as will be implemented in the RTS.

TABLE IV. PROCEDURAL AIP EXIT AT RWY34 FOR VIE AIRPORT WITH ASSOCIATED NON-PROCEDURAL EXIT

Aircraft ICAO category	Procedural exit	Non-procedural exit
Heavy	B4, B5	B1, B2
Medium	B5, B7	B1, B2, B4
Light	B7, B9	B1, B2, B4, B5

G. Tower simulation platform

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 in the Safe Clouds V1 RTS. The tower runway controller worked 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.



Figure 3. Tower controller working with the RU ML support tool on the iTWP with 3D external view of Vienna airport

H. Tower simulation platform

The RU ML support tool for predicting AROT / Nrex was integrated into the EUROCONTROL eDEP iTWP. The RU ML support tool for predicting AROT and / or Nrex RU indicates to the tower controller on the tower CWP HMI, whether not, each landing aircraft has a less than 80% prediction of taking the assigned runway exit. When the mouse is moved over the runway exit information either in the track label or in the EFS then a narrow will be displayed next to the runway exit. (Note the landing runway and assigned runway exit is also highlighted in the aircraft label). If an aircraft has, a less than 80% prediction of taking the assigned/procedural runway exit as defined in the AIP the arrow displayed will be red (as will the RWY and assigned RWY exit presented in the aircraft label). If the prediction of taking the assigned/procedural runway exit as defined in the AIP is more than 80% then a green arrow will be displayed (as will the RWY and assigned RWY exit presented in the aircraft label).

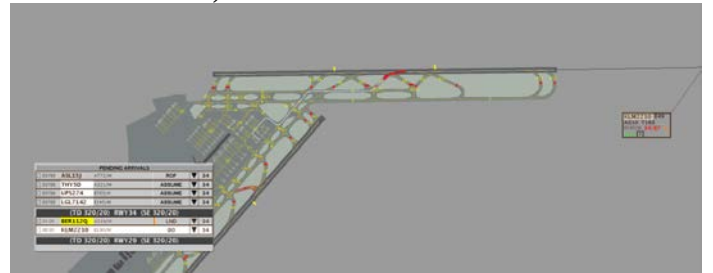


Figure 4. iTWP interface showing red arrow at RWY exit (B7) indicating the prediction that the approaching aircraft will take the procedural RWY exit for that aircraft (B7) is less 80%.

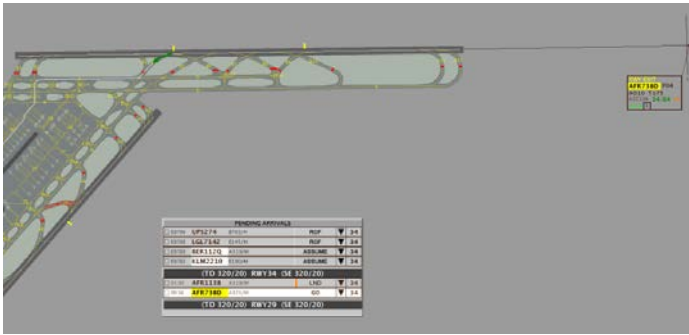


Figure 5. iTWP interface showing green arrow at RWY exit indicating the prediction that the approaching aircraft will take the procedural RWY exit for that aircraft (B4) is above 80%.

I. Conduct of RTS

The RTS took place over a 4-day period from 23rd to 26th May 2019. Two Vienna tower controllers participated in the RTS. Both controllers were already familiar with the eDEP iTWP simulation platform, as they had participated in several previous RTS conducted in SESAR1 WP6.8.1 and SESAR2020 PJ02, using the eDEP iTWP.

The controllers were initially briefed on the objectives of the RTS, the ML concept for RU and the ML RU prototype tool. Once fully briefed the controllers were each given a training exercise to re-familiarise themselves with the simulation environment, the iTWP HMI and also familiarise them with the RU ML controller support tool.

Following the training exercises, each controller was asked to work the tower runway positions, as they would do in real life operations under VMC with the initial prototype RU ML support tool. After each exercise, debriefs were conducted with the controllers to gain their feedback regarding the RU ML support tool prototype. Based on the controllers' feedback from the initial exercises, two additional versions of the RU ML support tool were developed and assessed by the controllers during the simulation. Therefore, over the 4 days of the RTS, each of the controllers worked with three slightly different versions of the RU ML support tool and provided their feedback. The three different versions of the RU ML support tool consisted of:

- 1) The initial prototype **RU ML support tool** with the Nrex prediction for an aircraft updated when the aircraft was at **2NM from the runway threshold**.
- 2) The **RU ML support tool** with the Nrex prediction for an aircraft updated when the aircraft was **at runway threshold** (therefore the information was updated later but had a higher percentage accuracy/reliability than the information updated when the aircraft was at 2NM from the runway threshold (approx. 6% more accurate).
- 3) The **RU ML support tool** with the Nrex prediction for an aircraft updated when the aircraft was **at 2NM** from the runway threshold **plus an automatic pop-up information alert** displayed on the iTWP HMI when an aircraft was predicted to take a non-procedural runway exit (i.e. with a less than 80% prediction of

taking the assigned/procedural runway exit as defined in the AIP) that would increase the AROT to above what was usual for that aircraft type.

The feedback obtained from all the controllers following each exercise was noted and is summarised per exercise in the results section below according to the three objectives defined in section II.A

IV. RESULTS FROM THE V1 REAL TIME SIMULATION

The results of this V1 validation activity are based solely on controllers feedback based on the three versions of the ML RU controller support tool tested in the RTS.

A. Operational needs

- The controllers felt that information based on ML regarding RU could be used to support operations and controllers work by enhancing controllers' situation awareness and hence provide potential safety benefits.
- Whereas, predictive information relating directly to runway exit (Nrex) was not considered to be needed by controllers to support their work, predictive information relating to a change in AROT was seen to be very useful and would support the operational needs of the controllers. (However, one of the controllers stated that the ML predicted Nrex would be 'a nice to have option although it was a bit of a gimmick')
- The ML predicted information relating to AROT or ideally information regarding the consequences of a change in AROT, especially if there is a potential negative impact on controllers work, was seen to be needed from an operational perspective and would support controllers in their work. The tower runway controllers stated that they only need to be alerted about unusual behaviour or if there is a potential situation where controller may have to do something, for example if the AROT of the preceding aircraft is greater than the time to touch down of the follower and there could be a potential loss of separation, then an information alert should be provided to controllers.
- Controller's reported that they would not act directly on the predictions (e.g. give a go-around to a follower aircraft) if reliability was not 100%, but they would monitor the situation more closely and wait to see how the situation unfolded.
- Although, controllers did report that they would use such AROT predictions to try and prevent any predicted AROT increases from occurring, for example by stating the procedural runway exit the aircraft is required to take when communicating with the pilot or requesting pilots to expedite the runway.
- Pilots may also like to have the information given to them by the controllers for example, one controller stated that pilots would like to know in advance if a preceding aircraft is staying longer on the runway and exiting further down the runway. (This feedback from the controllers is based on a real life incident in

operations as a pilot was complaining that the controllers gave such information too late when the follower was on the final approach and 1 or 2NM from the runway threshold).

B. Operational feasibility and acceptability of the ML RU controller support tool

- The ML RU controller support tool was considered operationally feasible and acceptable to the Vienna controllers that took part in the V1 simulation.
- The predicted information regarding AROT if automatically presented to the controllers as an information alert was seen as being “very valuable” as it would “draw the controllers attention to a potential situation” that may impact operations. This would help to enhance the tower runway controllers’ situation awareness relating to potential runway incursions, and therefore have potential safety benefits.
- However, the controllers stated that as the predicted information was not 100% reliable they would use the information presented to check and monitor a situation more closely. Controllers reported that they may use the information to issue instructions such as reminding the pilot to take the procedural runway exit or expedite the runway, or wait a little longer before giving a landing clearance in order to help mitigate any potential increase in AROT. However, the controllers said they would not act on the predictive information in terms of issuing a go-around (for an arrival aircraft following the concerned arrival) or giving a line-up clearance (to a departing aircraft following the concerned arrival).
- The controllers reported that the additional information based on ML predictions would not have any impact on their workload.
- The controllers did not feel the RU information based on ML predictions could be used as a means to increase runway throughput capacity.
- Although ML predictions could potentially optimise runway operations under certain circumstances. For example, in mixed mode runway operations if the leading arrival aircraft was taking an earlier exit the runway would be free earlier, therefore AROT would be reduced and perhaps a departure would be possible.
- When questioned, if the first aircraft was predicted to exit the runway early and the second aircraft was at 4.5NM would the controllers tell the second aircraft to maintain speed and reduce as late as possible (‘keep speed as long as possible’) to allow for additional space for a departure in between the second and third aircraft on final. The controllers responded that they would not do this based on predictive information. As stated previously, the controllers would use the alert as information only and would wait and observe the aircraft to see if it vacates earlier or not as there could be potential safety impact of over-relying and acting

on the predictive information based on ML in such a situation.

- Both controllers proposed that the predicted AROT determined by ML could be used to further optimise runway throughput operations by integrating the predicted AROT into the Optimised Runway Delivery (ORD) tool (AO-0328) developed within SESAR 2020 PJ02-01. In such an ‘advanced’ solution the AROT determined by the ML could be fed into the ORD tool to update the final target distance (FTD) chevron when lead aircraft is at 1.5NM - 2NM from the runway threshold. In this way, if AROT was the constraining factor between two arriving aircraft on the final approach any changes to the AROT based on ML prediction could be directly displayed to the controller via the FTD and the spacing between the aircraft pair optimised for the AROT constraint.
- The level of reliability/accuracy of the predicted information by ML that is acceptable to controllers needs to be determined to ensure that controllers can build adequate trust in the alert/ controller support tool and there are not too many false alerts.

C. Controller information requirements for a ML RU support tool

- The important information for the tower controllers is not the Nrex but the AROT. Therefore, the controllers do not need to know the predicted RWY exit but the predicted AROT or ideally the consequences of a change in AROT, especially if that consequence could have a negative impact on operations.
- Controllers require an automatic pop-up information alert showing that there may be an issue. Controllers do not want to “seek” for the information as implanted in the initial prototype (i.e. place mouse on the aircraft label to find the information); this is cumbersome and may lead to controllers missing the predicted information updates that could impact operations: One of the controllers stated that “constantly checking the Nrex by hovering the mouse on the aircraft label and then looking at the arrows displayed on the runway in the ASMGCS display took their attention awareness from checking what was happening the air on the final approach”.
- Controllers do not need to have an information alert presented if there is no potential negative impact on operations, for example, if the AROT is predicted to be less than expected as an aircraft takes an earlier non-procedural exit, an alert would not be needed.
- Therefore, an information alerts should be displayed only if there is a potentially negative situation predicted: For example with consecutive arrivals, if the time to threshold of the follower aircraft is smaller than the predicted AROT with a buffer of the lead aircraft or, in mixed mode operations if there is not enough room for the planned consecutive departure.

- If an alert is displayed the concerned aircraft (lead and follower) will need to be highlighted to ensure the controllers react to the correct aircraft.
- Updated predictions regarding Nrex are considered to be a ‘nice to have’ but not essential. The format the arrow indicating the runway exit on the HMI as assessed in the RTS are OK and easy to interpret. Therefore, Nrex predictions could be a selectable option for controllers.
- Controllers do not need to know the level of reliability/accuracy of the predicted information presented on the CWP HMI. (Therefore, the colour of the arrow indicating the reliability/accuracy of the predicted information, as implemented in the RTS, is not needed).
- The information should only be displayed when the reliability of the prediction is above a defined value (e.g. 80% as defined in the RTS was seen as sufficient but the exact value of reliability that is acceptable to controllers needs to be determined to ensure that controllers can build adequate trust in the alert/controller support tool and there are not too many false alerts).
- If implemented the alert should take into account whether there is a follower or not (arrival or departure), an alert would not be needed if there is no follower close to the lead that will have a prolonged AROT.
- Controllers reported that update to information based on ML predictions is required at latest when the follower aircraft is at 4NM, (i.e. lead aircraft at 1.5NM to 2NM from the runway threshold); this gives the controller time to react if necessary on the follower aircraft under both segregated and mixed mode runway operations. At 1-2NM you can also instruct the lead aircraft to expedite the runway and remind them to take the procedural exit, whereas, if you get this updated prediction on the lead aircraft when it is at the runway threshold it is too late. In the RTS when the Nrex was updated with predicted information at the runway threshold, this was considered to be too late for the controllers to react – both on the follower and lead aircraft. However, the Nrex updated prediction when the lead aircraft was at 2NM was considered OK even if the reliability of the prediction was slightly less (approx. 6% less in terms of reliability).
- In mixed mode runway operations the tower runway controllers need a tool that provides the sequence (EFS, AMAN-DMAN or a sequence management/gap spacing tool such as that developed in PJ02-01 for mixed mode runway operations). It was suggested that the updated AROT prediction should be incorporated into the sequence tool and help controller determine

whether or not there is a potential problem for the follower aircraft (arrival or departure) or a potential benefit (in the case of a departures following an arrival). This tool would be displayed in addition to the information alert.

- The controllers also suggested that the information alert should disappear on acknowledgement by the controller. If the potential separation infringement continues and runway incursion is likely, the RIMCAS can then be displayed.
- Both controllers proposed that an ‘advanced’ solution could be developed where the predicted AROT is integrated into the ORD tool (AO-0328) developed within SESAR 2020 PJ02-01. As mentioned previously in such an ‘advanced’ solution, the AROT determined by the ML could be fed into the ORD tool to update the FTD chevron when lead aircraft is at 1.5NM - 2NM from the runway threshold.

V. CONCLUSIONS AND RECOMMENDATIONS FROM THE RTS

- The controllers concluded that certain predicted information based on ML, such as AROT, could be used to support operations and controllers work by enhancing controllers’ situation awareness and hence provide potential safety benefits. ML predictions of Nrex were not considered to be needed by controllers to support their work but one of the controllers stated it would be a ‘nice to have option’. The operational needs and high level requirements for such a tool in operations are further detailed during a V2³ validation exercise.
- Therefore, based on the findings from the V1 validation activity we can conclude that the V1 maturity has been completed, as the ML RU tool was reported to meet controllers’ operational needs and provide some safety benefits.
- ML RU controller support tool for AROT was considered operationally feasible and acceptable to the Vienna controllers that took part in the simulation. Predicted Nrex information based on ML was also considered to be operationally feasible and acceptable by one of the Vienna controllers but was seen as something that would be a ‘nice to have’ option.
- Therefore, the impact of a ML RU controller support tool on controllers work and runway operations needs to be further investigated in the following V2 validation activities. Potential benefits and impacts relating to the ML RU controller support tool that need to be investigated further in the V2 validation activities.
- Three potential solutions were identified for a ML RU controller support tool for AROT predictions and proposed for further investigation in V2:

³ V2 develops and explores the individual concept elements and supporting enablers until the retained concepts can be considered operationally feasible.

- o A **simple solution** for segregated runway modes only. This solution would consist of an automatic pop-up information alert when there may be a potential issue e.g. the AROT of the preceding aircraft is greater than the average due to, for example, a non-procedural runway exit further up the runway.
- o An **intermediate solution** for mixed mode runway operations. This solution would consist of an automatic pop-up information alert as defined in the simple solution above **plus** the predicted AROT. Mixed mode runway operations would also require a sequence list of the arrivals and departures. The aircraft sequence of arrivals and departures with the ML predicted AROT could be presented in the EFS or AMAN-DMAN tool. Ideally the sequence list with the ML predicted AROT would be implemented as a decision aid (as done in SESAR 2020 PJ02-01) which could inform the controllers whether or not there is enough space between two arriving aircraft to allow for a departure.
- o An **advanced solution**. The advanced solution would consist of the predicted AROT determined by the ML being integrated into the ORD tool developed within SESAR 2020 PJ02-01 (AO-028). In an advanced solution with an ORD tool as developed in SESAR 2020 PJ02-01 input the AROT determined by the ML into the FTD chevron when lead a/c is at 1.5NM - 2NM from the runway threshold.

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