Real Time Simulation (RTS) Test Results

for

Interval Management in the Schiphol TMA

KDC/2014/0055 version v1.0

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Contents

1 Introduction

This document describes the test results for the Phase 2 Real Time Simulation "Interval Management (IM) Operations in the Schiphol TMA", part of the ASAS IM research effort as requested by KDC MT on June 6th, 2013.

1.1 Background

In 2008, the KDC ASAS project investigated the potential benefits of ADS-B based applications for the Schiphol environment. One of the recommendations was to further develop IM Operations at Schiphol including its airborne component termed Flight Deck Interval Management (FIM). IM as an Airborne Spacing application has the capability to mitigate potential runway throughput reductions as a consequence of introducing fixed arrival routes and Continuous Descent Operations (CDO) during daytime and in particular during peak-hours.

In the KDC research agenda [9] the problem statement is as follows:
"There is an urgent call from government and surrounding Schiphol communities to implement Continuous Descent Approaches (CDA) in the upcoming years. Such procedures would be based on partly fixed routes which will be introduced at Schiphol Airport as a result of an agreement between the Dutch regulator and the aeronautical sector ("Alders Advice till 2020"). Continuous Descent Approaches will improve fuel efficiency and environmental aspects, such as noise annoyance and emissions, compared to traditional step-down approaches. However, it is also anticipated that the introduction of CDAs, with a fixed lateral path, will have negative capacity consequences. Reduction of peak-hour capacity will hurt KLM/AF's network operations and will jeopardize Schiphol's future. For the Dutch aviation sector the introduction of CDAs without mitigating procedures or technology to alleviate the foreseen capacity drop is unacceptable."

In order to introduce CDAs with a high hourly capacity (≥ 34 landings per hour, per runway) additional measures are required. ASAS Interval Management (aka ASAS Sequencing & Merging in SESAR) is regarded, according to the current internationally accepted view, to be the most appropriate to address this shortfall. Initial operational trials have been conducted by United Parcel Services (UPS), in co-operation with the FAA, at Louisville Airport in the USA. More operational trials are under way at Philadelphia / US Airways and New York / JetBlue.

The KDC project "Interval Management in the Schiphol TMA" aims to further develop the IM Operation and associated procedures and systems, and in particular aims to demonstrate feasibility and validity of an IM concept of operation for the specific operational and environmental conditions of Schiphol.

In principle, an IM Operation has to be validated for each local situation given its specific airspace structure, approach and departure routes, procedures and demand and mix of air traffic. The Schiphol case is unique in the sense that research and development of CDOs in combination with IM has been carried out for large Terminal Manoeuvring Areas only (e.g. Dallas-Fort Worth). In order to support a strategic investment decision and because it concerns CDO procedures where aircraft fly near their performance limits (descending flight paths at near-idle thrust that limits the ability to decelerate), it is of importance to perform tests and evaluations with a very realistic character (e.g. simulations with a sufficient high fidelity).

1.2 Project objectives

The objectives of the project "ASAS Interval Management (ASAS IM)" are formulated hereafter. It should be noted that this version of the document concerns the second phase of the project (see red rectangle below). The first phase has been successfully completed [7], [8] and is one of the main building blocks of this second phase. Next project phases, as described below at a high level, will be detailed in a later stage and will take into account the results of preceding phases.

Concept Feasibility - Performance aspects (phase 1):

1. The objective of the first phase was to demonstrate the feasibility of the IM concept with respect to *performance* aspects and in particular for the specific operational and environmental conditions at Schiphol. Does IM indeed deliver the expected performance to

achieve the desired peak-hour capacity at Schiphol given a fixed route structure within the TMA and continuous descent approaches?

2. The local Operational Performance Assessment (OPA) to demonstrate this part of the concept feasibility consisted of three steps.

- To define the IM Operational Service and Environment Description for Schiphol;
- To define the required IM performance level notably aimed at operations in the Schiphol TMA and its environmental conditions;
- To actually perform the Operational Performance Assessment for the Schiphol TMA.

Concept Feasibility – Operational aspects: **phase 2**

3. The objective of the second phase is to develop and validate working procedures and support tools and to assess controller workload and acceptance.

4. The real-time simulation to validate and assess these operational aspects will consist of three main steps:

- To define IM working procedures and controller support tools;
- To develop and implement controller support tools;
- To prepare and execute a real-time simulation.

Concept Validation – Operational, performance and interoperability aspects (phase 3):

5. The objective of the third phase is to demonstrate technical feasibility of IM flight deck-based tools and to validate the IM concept in the operational environment of Schiphol.

6. The first small-scale operational trial to overall test and evaluate operational, technical, performance and interoperability aspects will consist of two main areas:

- To develop and install the FIM Equipment in a limited number of aircraft;
- To prepare and execute a first operational trial at Schiphol.

Concept Validation – Operational, performance and interoperability aspects (phase 4):

7. The objective of the fourth phase is to demonstrate technical feasibility of IM controller support tools and to validate these support tools in the operational environment of Schiphol.

8. The second small-scale operational trial to test and evaluate operational, technical, performance and interoperability aspects in its entirety will consist of two steps:

- To develop and install IM-related controller support tools, and
- To prepare and execute a second operational trial at Schiphol.

1.3 Document summary

This paragraph is meant to describe the main structure of this document. The first chapter introduces the project and its objectives. Chapter 2 describes the Concept of Operation of ASAS Interval Management at Amsterdam Airport Schiphol along with the result of the previous phase. In Chapter 3 the experiment design for the RTS study is described, followed by the Metrics and Analysis approach in chapter 4. Chapter 5 provides the schedule used during the experiment. Chapter 6 discusses the results of the RTS study and finally chapter 7 provides the conclusions and recommendations.

2 Interval Managament (IM) for Schiphol

2.1 IM Concept of Operations

For Schiphol, IM Operations start with Amsterdam Area Control (ACC) using an Arrival Manager (AMAN) or other means to build up a properly spaced sequence of aircraft to the designated runway. From this planned sequence, aircraft pairs can be determined. Each pair consists of an IM aircraft and a Target aircraft. The Target aircraft may initially be on a different route. ATC furthermore needs to assure that both aircraft arrive at their IAFs in time in order to be able to adhere to the fixed arrival routes and to start IM Operations. For that ATC uses the Speed And Route Advisor (SARA) tool. This tool helps ACC to deliver the aircraft on their designated Initial Approach Fixes (IAF) at the appointed time with a tolerance of +/-30 sec around the planned schedule time.

Prior to entering the TMA, the IM aircraft will receive an IM Clearance. For that ATC determines the IM Clearance parameters and assesses these to ensure that applicability parameters are met. The IM Clearance, which will be communicated over voice radio R/T, includes amongst others the aircraft to follow (Target Aircraft ID), the spacing requirement (Assigned Spacing Goal) and the Intended Flight Path Information of the Target aircraft. The Achieve-by Point is the Final Approach Point (FAP); Planned Termination Point is co-located with the Achieve-by Point. The IM tolerance of approximately 10 seconds is fixed and not communicated over voice R/T.

Upon reception of the IM Clearance, the flight crew acknowledges reception and enters the instruction into the FIM Equipment. The FIM Equipment checks the input to see if the data of both the Target and IM aircraft is of sufficient quantity and quality for IM Operation. When it determines that all execution requirements are met, an initial IM speed is calculated and displayed in the cockpit. The flight crew now determines if this speed is feasible and stays within any applicable regulatory and/or performance limits and assesses the overall feasibility of the IM instruction. When this assessment is successful the crew notifies ATC that the IM clearance is accepted and IM Operations have been initiated.

The flight crew now executes the IM Operation, either by manually inputting IM speeds to the auto flight system or by activating the automatic execution of the IM speeds. The auto thrust system adjusts the throttles to adhere to the commanded speed. During the IM Operation both the flight crew and the FIM Equipment will monitor the conformance with the IM Clearance. The flight crew may terminate the IM Operation at any time if out of conformance or unfeasible IM speeds are observed. If this occurs ATC is notified. ATC in the meantime monitors the progression of both flights. When separation and/or spacing issues are identified ATC determines whether to intervene. In some instances tactical adjustments to the Target aircraft may resolve the problem without impacting the IM aircraft. However modifications to the target aircraft's path or speed will cause the IM aircraft to react by changing speeds. In other instances ATC will suspend the IM Clearance so that it can be amended or ATC terminates it altogether.

Upon reaching the Planned Termination Point, the FIM Equipment will notify the flight crew of termination and removes the IM speed from the cockpit displays. The flight crew is now instructed to fly speeds in accordance with normal operational procedures, resulting in stabilized approach conditions at 1000 ft AGL.

A full description of the ConOps is provided in the Operational Service and Environment Definition (OSED) document [7], which describes the services, intended functions and associated procedures of the Schiphol IM Operation, along with the assumptions about the environment in which the application is specified to operate. In this document argumentation is provided for the choices made with respect to the IM concept elements for Schiphol.

2.2 Results of preceding research

Phase 1 addressed the performance aspects of the IM Operation at Schiphol. For that an IM Operational Service and Environment Description was developed, described in:

“Operational Services and Environment Definition - ASAS Interval Management” KDC/2011/0024. version 1.2, Knowledge and Development Centre Mainport Schiphol, March 2011. [7]

Based on the defined concept and environment conditions, IM performance levels were determined aimed at the specific operations in the Schiphol TMA. To assess whether the required performance could be achieved a batch simulation study was performed. The results of this analysis are provided in:

“Operational Performance Assessment for ASAS Interval Management in the Schiphol TMA”, KDC/2012/0069, version 1.0, Knowledge and Development Centre Mainport Schiphol, November 2012. [8]

The main results of the batch study indicated:

- The IM-concept works for the scenarios with an initial metering error of <= 30 sec;
- The timing accuracy as aimed for by SARA (~30 sec) is therefore sufficient for implementing IM-operations, but higher levels will improve the robustness of the system;
- Scenarios with an initial metering error of 60 sec can result in Loss of Separation further down the route, when Loss of Separation is defined as no closer than 3 Nm; It should be noted that the spacing performance at the Achieve-by Point was good in these scenarios, despite the temporary loss of separation.
- The IM-concept works for the current level of navigation performance RNAV-1, introduction of higher precision will improve the robustness of the system;
- Wind prediction error has a large influence on the spacing performance;
- Having trajectories with opposite wind effect amplifies the effect of wind prediction errors;
- Direct coupling of the IM Speeds through an auto thrust system greatly improves performance over manual MCP/FCU speed selections of the IM Speeds;
- The ability to use speed-brakes as a control method greatly improves performance; and
- A more complex route structure (4 vs. 2 IAFs feeding a single runway) reduces the overall performance as wind prediction errors of opposite trajectories are amplified.

Secondary conclusions:

- The use of RF-legs makes implementation easier, but it is possible to work with fly-by waypoints;
- Navigation performance I does not greatly influence the IM delivery accuracy performance, but it does cause large control space usage (i.e. more and larger speed change commands);
- Timing accuracy over IAF (CTA) does not greatly influence the IM-performance, but it does cause large control space usage;
- The speed difference between IM and Target Aircraft when crossing the ABP can be significant. The FIM Equipment should ensure that the IM Aircraft speed at the ABP is similar to the speed the Target Aircraft had at the ABP; and
- The IM speeds commanded by the spacing algorithm sometimes result in a flap retraction. The FIM Equipment should limit the IM speeds to prevent flap retractions.

3 Experiment Design

3.1 Research objectives

The objective of the RTS-study is to develop and validate working procedures and support tools; and to assess controller workload and acceptance. Results are determined through objective and subjective data analysis.

The primary goals are:
- to evaluate the presented IM concept;
- to evaluate controller working procedures;
- to evaluate controller support tools that support IM and non-IM aircraft; and
- to assess controller workload and acceptance.

For the working procedures the goal is to check whether they are correct, acceptable, clear, complete, and unambiguous.

Procedures to be thought of (amongst others) are:
- IM set-up, initiation (including target aircraft selection), execution and termination
- Integrating non-FIM equipped aircraft
- Some non-normals

The support tool variants will differ in the amount, or way of visualisation, of information presented to support the controller during the IM Operation.

Secondary goal:
- To evaluate IM performance in a real-time environment with humans in the loop (e.g., arrival spacing accuracy, number and duration of communications, pseudo-pilot feedback, arrival route conformance, IM success rate, schedule conformance and throughput).

3.2 Basic principles

Starting points for the proposed activities are:

1. To realize CDOs during daytime operations a number of measures are foreseen: fixed RNAV arrival routes from the Initial Approach Fix (IAF) to the runway threshold, the controller support tool SARA to deliver a stable and sufficiently spaced sequence at the IAFs and Interval Management techniques to retain runway throughput. The use of fixed RNAV arrival routes and SARA are therefore starting points for this study.
2. A phased introduction of FIM capability in the Schiphol fleet. Therefore, the study also has to take into account a transition phase where a part of the aircraft arriving at Schiphol are FIM equipped.
3. Confidence in IM Operations for both controllers and pilots has to be created. Stepwise developments are the cornerstone of this study; its purpose is to create building blocks that will ultimately form a coherent ensemble. These steps are necessary to develop confidence in IM within the controller and pilot community.

The KDC IM Concept of Operations [7] as delivered in the first phase of this project is leading. It should however be noted that it is a ‘living’ document in which lessons learned will be incorporated. The most important concept elements are described hereafter (Table 1).

Table 1: Selected IM concept elements

Concept element	Selected option
Target aircraft	Single target operations
First IM execution moment	Near Initial Approach Fix (IAF)
Target aircraft route prior to merge point	Segmented route to merge point
IM Clearance type	IM Achieve-by
Assigned spacing goal type	Time-based

Assigned spacing goal value	Pair-wise assigned spacing goal Determined on the ground
Achieve-by Point	Final Approach Point (FAP)
Planned Termination Point	Co-located with the Achieve-by Point
Passing the IM instruction to the flight crew	Radio-Telephony (R/T)
IM Speed implementation	Flight crew manually inputs IM Speeds
IM algorithm	Trajectory-based (i.e., time-to-go) algorithm
Start of CDO	At IAF Note: this only applies to IM Operations; the overall goal is to start CDO at Top-of-Descent.
CDO altitude profile	At or above constraints and/or altitude window constraints at waypoints
CDO speed profile	Nominal speed profile with +/-10% control margins
Horizontal separation minima	Current distance-based criteria (3/4/5 NM)
CTA accuracy of delivering aircraft (at the IAF)	+/- 30 seconds (99%) – SARA
TMA route structure	Fixed arrival routes, consisting of segmented routes between IAF and FAP/Runway
PBN regime in Schiphol TMA	RNAV-1, Fly-by turns, no RF legs
Surveillance regime in Schiphol TMA	Radar
ADS-B Surveillance	100% ADS-B OUT equipage, range ~90Nm
Meteo environment	Boeing Winds Service or similar
Ground IM automation	Tools to support the controllers in initiating, monitoring and, if necessary, terminating IM Operations

3.3 Scope

The scope of the RTS experiment is limited to that what can be achieved within the time and budget constraints:

- TMA operations only; all operations are in principle closed-path 2° CDO;
- High arrival demand (up to 35-36 arrivals to a single runway);
- Two sector operations. Sector West: service SUGOL and ARTIP to runway 06. Sector East: service RIVER and RINSI to runway 36R;
- Use West configuration (RWY06) to investigate CDO/IM Operations independent of known issues surrounding parallel runway operation. To avoid the need for an additional controller, traffic in the East configuration is scripted;
- No ACC and TWR controller involvement; one APP controller - performing both the FDR/DCO and ARR roles;
- Inbound traffic towards the IAF will be scripted to represent an organized flow that is sequenced and arrives within +/- 30 sec (99%) of their assigned time, i.e. Expected Approach Time (EAT);
- Departing traffic RWY 36L (scripted);
- Voice R/T only, no CPDLC;
- No cockpit simulation; IM Speed selection will be automated with input delay variance;
- Non-normal events; and
- Inclusion of SUSPEND/RESUME operations (available for use).

3.4 Research Questions and Hypothesis

Five research questions and associated hypotheses are defined:

RQ 1: Are the IM working procedures for the controllers correct, acceptable, clear, complete, and unambiguous?

H 1. *“Controllers will find the IM working procedures acceptable, but they will find the procedures using R/T challenging and will prefer an IM clearance delivery in two steps.”*

RQ 2: What is the minimum required and what is the preferred controller support for IM?
H 2. *“Controllers will require controller spacing tools for all levels of FIM equipage until they feel confident with the operation”*

RQ 3: Does IM enable the maintaining of an organized flow of CDO traffic inside the TMA?
H 3. *“The CDO success rate will increase with an increase of FIM Equipment and IM Operations.”*

RQ 4: Is controller workload of the simulated CDO/IM Operations acceptable?
H 4. “*The controller workload will decrease with an increase of the level of IM Operations.”*

RQ 5: Is the simulated CDO/IM Operation acceptable to controllers?
H 5. “*CDO/IM Operations is acceptable to controllers, though they will find the IM clearance phraseology and mixed equipage operations challenging, and require confidence building” (5% equipped un-acceptable with 35/hr, 50% equipped challenging, 95% equipped acceptable)*

3.5 Validation Questions

In order to prove/disprove a hypothesis and to support the primary goals, the following validation questions have been formulated:

VQ 1. Are the IM procedures (as presented during the experiment) acceptable (correct/timely/order) to the controllers? (H1, H5)
VQ 2. Do the controllers require the Target identification and IM clearance delivery in one or two steps? (H1)
VQ 3. Is the R/T phraseology (as used during the experiment) acceptable (correct/ acceptable/ clear/ complete and unambiguous) to the controllers? (H1, H5)
VQ 4. Is the mental effort required to initiate IM Operations acceptable to the controllers? (H4, H5)
VQ 5. Is the mental effort required to operate a mixed equipage environment acceptable to the controllers? (H4, H5)
VQ 6. Is the mental effort required to terminate IM Operations and revert to normal operations acceptable to the controllers? (H4)
VQ 7. Is the information presented by the provided support tool variants adequate for the IM monitoring task? (H2)
VQ 8. What is the preferred support tool variant according to the controllers? (H2)
VQ 9. What is the minimum required support tool variant according to the controllers? (H2)
VQ 10. Can the controller maintain safe CDO operations in all of the provided support tool variants? (H3)
VQ 11. Will the CDO success rate increase with an increase in the level of FIM Equipment and IM Operations (H3)
VQ 12. Do the controllers have confidence in the controller support tool(s)? (H2, H4, H5)
VQ 13. Do the controllers have confidence in the IM Operation? (H2, H4, H5)
VQ 14. Does CDO/IM Operation acceptability change under different wind conditions? (H5)

Table 2 Overview of Validation Questions with corresponding Hypotheses

Validation Question / Research Hypothesis	VQ 1	VQ 2	VQ 3	VQ 4	VQ 5	VQ 6	VQ 7	VQ 8	VQ 9	VQ 10	VQ 11	VQ 12	VQ 13	VQ 14	Total
RQ1/H1	X	X	X												3
RQ2/H2							X	X	X			X	X		5
RQ3/H3										X	X				2
RQ4/H4				X	X	X						X	X		5
RQ5/H5	X		X	X	X							X	X	X	7

Support questions to support the secondary goal:

SQ 1. Is the arrival spacing accuracy (at the ABP) sufficiently high?

SQ 2. Is the minimum separation not infringed?
SQ 3. Is the success rate of IM Operations sufficiently high?
SQ 4. Is the schedule conformance sufficiently high?
SQ 5. Do the average flight time and distance increase?
SQ 6. Is the route conformance sufficiently high?
SQ 7. Is the operationally-required throughput achievable?
SQ 8. Do the number and duration of communications change?
SQ 9. Do the pseudo-pilots find the presented IM Operation acceptable?

3.6 Independent Variables

The independent variables (variables which are set by the user in order to isolate causality within the operation) are presented in this section and discussed in the subsequent sections. As this RTS experiment is limited in the number of participating subjects, i.e. approach controllers, there will not be a full factorial design.

Ad 1) Controller Tools (two levels)
The APP controller will be presented with two implementations of support tools. In the first implementation only necessary tooling is provided to initiate, execute, monitor and terminate the IM Operations ("need to have"). Prior discussions with controllers have revealed that this must include a merge (ghosting) tool as the scenarios include merging of fixed arrival routes (no vectoring allowed).

The second implementation will add information on the likelihood of success, the trend towards achieving the spacing goal, the current spacing error and advisory speeds for unequipped aircraft.

The goal is to determine whether additional tooling is required and if so which elements are preferred.

Ad 2) FIM equipage (three levels)
FIM equipage levels will vary between an initial start-up level, in which only a small number or aircraft are IM capable, up to a representation in which most aircraft are FIM equipped. The start-up level represents an environment in which IM is introduced and the controller has to manage a few IM aircraft among many non-IM aircraft during times of high demand.

The second level of equipage represents an environment in which the SkyTeam Group made an investment decision to equip their fleet with FIM. This amounts to ~50% of the aircraft being FIM equipped.

The third level represents an environment where most aircraft are FIM equipped and the controller has to manage a few unequipped aircraft among ongoing IM Operations.

Note: All aircraft will be ADS-B OUT equipped and broadcasting position and state.

Ad 3) Wind Fields (two levels)
Previous research has indicated that the spacing performance is dependent on accurate wind prediction. Furthermore trajectories with opposite wind effect amplify the effect of wind prediction errors. As wind plays such a significant factor, the study wants to determine whether the IM Operational acceptability changes under different wind conditions. In order to study the effect of wind, two levels have been defined a benign wind condition and a moderate wind condition. The wind forecast is derived from data 3-hour prior to the actual operation.

3.7 Disturbances

Disturbances are added to the experiment environment to create variety in the operations and increase the level of realism. The disturbances for the RTS experiment include:

- Metering accuracy: Inbound traffic towards their assigned IAF will be scripted to represent an organized flow that is sequenced and arrives within +/- 30 sec (99%) of their assigned time, i.e. Expected Approach Time (EAT).
- Traffic mix: ~12% Heavies, ~2% Boeing 757s, and ~86% Mediums, based on the average traffic mix of the most stringent peak-hour of the 2010 summer period.

- Traffic distribution: the distribution of traffic over the four IAFs will differ between the scenarios
- Pilot performance will vary as a result of variance in the pilot model reaction time, which is used for IM speed selection.
- Non normal events will be included, distributed among the experiment runs:
    1. Incorrect Target Aircraft selection (correct readback) → separation issue;
    2. Incorrect readback of Target Aircraft;
    3. Unable Target Aircraft selection (e.g. out of ADS-B range);
    4. Unable to accept IM Operations (e.g. equipment failure, data quality);
    5. Unable to continue with IM Operations (e.g. equipment failure, data quality, IM speed too low/too high);
    6. Delivery at IAF well outside +/- 30 seconds;
    7. Incorrect spacing (e.g. aircraft flies profile speeds instead of IM speeds → with or without separation issues);
    8. Incorrect spacing (e.g. aircraft follows different spacing goal than the assigned one → with or without separation issues); and
    9. Unable to continue the transition (e.g. RNAV equipment failure).

3.8 Experiment Matrix

The independent variables used in the experiment consist of:

1. Controller tools (two levels)
    i. Basic APP + “need to have” + Merge tool
    ii. Basic APP + “need to have” + Merge tool + Controller Spacing Symbology
2. FIM equipage (three levels)
    i. 5% FIM equipped
    ii. 50% FIM equipped (e.g., SkyTeam Group investment decision)
    iii. 95% FIM equipped
3. Wind field (two levels)
    i. Light wind conditions
    ii. Moderate wind conditions

The matrix follows from the selected independent variables and is shown in Table 3.

Table 3 Experiment Matrix HITL Experiment

FIM Equip. level / **Controller Tools**	5% FIM equipped	50% FIM Equipped	95% FIM Equipped
Basic APP incl merge tool + “need to have”	Light wind Moderate wind	Light wind Moderate wind	Light wind Moderate wind
Basic APP incl merge tool + “need to have” + spacing symbology	Light wind Moderate wind	Light wind Moderate wind	Light wind Moderate wind

Number of cells: 6 (2x3)
Number of wind conditions: 2 (light and moderate)
Total number of experiment runs = 12 (6x2)
The nine non-normal events will be distributed over the twelve experiment runs; a number of experiment runs will not include any non-normal.

APPENDIX B provides a more detailed definition of the training and experiment runs.

3.9 Controller Tool Variants

Two controller tool variants are proposed which are discussed in more detail in this section.

3.9.1 Controller Tool Variant 1: Basic APP + Merge Tool

This variant represents the basic support system for an Approach controller. This includes all required information to determine IM feasibility and information in order to initiate, execute, monitor and terminate IM Operations. These information elements include:

Set-up phase data elements
- Arrival sequence
- Aircraft arrival transitions
- Aircraft equipage levels
- Aircraft positions

Initiation phase data elements
- Target aircraft identifier
- Target's intended flight path information
- Assigned spacing goal
- Achieve-by Point
- IM status indicator

Execution phase data elements
- IM status indicator

Termination phase data elements
- IM status indicator

Suspend phase data elements
- IM status indicator

Mapping of essential data elements on the HMI

The working position of an APP controller is shown below, both as photograph and diagram.

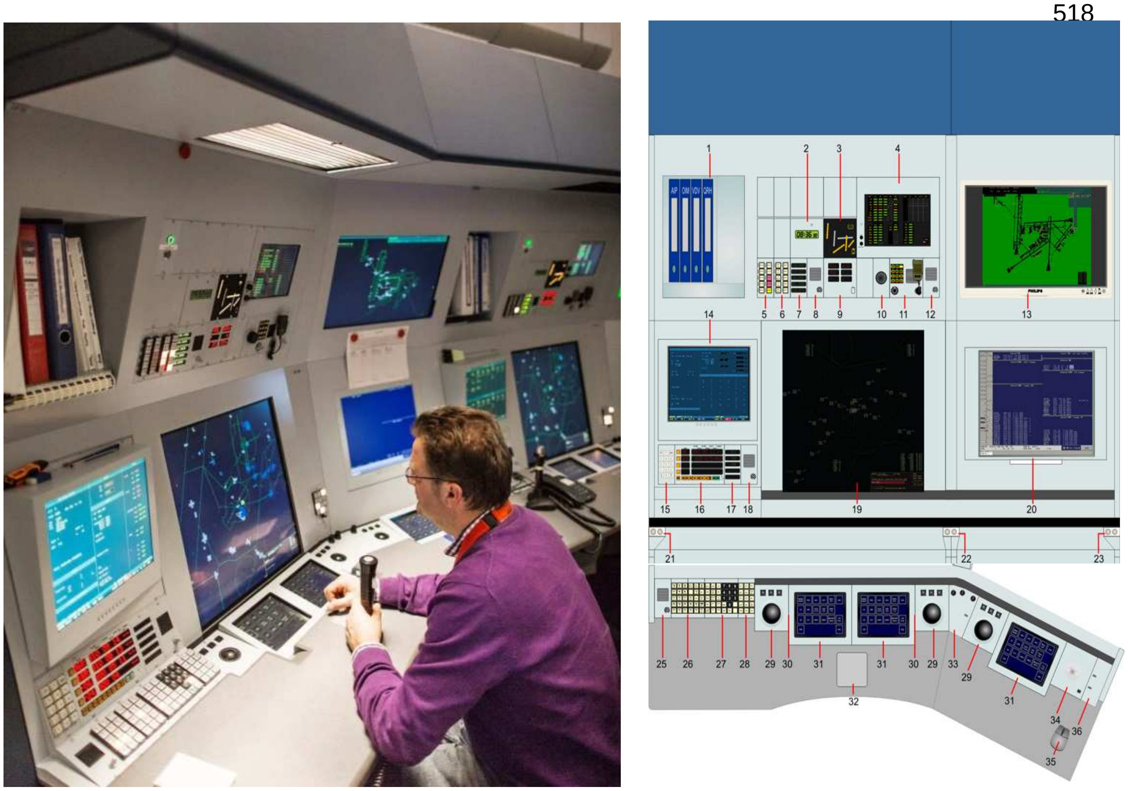

Figure 1: APP controller working position

IM data elements are integrated in: the radar display (19), the electronic data display (EDD, 20) and the touch input devices (TIDs, 31). The merge tool is integrated in the radar display (19).

Radar display

The radar display shows the *aircraft position* of all flights, which is identified as one of the necessary IM data elements. As aid for the controller the fixed RNAV arrival routes in the TMA can be displayed on the radar display. This option can be switched on and off by the individual controller.

Track labels on the radar display typically contain in the first line the aircraft identification; in the second line mode C and instructed flight level; in the third line aircraft type and arrival transition (*the intended flight path information*), SID or heading; and in the last line ground speed, WTC (if not medium) and instructed speed.

The optional third field on the second line displays the pilot selected altitude (from enhanced mode S), but only if this does not conform to the instructed level.

Figure 2. Typical track label.

The track label field for instructed speed will also be used as *IM status indicator*. Currently this field shows the instructed speed or the characters ‘SPD’ if no speed has been instructed.

During the IM set-up phase the field will indicate if all conditions with regard to equipment, positions and routes for IM Operation have been met. The characters ‘SPD#’ are used to indicate this situation to the controller.

During the execution phase the field shall show ‘IM’ to indicate that the speed is the flight’s responsibility controlled by the agreed spacing goal. On passing the Achieve-by Point ‘IM’ will automatically be removed from the track label. Also, controller inputs like SPD will terminate an IM Operation and update the label with the instructed speed.

Figure 3. Track labels showing aircraft eligible for IM-operations (SPD#, left) and aircraft engaged in IM-operation (IM, right).

The radar display also contains an Interaction Area, located in the bottom right hand corner of the screen. This area consists of: an on-request line (1), Mode S-block (2), status block (3), clock (4), message area (5) and input templates (6).

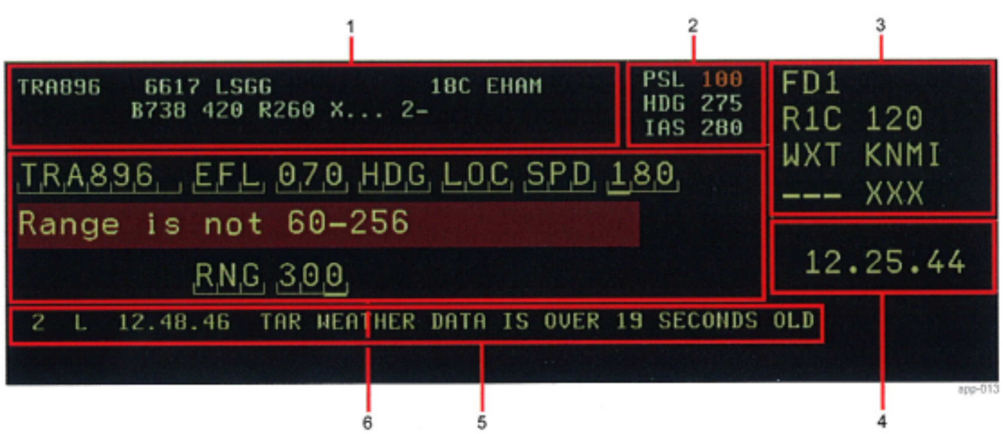

Figure 4. On-request line, displayed in the lower right corner of the plan view display.

The on-request line (ORL) shows information of the flight selected on the radar display. The first line of the ORL contains: aircraft identifier, SSR-code, departure aerodrome and runway, *arrival transition* or SID, arrival runway and aerodrome; while the second line contains items like aircraft type, TAS, RFL, XFL and entry - exit sector numbers.

A third line is added to the on-request line to present the active or suggested IM *target identifier*, the arrival transition *(intended flight path)* of the target and the *spacing goal*. The format used is '[#]IM <call sign> <arrival route> <interval>; the '#' is not shown during the execution phase. For example '#IM KLM1094 S2X 96' indicates the suggested spacing instruction to cross the relevant waypoint of the flight's arrival route 96 seconds after the KLM1094 who is on the SUGOL2X (S2X) arrival route. In the illustrated example below the selected flight, KLM1830, is on the ARTIP2X (A2X) arrival route.

Figure 5. Active / suggested target identifier and target spacing goal.

During IM execution this spacing goal is displayed as 'IM KLM1094 S2X 96'.

The Mode S-block is located immediately to the right of the ORL and displays enhanced Mode S data of the selected flight: pilot selected level (PSL), heading (HDG) and indicated air speed (IAS).

Figure 6. Mode S-block.

The pilot selected level is displayed in orange if it does not conform to the instructed level.

Electronic Data Display

The illustration below shows the original EDD of a FDR/DCO controller. The layout is slightly different for an ARR controller. The second illustration shows a single flight strip of the display in more detail.

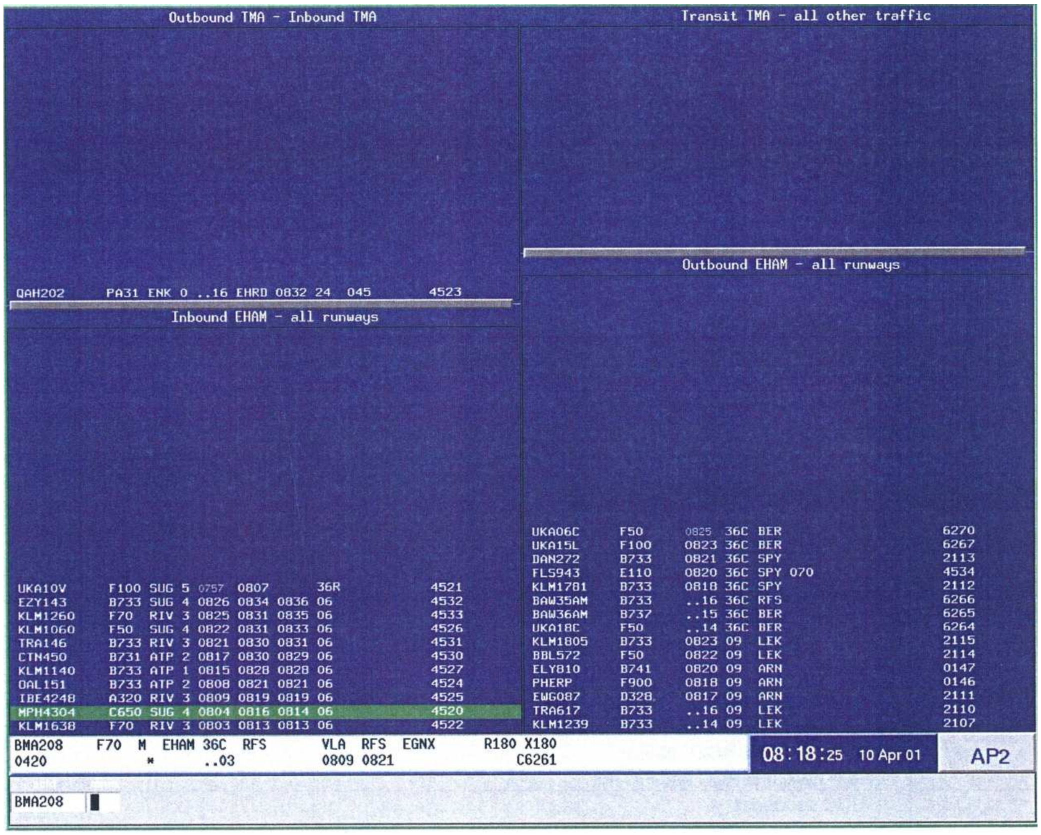

Figure 7. Electronic Data Display showing the different sequence lists.

Figure 8. Close-up of one line on the EDD, showing callsign, aircraft type, IAF, entry sector, ETA over IAF, ETA at the runway, STA by AMAN, runway number, gate and SSR-code.

The EDD consists of four flight strip areas (inbound EHAM, outbound EHAM, TMA inbound/outbound and TMA transit). In each flight strip area flights are sorted by allocated runway, and additionally on calculated landing slot.

The flight strip for an inbound flight shown above displays: the flight identification, aircraft type, *arrival transition* (or IAF), entry sector number, expected time at the IAF, ETA, landing time determined by AMAN, runway, gate and SSR-code.

The EDD also contains an on-request line, displaying information of the flight selected in the EDD. In the figure field 9 is reserved for the arrival transition (for inbounds) or exit COP (for outbound flights).

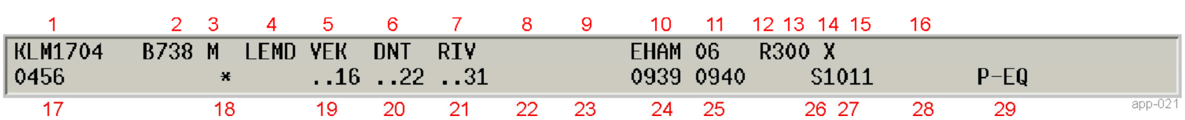

Figure 9. On-request line on the EDD.

The on-request line of the EDD is extended with *FIM equipage level* information. Field 29 is currently used for the status of RNAV equipment (either R-EQ, R-NO or R-UN). Field 30 is added to be used to display the FIM equipage level of the selected flight (either 'IM-EQ', 'IM-NO' or 'IM-UN').

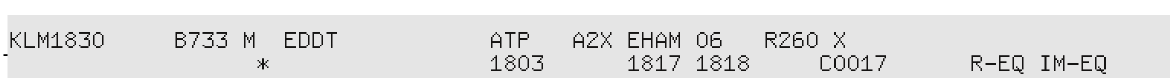

Figure 10. ORL augmented with IM-equipment status information.

Also available on the EDD are the IM data elements *Arrival sequence* and *Aircraft arrival transitions*. The transitions are shown in field 9 of the flight strip, which contains the transition, stack RP, TMA entry point or ADEP for inbound EHAM flights.

Touch input display

Inputs to the radar display are made using two touch input displays, while inputs to the EDD are made on a third TID. Shown below is the main menu page of the radar display TID for flight related inputs.

Figure 11. Touch input device layout. The main menu has an additional IM-button.

Support for the IM clearance input is implemented by adding a button labelled ‘IM’ on a free location in the main menu.

An example of the layout for the IM menu page is given below on the left; the actual menu contents depend on the selected flight and are dynamically created when the menu is opened. The layout is based on the assumption that a reminder of the *Achieve-by Point* of the IM Clearance is not required as the controller will be familiar with the correct points. If the selected flight is eligible for interval management the button in the top left corner of the menu will show the suggested target aircraft identifier and the suggested spacing goal. Pressing this button, followed by the “EXQ”-button (or only the latter button) will complete the IM input.

The IM menu also allows the input of alternative spacing instructions at controller discretion, cancellation of an active IM Operation and suspend or resume inputs for IM Operations.

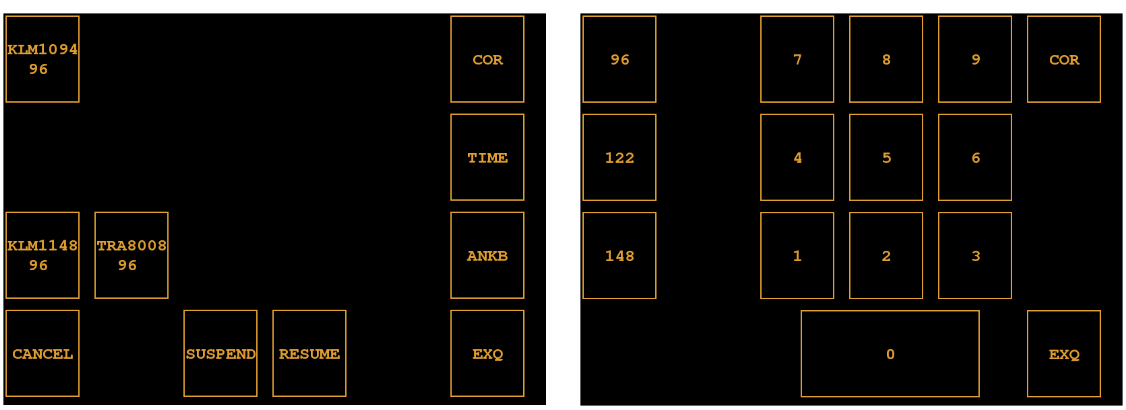

Figure 12. TID IM-sub-menus. Left shows the most logical target for IM-operations, followed by the second and third target posibilities, along with suspend and resume buttons. The right submenu shows the three standard time intervals.

Up to four alternative IM instructions (with target identifier and spacing goal) can be shown on the third line of the TID. Additionally the controller can use the “TIME” button to select other spacing goals from a menu shown above to the right.

The button labelled with ‘ANKB’ in the IM menu opens an alphanumerical keyboard to input a target identifier in case the desired flight is not shown in the IM menu. The controller also has to enter the spacing goal in such cases.

Merge tool

Controllers have indicated that a concept involving the merge of two fixed arrival routes on a single runway requires support, by, for example, a system tool.

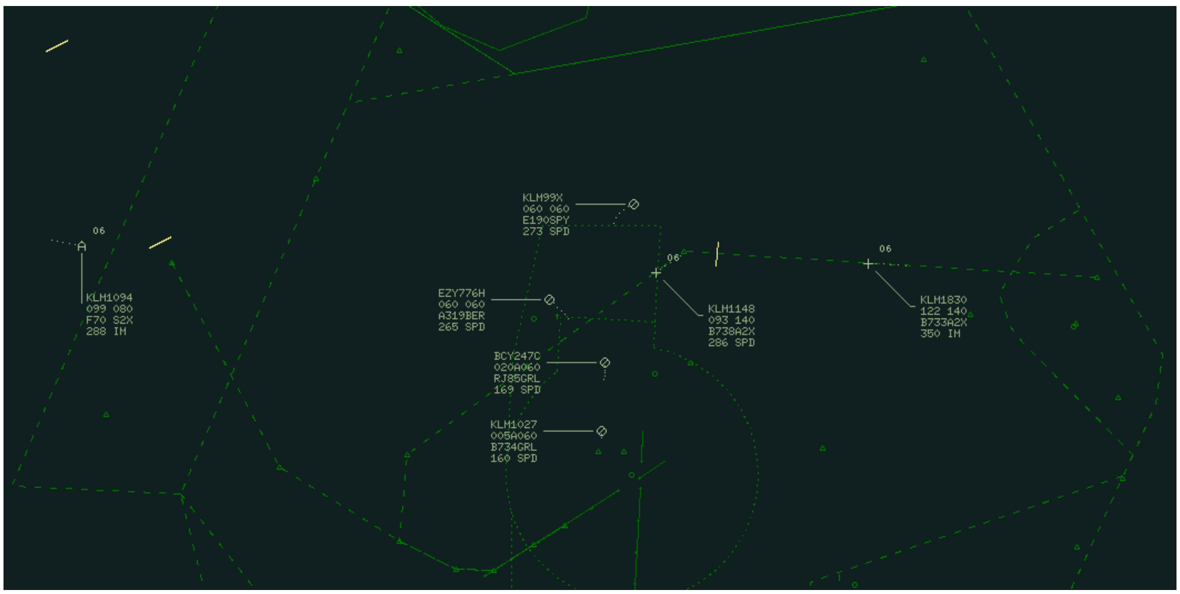

Figure 13. Merge tool display.

The merge tool provided by the system shows markers (also called ‘ghost’ plots) in the shape of yellow lines perpendicular to the corresponding segment of the arrival transition on which the marker is displayed. The ghost plot’s position is calculated using a distance based projection. Flights for one arrival transition are displayed on the other arrival transition for the same runway and vice versa. In the example above, ghosts of the KLM1148 and KLM1830 are displayed on the (extended) SUGOL2X arrival transition, while the ghost of the KLM1094 is displayed on the ARTIP2X arrival transition (behind the KLM1148).

3.9.2 Controller Tool Variant 2: Additional Controller Spacing Symbology

Additional data elements described in the test plan are:

- Indication of probability of success (“conformance zone”)
- Spacing marker (desired nominal position)
- Early/late indication (or Goal/Predicted spacing, and/or speed advice for non-IM)
- Wake vortex zone indication (of target aircraft)

Mapping of additional data elements on the HMI.

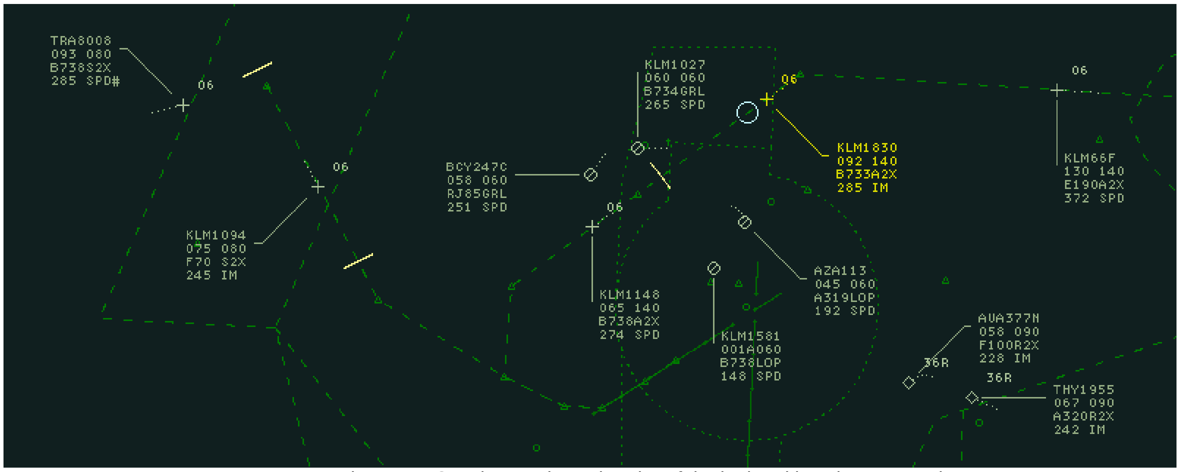

Figure 14: Spacing marker. The aircraft is depicted in a 'late' scenario

Spacing marker

The spacing marker is depicted as a solid circle, see Figure 14. The spacing marker indicates where the aircraft should have been, if it were to fly the arrival using the nominal speed profile through the forecasted wind field. An aircraft flying in the middle of its spacing marker will achieve the required in-trail spacing at the Achieve-by Point when it continues flying the nominal speed profile given a perfect wind forecast.
The radius of the circle is determined by the nominal ground speed at the location of the Spacing Marker multiplied by the IM Tolerance (=10 sec).

Conformance zone

The conformance zone provides an indication of the probability of successful completion of the IM-operation. A dashed circle depicts the area from which a 95% confidence level that the spacing will be met within IM tolerance at the Achieve-by Point (see Figure 14). Consequently, an aircraft flying outside its conformance zone needs to suspend its IM Operation and the controller will need to issue speed and/or heading instructions to restore the correct spacing. It may even be necessary to take the aircraft out of the sequence completely.

For this display the desired nominal position of the flight, and the distances corresponding to the conformance zone and IM tolerance have to be calculated by the ground system.

After discussions with the air traffic controllers, it was decided not to use the conformance zone indication, as it would clutter up the plan view display too much.

Wake vortex zone indication

The wake vortex zone is depicted as a triangular ‘tail’ behind each aircraft and provides an extra indication of the minimum allowable spacing. The length of the zone depends on the ICAO wake vortex separation minima applicable to the aircraft pair and is only visible when an aircraft is selected as Target for IM Operation.

After discussion with the controllers, however, it was decided that the situation regarding wake vortices is not significantly different from current day operations and that extra wake vortex information is not required.

Early / Late indication and Predicted Spacing Interval

Non-IM aircraft will either fly standard (nominal) speeds, or receive speed instructions. To support the controller, an early/late indication is displayed in the third line of the on-request line (in the right-hand, lower corner of the radar display), see Figure 15, upper. For the IM aircraft, the third line displays the predicted spacing interval at the Achieve-by Point (variant 2 only), as calculated by the ground system, to support the monitoring task of the controller, see Figure 15, lower.

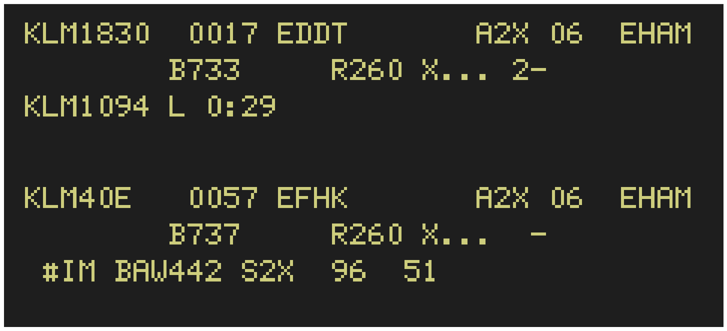

Figure 15. Augmented on-request line of radar display for non-IM and IM aircraft.

3.10 Experiment configuration

3.10.1 NARSIM

NARSIM is the real time ATC simulator developed by NLR. It is a flexible and innovative simulation platform enabling research and development in the field of ATM. The platform allows the simulation of ATC processes with both air traffic controllers and pilots in the loop. The traffic situation displays, other controller working position displays and input devices are configurable and can be adapted to match those in operational use.

NARSIM has been used, since its origin in 1987, for a variety of customers, including the European Commission, Eurocontrol, the European Space Agency (ESA), the German aeronautics and space research centre (DLR) and the air navigation service providers of Luxembourg, Sweden and The Netherlands. It can offer an especially close match to the working environment of the ATM system of both radar and tower controllers of ATC the Netherlands.

The NARSIM platform enables visualisation of new conceptual ideas at a very early stage of the design process. Ideas can be communicated in a clear and unambiguous way and quickly evaluated towards operational feasibility. Involvement of controllers in this way is generally accepted as an aid to foster implementation of, for example, new controller tools.

NARSIM is and has been used to evaluate and validate new ATM technologies, such as airport ground movement guidance control systems (A-SMGCS), Runway Incursion algorithms, Continuous Descent Operations (CDO), Arrival and Departure Management, CPDLC applications, and Human Machine Interface (HMI) prototyping.

The real-time simulations will be run on the NARSIM radar simulation platform. This platform comprises modules that work together to form a complete simulation of an ATC environment. Examples of such modules include Airport, Weather, Radar, Controller working positions, AMAN and TP modules. The simulation consists of one or more controller working positions and one or more pseudo-pilot workstations connected to the different simulation components.

The communication between controller and pseudo-pilot using voice commands uses R/T equipment in the same way as in current-day practice. The controller is presented with a radar screen that closely resembles the operational system. This radar screen is enhanced with essential IM functionality and (during some runs) with additional controller support tools.
The role of the pseudo-pilots is to provide the controller with realistic interaction via R/T and to control the aircraft by providing inputs to the simulator following the instructions of the controllers.

3.10.2 Spacing Algorithm

The spacing algorithm used in this simulation is a trajectory based or Time-To-Go (TTG) algorithm, developed by NASA Langley Research Center (LaRC), called ASTAR (Airborne Spacing for Terminal Arrivals). ASTAR is the latest iteration in a series of TTG spacing algorithm developments and has become the current state-of-the-art.

It calculates based on the route (trajectory) the estimated time of arrival using nominal leg speeds (see 3.11.3.3). Only position on the trajectory is used, Nominal speeds for the trajectory are used to stabilize the arrival flow and prevent large speed excesses. This does however require that all aircraft are able to fly these nominal speeds which may exclude some commuter aircraft.

The inner workings of ASTAR are illustrated in Figure 16 where two aircraft are engaged in IM (called a spacing pair). The Target Aircraft is flying its assigned approach while continuously broadcasting state vector information. The IM Aircraft is coupled to the Target Aircraft and required to achieve an assigned spacing interval, which is illustrated on the y-axis in the Figure. It is emphasized that the Target and IM Aircraft do not need to be on the same trajectory.

$$t_{spacing} = \Delta t + TTG_{lead} \quad (1)$$

$$\varepsilon_{spacing} = TTG_{ownship} - t_{spacing} \quad (2)$$

The position of the Target aircraft broadcast over ADS-B, together with knowledge of the named procedure, allows the IM Aircraft to calculate a Time To Go (TTG) for the Target (TTGtarget) to the Achieve-by Point. With the Target Aircraft TTG and the IM Aircraft TTG, the spacing error ($\varepsilon_{spacing}$) can readily be calculated. The TTG calculations are based on groundspeed / distance. Hence, if wind is non-zero, a wind forecast is required.

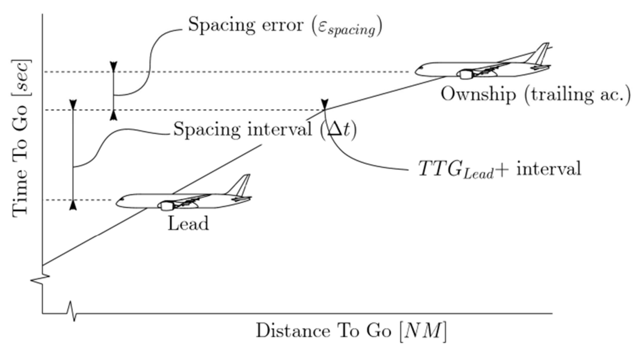

Figure 16: Time To Go spacing algorithm

The algorithm aims to achieve the spacing goal, i.e., reduce spacing error ($\varepsilon_{spacing}$), to zero at the achieve-by-point. The error is minimized by commanding speed deviations from the nominal speed profile to either gain or lose time on the current TTG. This deviation is limited to ±10% of the nominal speed ($V_{nom}^{\pm 10\%}$) to maintain system stability. A temporary increase of the spacing interval is allowed in principle, as long as it does not reduce spacing precision at the achieve-by-point.

3.11 Scenario Design

3.11.1 Traffic Samples

Aircraft are created well outside the TMA and fly towards the IAF such that they cross the IAF properly sequenced and with an initial CTA error, which is normally distributed (μ=0 sec, σ=10 sec).

The total demand is either 60 or 70 arrivals per hour (30 or 35 ac/rwy); the maximum value is based on the currently declared capacity during arrival peaks. The movements are evenly distributed over the 20-minutes blocks.

The traffic mix is ~12% Heavies, ~2% Boeing 757s, and ~86% Mediums, based on the average traffic mix of most stringent peak-hour of the 2010 summer period at Amsterdam Airport Schiphol.

The arrival configuration is from four IAFs (ARTIP, SUGOL, RIVER, and RINSI) to two landing runways. Runway 06 and 36R are the runways-in-use. Operation on RWY 36R is scripted.

The distribution of traffic over the four IAFs varies per sample, see APPENDIX B.

3.11.2 Assigned Spacing Goal

The Assigned Spacing Goal (ASG), to be achieved at the Achieve-by Point (i.e., FAP), is given as a function of the aircraft pair. The wake turbulence categories of the aircraft in the pair determine the ASG value, see table below. These values are based on the defining traffic throughput and traffic mix for IM Operations at Schiphol [8], a throughput of 35 landings per hour per runway and a traffic mix of 12% Heavies, 86% Mediums and 2% Boeing 757s. The Arrival Manager (AMAN) takes these values and the location where to achieve them into account when performing its sequencing and scheduling.

Table 4 Assigned Spacing Goals (in seconds).

Trail / Lead	***Heavy***	***757***	***Medium***
Heavy	122	148	148
757	122	148	148
Medium	96	96	96

3.11.3 Arrival/Departure Configuration

Figure 17 shows the general route structure of the Schiphol TMA that was used in the RTS. It is based on published day SIDs for take-off runway 36L, and "published" Instrument Approach Procedures (IAPs) from the four Initial Approach Fixes to the runways 06 and 36R. An IAP includes both a transition and an ILS approach procedure. It should be noted that these transitions are just defined for the KDC ASAS IM RTS.

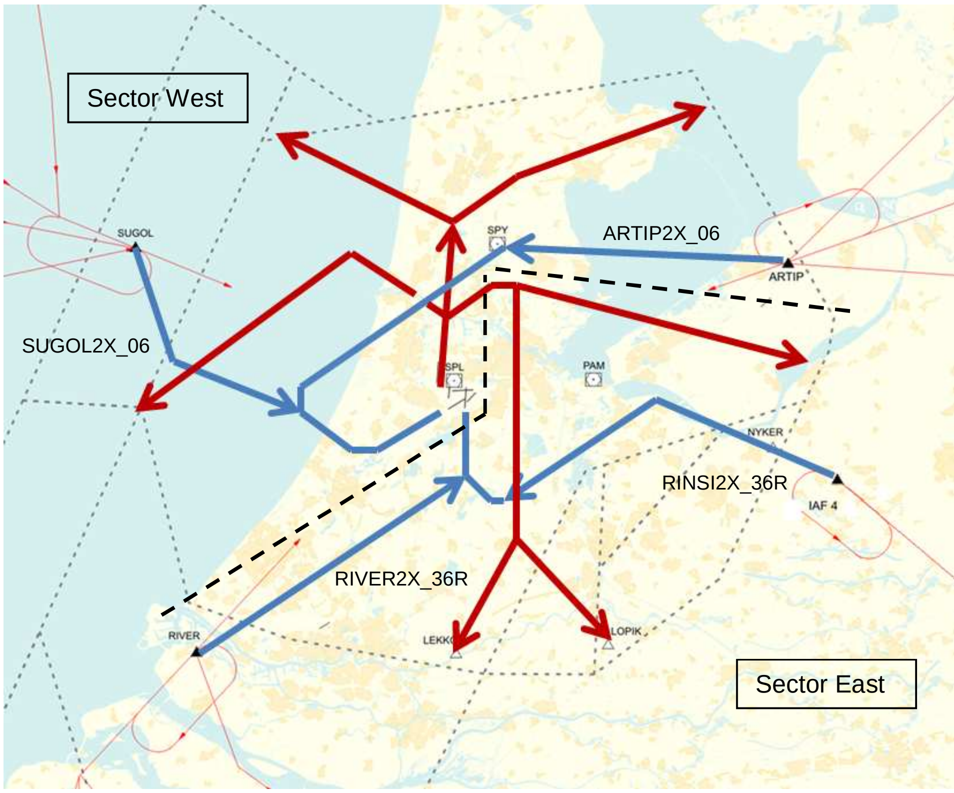

Figure 17: Arrival Transitions RWY 06 and RWY 36R, Departure RWY 36L (Blue arrivals, Red departures)

3.11.3.1 Instrument Approach Procedures – Transitions to ILS06/36R

Figure 18 and Figure 19 present the "published" IAPs that were used in the RTS. The tables below the figures define the named fixes and their attributes in terms of latitude and longitude, altitude and flight path angle constraints, and nominal speeds. Also the nominal decelerations are given (as applicable), they are used in the ASTAR IM algorithm.

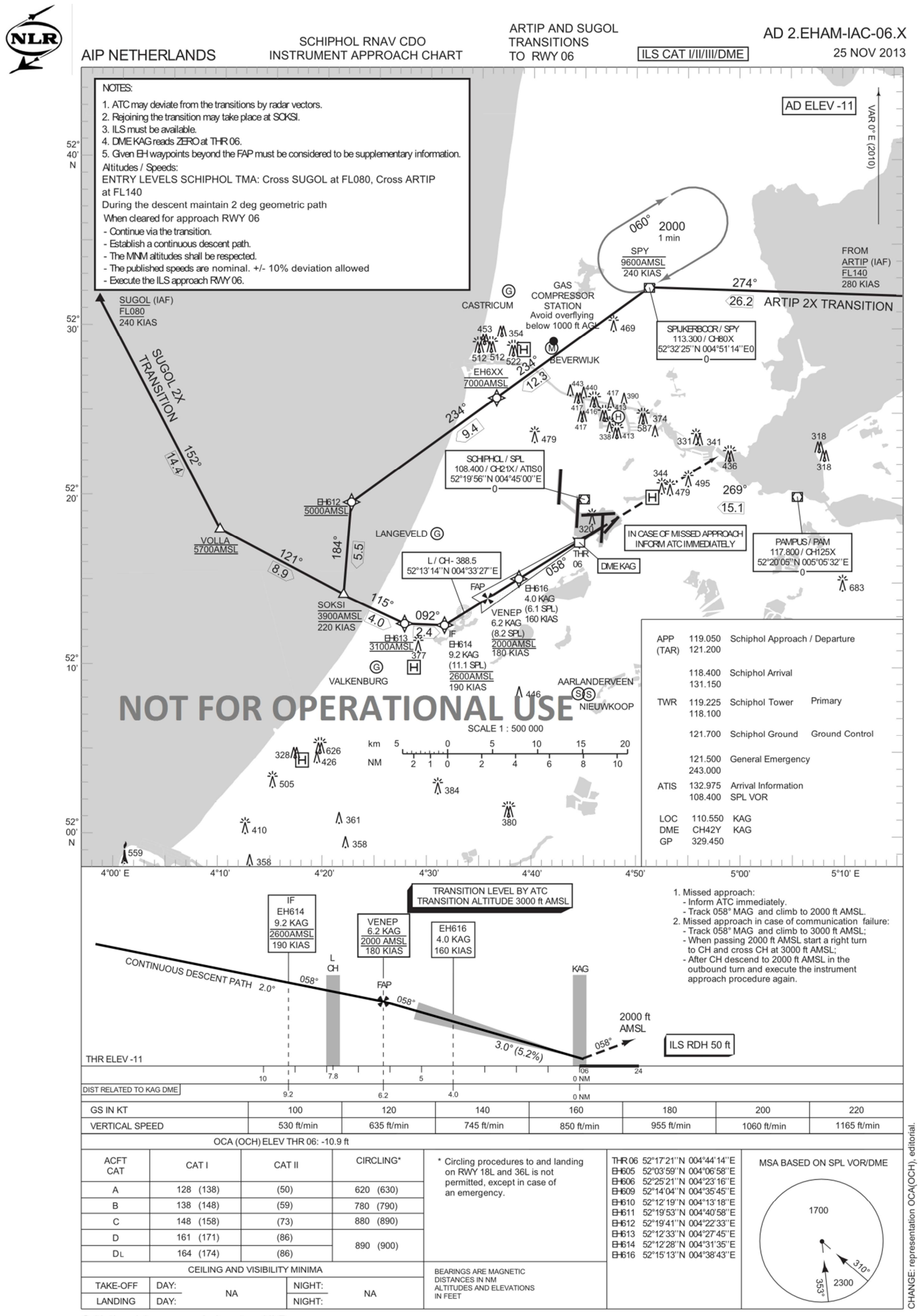

Figure 18 Instrument Approaches – The ARTIP and SUGOL Transitions to Runway 06

Table 5 Definition of the SUGOL2X Transition

Name: EHAM_SUGOL2X_06						
Waypoint	**Lat [deg]**	**Lon [deg]**	**Altitude [ft]**	**Path angle [deg]**	**Nom. Speed [kts]**	**Nom. Decel. [kts/s]**
SUGOL	52.525556	3.967222	8000	0.0	240	0.0
VOLLA	52.314167	4.156111	5700	2.0	-	-
SOKSI	52.237377	4.364433	3900	1.897	220	0.3
EH613	52.209167	4.462500	3100	1.890	-	-
EH614	52.207779	4.526389	2600	2001	190	0.3
EH609/VENEP	52.234444	4.595833	2000	2.0	180	0.4
EH616	52.253613	4.645278	(1310)	(3.0)	160	0.6
_STABLE	52.262444	4.667770	1000	3.0	FAS	1.0
EHAMRW06	52.289124	4.737269	39.1	3.0	FAS	-

Table 6 Definition of the ARTIP2X Transition

Name: EHAM_ARTIP2X_06						
Waypoint	**Lat [deg]**	**Lon [deg]**	**Altitude [ft]**	**Path angle [deg]**	**Nom. Speed [kts]**	**Nom. Decel. [kts/s]**
ARTIP	52.511111	5.569167	14000	0.0	280	0.0
SPY	52.540279	4.853781	9600	2.0	240	0.3
EH6XX	52.42064	4.583445	7000	2.01	-	-
EH612	52.328056	4.375834	5000	2.01	-	-
SOKSI	52.237377	4.364433	3900	1.896	220	0.3
EH613	52.209167	4.462500	3100	1.890	-	-
EH614	52.207779	4.526389	2600	2.001	190	0.3
EH609/VENEP	52.234444	4.595833	2000	2.0	180	0.4
EH616	52.253613	4.645278	(1310)	(3.0)	160	0.6
_STABLE	52.262444	4.667770	1000	3.0	FAS	1.0
EHAMRW06	52.289124	4.737269	39.1	3.0	FAS	-

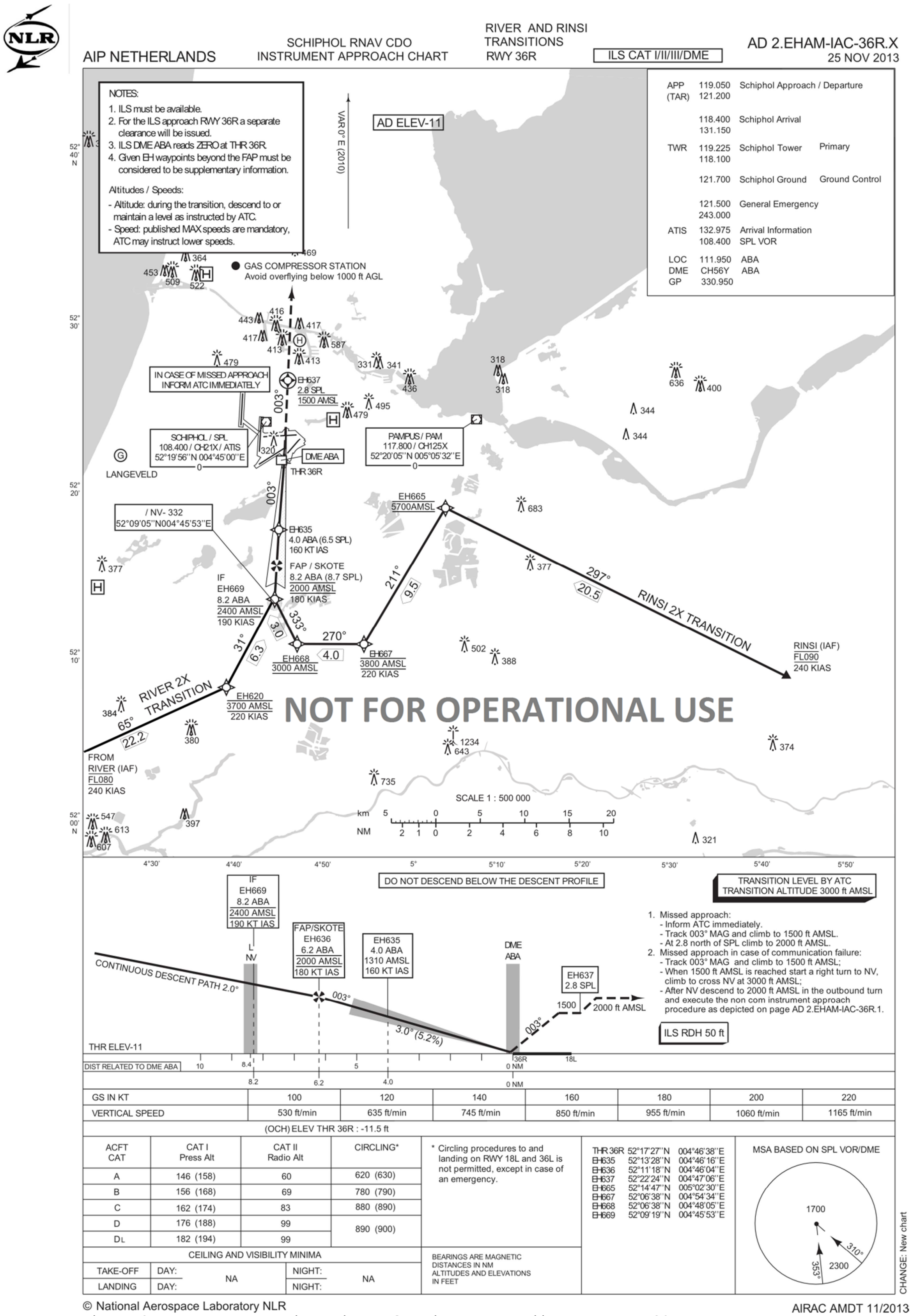

Figure 19 Instrument Approaches - The RINSI and RIVER Transitions to Runway 36R

Table 7 Definition of the RIVER2X Transition

3.11.3.1.1.1.1.1 Name: EHAM_RIVER2X_36R						
Waypoint	**Lat [deg]**	**Lon [deg]**	**Altitude [ft]**	**Path angle [deg]**	**Nom. Speed [kts]**	**Nom. Decel. [kts/s]**
RIVER	51.912777	4.132500	8000	0.0	240	0.0
EH620	52.064999	4.677500	3700	2.0	220	0.3
EH669	52.155281	4.764722	2400	1.942	190	0.3
EH636/SKOTE	52.188332	4.767778	2000	2.0	180	0.4
EH635	52.224445	4.771111	(1310)	3.0	160	0.6
_STABLE	52.240707	4.772636	1000	3.0	FAS	1.0
EHAMRW36R	52.290825	4.777347	39.1	3.0	FAS	-

Table 8 Definition of the RINSI2X Transition

3.11.3.1.1.1.1.2 Name: EHAM_RINSI2X_36R						
Waypoint	**Lat [deg]**	**Lon [deg]**	**Altitude [ft]**	**Path angle [deg]**	**Nom. Speed [kts]**	**Nom. Decel. [kts/s]**
RINSI	52.093212	5.539919	9000	0.0	240	0.0
EH665	52.246387	5.041667	5700	2.0	-	-
EH667	52.110554	4.909444	3800	1.895	220	0.3
EH668	52.1105554	4.801389	3000	1.890	-	-
EH669	52.155281	4.764722	2400	1.879	190	0.3
EH636/SKOTE	52.188332	4.767778	2000	2.0	180	0.4
EH635	52.224445	4.771111	(1310)	3.0	160	0.6
_STABLE	52.240707	4.772636	1000	3.0	FAS	1.0
EHAMRW36R	52.290825	4.777347	39.1	3.0	FAS	-

The speeds represent nominal speeds and not constraint speeds. The nominal speeds are used to provide a baseline speed profile around which the spacing algorithm will deviate.

3.11.3.2 Altitude profile

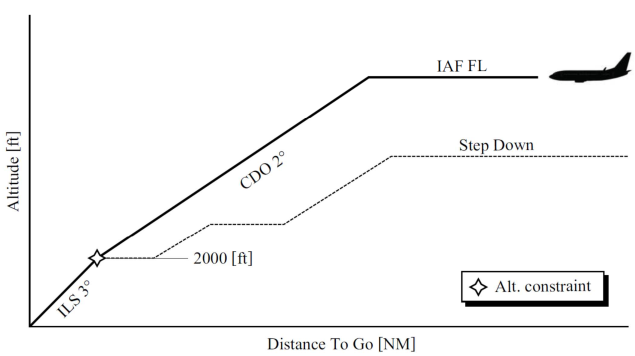

Figure 20: Vertical profile, the profiles are similar for each transition, the only difference is the IAF entry FL

The FIM algorithm uses speed-control by means of thrust to minimize the spacing error. In order for this to be effective, it is required that speed deviations from the nominal speed profile are allowed, to gain or lose time during the approach. Full idle CDOs eliminate the possibility for an aircraft to slow down by means of thrust and are therefore unsuitable for use with ASTAR. A 2°, fixed-geometric angle CDO is used as a compromise between noise benefits and speed control-space, Ref [7] . Control-space on a 2° CDO is available since the aircraft is not flying full-idle, i.e., the descent angle is such that limited thrust is required to maintain speed. Therefore, deceleration while on the profile is still possible by reducing thrust further to idle, which may be required if the aircraft needs to slow down in IM Operations. Noise benefits are inferred to come from the reduced thrust and an altitude profile which is higher than ordinary step down profiles, see Figure 20.

Figure 20 shows the altitude profile as proposed for the RTS. The vertical profile from the runway back up to the IAF crossing altitude is equal for all four transitions. The IAF crossing altitude differs according to the path distance to the runway. After passing the intermediate top of descent point, a 2° continuous descent path is followed up to the Final Approach Point (FAP) at an altitude of 2000 ft where the 3° glideslope will be intercepted. From the FAP the aircraft follow a standard approach to the runway. The FAP is both the Achieve-By Point as well as the Planned Termination Point.

3.11.3.3 Speed profile

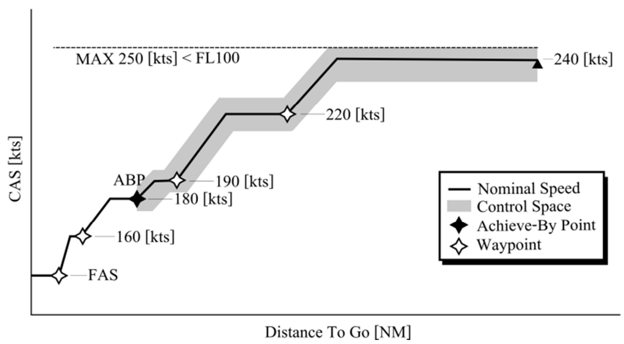

Figure 21: Speed profiles are equal for the four transitions, this is the nominal profile, ASTAR commanded speeds are within 10% of this profile

The speed profile is illustrated in Figure 21. All speeds in the figures are in Calibrated Air Speed (CAS). Requirements for the speed profile are operational feasibility and good control-space margins for all types of aircraft. The speed profile for the transition may differs in the TMA entry speed but below 10,000 ft a similar nominal profile of 240/220/190/180/160/FAS is defined. The speed control-space is illustrated in Figure 21 with a grey fill colour and is defined as 10% around the nominal speed with a max of 250 kts below 10,000 ft. The current 220 kts / 15 SPL restriction is not applicable for this route structure. Note that the figure is not to scale.

3.11.4 Wind conditions

To test the IM concept in various wind conditions, two wind conditions are defined. The tables in APPENDIX A provide the actual and forecast wind data for these two conditions. Condition #1 is the 40th percentile of the average wind speed between the surface and FL100 (based on KNMI HiRLAM data for the entire year of 2013, with a sampling of three hours); condition #2 is the 78th percentile. Note: condition #2 is the most severe wind condition in 2013 when runway 06 could have been used.

The forecast wind data is based on HiRLAM data of 3 hours before the actual operation. And only forecast wind data at specific flight levels are used, representing system operation at LVNL (e.g., current Inbound Planner (IBP), initial version of a new Arrival Manager and SARA) and the minimum wind data requirements for FIM Equipment.

International Standard Atmosphere is assumed in this RTS, including a QNH of 1013.25 hPa.

3.12 Procedural Flow

The IM Operation will be based on the following procedural flow (optional phases or steps are between brackets):

1. Set-up phase
2. Initiation Phase
3. Execution Phase
4. Termination Phase
5. (Suspend Phase)

3.12.1 Set-up Phase

Goal is to verify proper arrival sequence, clear the IM aircraft for the arrival transition and determining that IM Operations for that aircraft is beneficial (i.e. has a positive effect on operation and is considered the path of least resistance) and viable (meets defined applicability parameters).

Set-up Phase		
Step:	Action:	R/T
1	The aircraft contacts APP with already having received the to be expected arrival transition	1
2	The controller verifies the proper ***arrival sequence*** for the runway in use.	-
3	The controller clears the aircraft for the ***arrival transition.*** The arrival transition includes the portion of the approach up to the Final Approach Point (FAP), thereby provided the necessary intended flight path information up to the Achieve-By Point.	2
4	The flight crew provides a readback of the cleared arrival transition	3
5	The controller determines that the use of an IM Operation would be beneficial and viable. As part of that process ATC determines whether the applicability parameters are met. These include confirming that the IM Aircraft is IM capable (appropriate ***equipment)***, that the Target Aircraft is ADS-B OUT equipped, both aircraft have compatible ***positions*** and ***routes*** (e.g. Target aircraft is not being vectored and is assigned an appropriate arrival transition)	-

Necessary data elements:

- Arrival sequence (#1, #2, etc)
- Aircraft arrival transitions
- Aircraft equipage levels
- Aircraft positions

3.12.2 Initiation Phase

Goal is to select the proper Target Aircraft and clear the aircraft to the appropriate flight level. When the aircraft can be cleared for the approach an IM instruction is issued.

Initiation Phase		
Step:	Action:	R/T
1	The controller requests the IM aircraft to select the ***Target Aircraft*** including the Target Aircraft's Intended Flight Path Information ***(IFPI),***	4
2	The flight crew provides a readback of the target selection	5
(3)	a) The flight crew is unable to select the Target Aircraft due to inability to identify, b) The flight crew is unable to select the Target Aircraft due to the IFPI not being in conformance with the selected Target Aircraft;	6a 6b
(4)	The flight crew selects the wrong Target Aircraft. Controller request confirmation of correct traffic.	7
5	The controller determines the ***Assigned Spacing Goal*** and ***Achieve-by Point*** and includes this in the IM clearance.	8
6	The speed information in the radar label changes to IM	-
7	The flight crew provides a readback of the IM clearance (which is effectively a clearance acceptance, like the other readbacks)	9

8	The flight crew makes the IM data available to the FIM Equipment	-
9	The FIM Equipment will provide the IM speed and/or status flags	-
10	The flight crew assesses the feasibility of the IM Operation, including IM speed, and enters the speed in the autopilot speed window or activates the automatic execution of the IM speeds	-
(11)	If the flight crew is unable to accept or to continue the IM clearance will they inform ATC and may state the reason	12
(12)	The controller instructs the aircraft to cancel interval spacing and to maintain a given speed	13
(13)	The controller clears the aircraft to the next available Flight Level *Note: this step is applicable to the ARTIP transition to runway 06.*	
(14)	The flight crew provides a readback of the descent clearance *Note: this step is applicable to the ARTIP transition to runway 06.*	
15	The controller is able to clear the aircraft for the approach.	10
16	The flight crew provides a readback of the approach clearance	11

Necessary data elements:

- Target Aircraft identifier
- Target Aircraft's Intended Flight Path Information
- Assigned Spacing Goal
- Achieve-by Point
- IM Operation active

3.12.3 Execution Phase

Goal is to monitor the IM Operation and provide separation assurance when necessary.

Execution Phase		
Step:	Action:	R/T
1	The FIM Equipment provides appropriate IM speeds to achieve the assigned spacing goal. The flight crew activates the automatic execution of the IM speeds or manually sets the IM speed value in the MCP/FCU speed window. The Autothottle follows the IM speed.	-
2	The flight crew monitors the progression of the IM Operation to ensure that the Assigned Spacing Goal remains feasible, no faults occur with the FIM Equipment, and that the operation stays in conformance with both the arrival/approach clearance and IM Clearance	-
3	The controller monitors the procedure execution while providing separation. The task includes monitoring: • Separation of merging traffic • Spacing is progressing in the correct direction	-

Necessary data elements:

- Merge tool
- Indication of probability of success
- Early / Late indication
- Spacing marker
- Predicted Spacing Interval at the Achieve-by Point

3.12.4 Termination Phase

Goal is to terminate IM Operation and resume conventional control.

Termination Phase		
Step:	Action:	R/T
1	a) The aircraft is unable to continue with IM and informs ATC	12

	b) The controller opts not to continue IM for given aircraft c) IM Operation is automatically terminated when the IM Aircraft crosses the defined Planned Termination Point (= Achieve-by Point)	14 -
2	a) The controller instructs the aircraft to maintain a given speed b) The flight crew provides a readback of the IM termination instruction c) After crossing the Planned Termination Point; a. Aircraft maintains last IM speed until deceleration is required for ILS approach b. Aircraft is instructed to maintain a given speed	13 15 -
3	The speed information in the radar label changes to either SPD or the speed value instructed by the controller	-

Necessary data elements:

- IM Operation not active in the radar label

3.12.5 Suspend Phase

Goal is to temporarily suspend IM Operation, modify the IM instruction or re-position the aircraft if necessary and resume when appropriate.

Suspend Phase		
Step:	Action:	R/T
1	The controller determines that a temporarily suspension of IM Operations is required	16
2	The flight crew provides a readback of the IM suspend instruction	17
3	The speed information in the radar label changes to either SPD or the speed value instructed by the controller and the EHS (selected/current) Indicated Airspeed	-
4	The controller modifies the IM clearance or vectors the aircraft into position	-
5	The controller instructs to resume IM Operations	18
6	The speed information in the radar label changes to IM	-
7	The flight crew provides a readback of the IM resume instruction	19
8	The flight crew makes the data available to the FIM Equipment	-
9	The FIM Equipment will provide the IM speed and/or status flags	-
10	The flight crew assesses the feasibility of the IM Operation, including IM speed, and enters the speed in the autopilot speed window or activates the automatic execution of the IM speeds	-
(11)	In case the flight crew is unable to accept the IM clearance, they will inform the controller and may state the reason;	12
(12)	The controller instructs the aircraft to cancel interval spacing and to maintain a given speed	13

Necessary data elements:

- IM Operation (not) active

3.13 Pilot-controller phraseology

Step #	Description	GND-ATC	AC-FC
1	Contact APP		Schiphol approach <call sign>
2	Arrival transition and FL clearance	<call sign> follow <transition> transition, ILS runway <rwy>, continue descent flight level <FL> according profile, weather information <ATIS>	
3	Readback Arrival transition clearance		<transition> transition, ILS runway <rwy>, descending FL <FL> according profile, we have <ATIS>,<call sign>
4	Request Target Aircraft Selection	<call sign> for interval spacing select traffic <acid> on <ifpi>	

5	Readback Target Aircraft Selecting		Selecting traffic <acid> on <ifpi>, <call sign>
6	Target Aircraft not Selected or no longer available		a) <call sign>, Negative Traffic b) <call sign>, Negative Traffic, transition invalid
7	Incorrect Target Aircraft selected	<call sign> confirm traffic <acid>	
8	Transmit IM clearance	<call sign> cross <wpt> <interval> seconds behind traffic	
9	Readback IM clearance		Cross <wpt> <interval> seconds behind traffic, <call sign>
10	Transmit approach clearance	<call sign> descend to 2000 ft according profile, QNH <hPa>, cleared for the approach	
11	Readback approach clearance		Descending 2000 ft according profile, QNH <hPa>, cleared for the approach, <call sign>
12	Pilot advising of IM termination IM unable initiate or continue		<call sign>, unable interval spacing due to - equipment failure - IM speed too high/low - data quality etc.
13	Controller response	Roger <call sign>, cancel interval spacing, maintain <spd> knots	
14	IM Termination Instruction (in case of abnormal termination)	<call sign> cancel interval spacing, maintain <spd> knots	
15	Readback IM Termination		Interval Spacing cancelled , maintaining <spd> knots, <call sign>
16	Suspend IM Instruction	<call sign> suspend interval spacing, maintain <spd> knots	
17	Readback Suspend Instruction		Suspending interval spacing, speed <spd> knots, <call sign>
18	Transmit resume instruction	<call sign> resume interval spacing	
19	Readback resume instruction		Resuming interval spacing, <call sign>

<call sign>	call sign of the IM aircraft
<rwy>	runway identifier
<hPa>	QNH value in hectopascal
<acid>	target aircraft identification [1]
<rel-pos>	relative position [1-12]
<interval>	ASG in seconds
<wpt>	waypoint name
<transition>	name of the RNAV transition
<arrival>	name of the Standard Arrival Route (STAR)

[1] In the RTS, the following guidance was given to controllers concerning the use of Target Aircraft ID:

1. Use a telephonic format as the normal method
   - Delta one two three
2. Have the option to use a letter format when the controller believes there may be pilot confusion about the airline three letter designation
   - D[di:] A[eI] L[el] one two three, or
   - Delta Alfa Lima one two three
3. If the controller uses a telephonic format and the pilot has confusion about the three letter designation, the pilot could ask for clarification. Then use a letter format.

<spd>	indicated airspeed in knots
<FL>	pressure altitude in flight levels
<alt>	barometric altitude in feet
<app>	name of the final approach procedure
<ifpi>	intended flight path information o same route o <transition>

4 Daily Schedule

08:30-09:30	Welcome, introduction, briefing, pre-experiment questionnaire
09:30-11:00	Training run, including post-training questionnaire
11:00-12:00	Experiment run #1, incl. post-run questionnaire #1
12:00-12:30	Lunch
12:30-13:30	Experiment run #2, incl. post-run questionnaire #2
13:30-14:30	Experiment run #3, incl. post-run questionnaire #3
14:30-14:45	Tea/coffee
14:45-15:45	Experiment run #4, incl. post-run questionnaire #4
15:45-16:30	Post-experiment questionnaire and debriefing

5 Metrics and Analysis

To measure the performance of the different scenarios and to be able to compare the results, the following metrics have been defined:

IM Performance metric:

- Number of violations of required separation
- Success rate of IM Operations
- Percentage of IM-capable aircraft receiving IM clearance
- Number of controller-to-pilot instructions

Controller performance metrics

- Inter-arrival spacing precision
- Percentage of un-interrupted IM Operations
- Controller acceptability of IM Operations
- Controller workload during IM operations (NASA TLX)
- Controller situation awareness during IM operations

Airborne performance

- IM spacing goal conformance

5.1 IM Performance Metrics

5.1.1 Number of Violations of Required Separation

This metric is calculated by counting the number of aircraft with in-trail separation less than the required separation. IM is expected to not impact the safety of operations. The increase in FIM equipage levels and the introduction of spacing symbology is expected to reduce the number of violations. Wind is expected to have a stronger effect on the non-IM aircraft than on IM-aircraft.

Measurement Approach:	In-trail separation will be monitored for each simulation run. The number of separation violations will be counted. The margin will be specified as a difference between a maximum allowable number of violations and the observed number.
Improvement Threshold:	Improvement in the number of separation violations is demonstrated by: • (Number of Separation Violations in scenario A) < (Number of Separation Violations in scenario B)
Performance Goals:	Goal: Number of separation violations less than or equal to the maximum allowable value for all equipage levels, wind conditions and ATCo tools. (Number of Separation Violations) ≤ (Maximum Allowable Number of Separation Violations) **Desired Margin [Integer]:** Number of separation violations 1 violation fewer than Performance Goal
Performance Calculation Method:	First, calculate the aircraft-to-aircraft separation for each track update and compared to the required separation. The number of loss-of-separation events (contiguous sets of tracks having less than the required separation) will be counted. The required separation is specified in Table 1. Additionally, it is subject to the particular assumptions of the traffic scenario simulated (FIM equipage level, wind scenario, controller spacing symbology). In actual operations, separation violations are rare and not operationally acceptable. However, simulations are not as realistic as actual operations, so a non-zero number of separation violations is expected. Therefore, the maximum allowable number of separation violations is non-zero but selected to ensure that the simulation remains a reasonable reflection of actual operations.

	See Raw Data Elements and Sources for value of maximum allowable number of separation violations. Precision: Performance values and achieved margins are reported as whole integers. Scope: This metric is individually reported for each simulation run.	
Raw Data Elements and Sources:	Aircraft-to-aircraft separation for each track update	Source: Results of post- processing of NARSIM data
	Flight plan data for each flight (to determine weight class category for required separation calculation)	Source: NARSIM traffic samples
	Maximum Allowable Number of Separation Violations per run	N= 3

5.1.2 Success Rate of IM Operations

This metric is calculated as the percentage of uninterrupted IM Operations. An IM Operation is considered uninterrupted when the flight is not given any radar vectors by the terminal controller between the IAF and the Planned Termination Point.

Measurement Approach:	IM Operations will be monitored for each simulation run. The number of uninterrupted IM Operations will be counted; the percentage of uninterrupted IM Operations will be calculated.
Improvement Threshold:	Improvement in the success rate of IM Operations is demonstrated by: • (Percentage of Uninterrupted IM Operations with 95% FIM equipage) > (Percentage of Uninterrupted IM Operations with 50% FIM equipage) > (Percentage of Uninterrupted IM Operations with 5% FIM equipage)
Validation Criteria:	Data is considered valid if: • Radar vectors are not given to aircraft identified as uninterrupted IM operations
Performance Goals:	Goal: Success rate greater than 90% (Percentage of Uninterrupted IM Operations with FIM equipage 95%) > 90%
Performance Calculation Method:	First, count the number of uninterrupted IM Operations as follows: A flight is considered interrupted if it has any heading or speed commands, IM suspend or IM cancel commands between the IAF and the Planned Termination Point. Then, calculate the percentage of uninterrupted IM Operations as follows: • Percentage of Uninterrupted IM Operations = 100×(Number of Uninterrupted IM Operations ∕ Number of IM Operations Flights Precision: Performance values and achieved margins are reported as whole integers. Scope: This metric is individually reported for each simulation run.

5.1.3 Percentage of IM Capable Aircraft receiving IM clearance

This provides an indication for the success of the IM-concept by calculating the number of IM capable aircraft that actually receive an IM-clearance.

Measurement Approach:	IM Operations will be monitored for each simulation run. The number of IM capable flights and the number of flights that receive an IM-clearance will be counted; the percentage of IM Operations will be calculated.

Improvement Threshold:	Improvement in the success rate of IM Operations is demonstrated by: • (Percentage of IM cleared aircraft with 95% FIM equipage) > (Percentage of IM cleared aircraft with 50% FIM equipage) > (Percentage of IM cleared aircraft with 5% FIM equipage)
Validation Criteria:	Data is considered valid if: • A FIM equipped and capable aircraft has received and accepted an IM clearance.
Performance Goals:	Goal: Success rate greater than 90% Desired Margin [%]: Additional 10% increase in success rate (i.e., success rate greater than 80%)
Performance Calculation Method:	First, count the number of IM capable flights, and the number of flights that receive an IM clearance. Then, calculate the percentage of IM cleared aircraft as follows: • Percentage of IM cleared aircraft = 100×(Number of IM cleared flights ⁄ Number of IM capable flights Precision: Performance values and achieved margins are reported as whole integers. Scope: This metric is individually reported for each simulation run.

5.1.4 Number of Controller-to-Pilot Instructions

This metric is calculated as the mean number of controller-to-pilot instructions per arrival flight. The types of instructions relevant to this metric are only those that affect the aircraft's flight path or are related to IM Operations. Increasing the FIM equipage level is expected to reduce the number of controller-to-pilot instructions.

Measurement Approach:	Controller-to-pilot instructions will be monitored for each simulation run. The number of controller-to-pilot instructions for arrival flights will be counted. The percentage change in the mean number of instructions will be calculated.	
Improvement Threshold:	Improvement in the number of controller instructions is demonstrated by: • (Mean Number of Controller-to-Pilot Instructions with FIM equipage 95%) < (Mean Number of Controller-to-Pilot Instructions FIM equipage 50%) < (Mean Number of Controller-to-Pilot Instructions FIM equipage 5%)	
Performance Goals:	Goal: No increase in the mean number of controller-to-pilot instructions for increasing equipage levels. Desired Margin [%]: 15% decrease in the number of controller-to-pilot heading and altitude instructions	
Performance Calculation Method:	First, count the controller-to-pilot instructions by type (heading, speed, altitude, etc.) The number of controller-to-pilot instructions is expressed in units of instructions per flight. The mean number of controller-to-pilot instructions is calculated across all flights of a particular simulation run. Scope: This metric is individually reported for each simulation run.	
Raw Data Elements and Sources:	Inventory of controller-to-pilot instructions (aircraft ID, type, time, location, controller position, etc.)	Source: Audio recording transcription

5.2 Controller Performance

5.2.1 Inter-Arrival Spacing Precision

This metric is calculated by the standard deviation of excess in-trail spacing at the Achieve-By Point on a per-runway basis. Excess spacing is defined as the difference between the minimum spacing and the observed spacing, as explained in Section 6.4. IM is expected to increase the inter-arrival spacing precision (i.e., decrease the standard deviation of the excess in-trail spacing at the Achieve-by Point).

Measurement Approach:	The excess in-trail spacing at the Achieve-By Point will be calculated for all pairs of aircraft for each simulation run. The standard deviation of excess spacing will be calculated.
Improvement Threshold:	Improvement in the inter-arrival spacing precision is demonstrated by: • (Std. Dev. of Excess Spacing with 95% FIM equipage) < (Std. Dev. of Excess Spacing with 50% FIM equipage) < (Std. Dev. of Excess Spacing with 5% FIM equipage)
Performance Goals:	Goal: Inter-arrival spacing precision increases with increasing FIM equipage level..
Performance Calculation Method:	First, measure each aircraft's inter-arrival spacing as the aircraft immediately preceding it (on the same runway) passes the Achieve-by Point. The excess spacing is the difference between the measured spacing and the planned spacing. All spacing-related values are expressed in units of nautical miles. The std. dev. of excess spacing is calculated across all flights of a particular simulation run.

5.2.2 Percentage of Uninterrupted IM Operations

This metric is calculated as the percentage of IM Operations that are not terminated early by ATC. An IM Operation is considered terminated early when ATC does not initiate interval spacing, cancels interval spacing, or suspends and does not resume interval spacing prior to the Planned Termination Point. Some causes for this event include: the controller needing to use additional speed control or radar vectors, the controller needing to resolve interactions with other traffic flows, or the controller simply not being comfortable with the particular traffic situation.

Measurement Approach:	IM Operations will be monitored for each simulation run. The number of IM Operations that are terminated early by ATC will be counted. The percentage of uninterrupted IM Operations will be calculated. The margin will be calculated as the difference between the maximum acceptable percentage of ATC-terminated IM Operations and the measured percentage.
Improvement Threshold:	Improvement in the rate of early IM termination by ATC is demonstrated by: • (Percentage of uninterrupted IM Operations) > (Minimum Acceptable Percentage of uninterrupted IM Operations) NOTE: The "Minimum Acceptable Percentage" can only be based on engineering judgment. This is a base requirement with no prior basis for comparison.
Performance Goals:	Goal: Rate of early IM termination by ATC is less than 10%□(Percentage of ATC-Terminated IM Operations) < 10%
Performance Calculation Method:	First, calculate the percentage of IM Operations terminated by ATC: • Percentage of Uninterrupted IM Operations = 100 - 100×(Number of IM Operations Terminated by ATC) ∕ (Number of Flights that received an IM Clearance) A flight is considered eligible for IM Operations if it is FIM equipped.

5.2.3 Controller Acceptability of IM Operations

This metric is calculated as the controller's subjective acceptability of the IM Tools and associated operations. The IM Operations are expected to be considered acceptable by the controllers.

Measurement Approach:	Controller acceptability of IM Operations will be measured using pre- and post-experiment questionnaires, where the controllers will be asked to indicate their

	trust and acceptability in the system and procedures.	
Performance Goals:	Goal: Minmum score of 7 after the experiment.	
Raw Data Elements and Sources:	Controller ratings.	Source: Post-experiment controller questionnaire

5.2.4 Controller Workload during IM Operations

This metric is calculated as the controller's perceived workload rating of the IM Operations. This metric purposely does not separate workload by particular controller tools or associated operations. The IM Operations are expected to achieve controller workload ratings of "low to slightly higher than moderate" in order to be considered acceptable.

Measurement Approach:	The controller workload of IM Operations will be measured using the NASA Task Load Index (TLX) (APPENDIX C). This assessment tool is a subjective, multidimensional evaluation of the controller's perceived workload in order to characterize the effectiveness of the IM scenario. The total workload has six subscales: Mental Demand, Physical Demand, Time Pressure, Effort, Success (reversed), and Frustration. A 7-point scale, 1=very low and 7=very high will be used. The mean value of each subscale will be calculated using the "raw" TLX scores. Individual weighting will not be used, and an overall task load index will be reported.
Improvement Threshold:	Improvement in controller workload is demonstrated by: • (Mean NASA TLX Workload Subscale Ratings) < (Minimally Acceptable NASA TLX Workload Subscale Ratings)
Performance Goals:	Goal: Mean NASA TLX ratings less than or equal to 5.
Performance Calculation Method:	Calculate the mean value of the NASA TLX subscale ratings across all controllers of a particular simulation run, as well as, across all controllers of all simulation runs combined.

5.2.5 Controller Situation Awareness during IM Operations

This metric is calculated as the controller's subjective situation awareness level, by using a Situation Awareness for Shape (SASHA) questionnaire.

Measurement Approach:	Controller situation awareness during IM Operations will be measured using questionnaires after each run, where the controllers will be asked to indicate their level of situation awareness.	
Performance Goals:	Goal: Minmum score of 4.	
Raw Data Elements and Sources:	Controller SASHA ratings.	Source: Post-run controller questionnaire

5.3 Airborne Performance

5.3.1 IM Spacing Goal Conformance

This metric is calculated by the difference between the assigned spacing goal and the actual in-trail spacing between the Target and IM aircraft when the IM aircraft crosses the Achieve-by Point.

Measurement Approach:	The IM spacing error at the Achieve-by Point will be calculated for all pairs of IM aircraft for each simulation run. The percentage of operations with IM spacing errors within 10 seconds will be calculated. The margin is calculated as the difference between the observed percentage of IM spacing error that are less than 10 seconds and the minimum acceptable percentage.

Improvement Threshold:	Improvement in the spacing goal conformance is demonstrated by: • (Percentage of IM Spacing Errors within 10 seconds) > (Minimum Acceptable Percentage of IM Spacing Errors within 10 seconds) Note: The “Minimum Acceptable” value can only be based on engineering judgment. This is a base requirement with no prior basis for comparison.	
Validation Criteria:	Data is considered valid if: • The IM Operation was not interrupted	
Performance Goals:	Goal: At least 95% of all IM spacing errors are within 10 seconds (Percentage of IM Spacing Errors within 10 seconds) ≥ 95%	
Performance Calculation Method:	First, calculate the IM Spacing Error for the pair of tracks when the IM aircraft reaches the Achieve-by Point. The IM Spacing Error is expressed in units of seconds. For IM Operations that terminate at the Achieve-by Point, IM spacing error should be calculated as Achieved Spacing minus Spacing Goal. Achieved Spacing is measured as the time that the IM aircraft crosses the Achieve-by Point minus time that target aircraft crosses the Achieve-by Point. For IM Operations that terminate prior to the Achieve-by Point, IM spacing error is not calculated.	
Raw Data Elements and Sources:	Assigned spacing goal for each IM flight	Source: NARSIM data log file and RT transcripts
	Observed Achieve-by Point crossing times for the Target aircraft and IM aircraft	Source: Results of post-processing of NARSIM data

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6 Results and Analysis

6.1 Controller Acceptance and Workload

6.1.1 Controller Acceptance Ratings

The participating controllers were asked to fill out questionnaires post-training (before the experiment) and after the experiment. As can be seen in Table 9, The controllers had confidence in the system, although Controller 1 showed a alightly reduced confidence after the experiment. This controller indicated that the runs where he had to cope with non-conforming traffic had been difficult to complete and he had initially expected more support from the system than he had encountered.

Table 9. Controller confidence in the system. Scale (1-10)

	Post-training	Post-experiment
Controller 1	8	7
Controller 2	7	8
Controller 3	9	10

As part of the post-experiment questionnaire, the controllers were asked to indicate their level of acceptance of the IM-concept in and the IM-procedure as presented during the experiment. Table 10 shows that all three controllers felt very confident that the IM-concept is viable and can be implemented in the future.

Table 10. Controller acceptance of the IM Concept and procedure. Scale (1-10)

	IM Concept	IM Procedure
Controller 1	9	9
Controller 2	8	8
Controller 3	8	8

6.1.2 Controller Workload

After each simulation run, the controllers were asked to fill out a NASA Task Load Index (TLX) to give an indication of the perceived workload for each scenario.

As can be seen in Figure 22, the effect of the traffic sample shows a slight increase in workload with increasing traffic density. (Traffic scenario A has an average throughput of 36.3 aircraft per hour, scenario B has 25,7 and scenario D has 32.6 aircraft per hour on the landing runway 06). The effect of FIM equipage level is less prominent, but seems to indicate a slight increase for the 50% scenario. One possible explanation might be that having to deal with both IM and non-IM aircraft is more difficult for the controller than a predominantly IM (95%) or non-IM (5%) traffic mix. This is something to take into account when implementing IM-operations.
The effect of HMI seems negligible on TLX, indicating that the extra tools available for the controller did not lower workload. The tool that controllers found most useful, the merge tool, was available in both HMI configurations, so its effect cannot be measured. During the post experiment debriefing, all controllers indicated that they found the merge tool very useful.

As expected, the effect of introducing non-nominal events has a detrimental effect in workload, but not a very large effect, as can be seen in Figure 22 (*yes* means non-nominal aircraft were introduced into the scenario, no means no non-nominals were present).

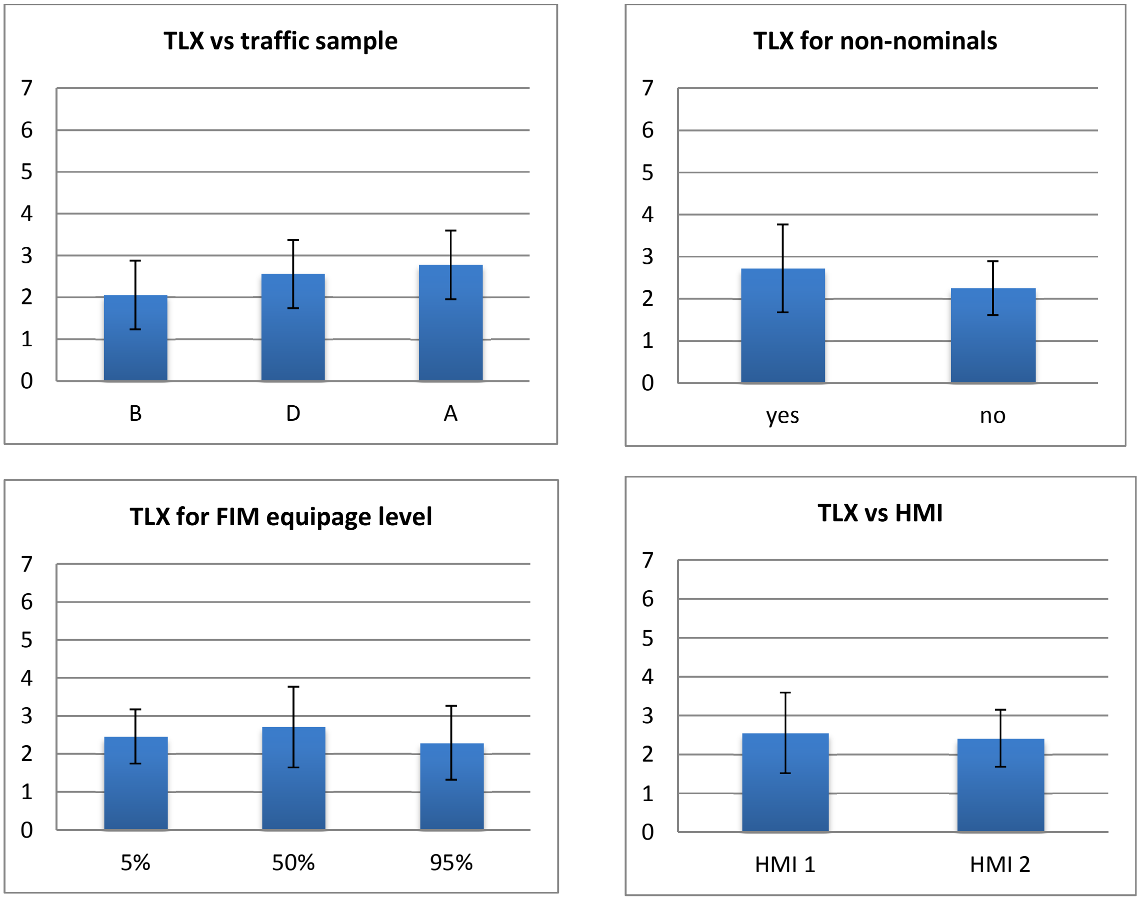

Figure 22 Means and standard deviations (in units on a scale 1-7) of the NASA TLX scores..

6.1.3 Controller Situation Awareness (SASHA)

During a number of runs non-nominal aircraft behaviour was introduced. The workload and situation awareness rating varied with the success with which the controllers were able to cope with the situation. As a result the average SASHA-rating is slightly lower for the non-nominal runs, as can be seen in Figure 23.

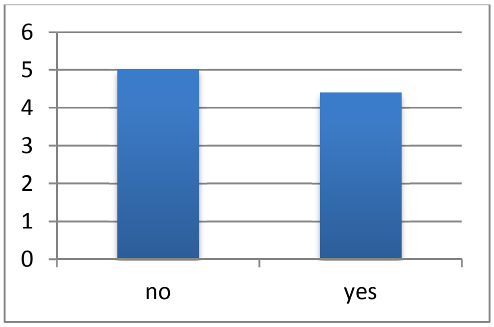

Figure 23. Controller average SASHA rating (in units on a scale 0-6) for runs without and with non-nominal aircraft (no means no non-nominals were present, *yes* means non-nominal aircraft were introduced into the scenario).

6.1.4 Controller feedback

The bullet list below gives a summary of the feedback provided by the LVNL controllers who participated in the IM RTS, it also includes the feedback of the project's operational expert from LVNL.

- In general controllers were (very) positive about both IM Operations and the Merge Tool, which is not directly related to IM but is deemed a minimum requirement for operating fixed routes in the Schiphol TMA.
- The IM aircraft generally fly higher speeds close to final approach than a controller would instruct. It was asked why the IM algorithm does not perform more error corrections at an earlier stage. It could be wind errors or trajectorory prediction that caused an increase in the error as well as the algorithm not being aggressive and leaving too much error until the end. A detailed analysis of the ASTAR data is recommended prior to the next KDC IM research step.
- During the initial part of final approach, IM aircraft sometimes flew as slow as 160-165 KIAS, while the distance to their lead was okay (approx. 4 NM). They were still correcting spacing errors as these speeds are lower than the nominal speeds of 180-190 KIAS. As a consequence the natural compression towards 3 NM will not occur during the initial deceleration on final approach (180 → 160). This in the end will have a negative effect on throughput, because the Assigned Spacing Goals will have to be adjusted to take this effect into account. It was strongly recommended to apply a minimum of 180 KIAS to the IM speed.
- The IM Clearance phraseology should and could be improved. In particular the first part, the target selection ("FOR INTERVAL SPACING, SELECT TRAFFIC TRA345 ON THE ARTIP2X TRANSITION") did not become an easily an naturally spoken phrase, even at the end of the RTS. Suggestions are:
    - Delete 'FOR INTERVAL SPACING", if needed put IM information in the ATIS.
    - TRAFFIC IS TRA345, ON THE ARTIP2X TRANSITION, though TRAFFIC IS is also used in FIS.
    - TRAFFIC TO FOLLOW IS TRA345, ON THE ARTIP2X TRANSITION
- It was strongly recommended to downlink the following information in order to close the 'loop' for the controller: (1) selected target aircraft and (2) selected Assigned Spacing Goal.

  An example of downlinked information that currently closes the loop for the controller is as follows: (a) 250 knots is instructed, (b) adherence to it may be checked by the controller through the actual IAS, which is downlinked by the aircraft through Enhanced Mode S.

  This recommendation is based on scenarios with non-normal events (i.e., incorrect target readback/selection and incorrect ASG entry by the flight crew) in which the safety was not compromised (because controllers intervened by means of speed, altitude and heading instructions), but the efficiency was affected. Due to the tight sequence of the inbound flow, many aircraft were given tactical instructions. If the controller had known the problem earlier, (s)he could have prevented it or could have taken corrective action at an earlier stage (i.e., not near the merge point/final approach).

- It was suggested to use distance in the IM Clearance instead of time (e.g. Cross VENEP 4.2 Miles Behind Traffic). Since the Achieve-by Point is co-located with the Planned Termination Point, the onboard IM system could internally use the equivalent time-based ASG.
- When an aircraft is vectored, which takes it off the previously assigned route, it could be beneficial to use the 'vector then turn' IM Clearance type. It was suggested to consider this clearance type in future work.
- It was asked how much time it would take for the flight crew to start executing the IM Operation after receiving the IM Clearance. If this would take a long time, the operational impact needs to be assessed.
- It was suggested to consider IM initiation by ACC, in particular for aircraft that will fly the same transition.
- It was suggested to add an additional altitude constraint to several SIDs, to ensure that the crossing of outbounds and inbounds will occur with sufficient altitude separation. E.g., minimum FL70 at VOLLA on the GORLO departure; VOLLA is the crossing point with the SUGOL2X transition.
- For IM Operations trust was quickly built up. In general the spacing evolved as the controller would have managed it. Sometimes the distance spacing did not reduce as quickly as the controller would have managed it, but in these cases at least the aircraft was reducing speed to correct the spacing error.
- Several HMI improvements were suggested:
    - The '#' symbol disappeared when the controller entered a speed instruction. It was then no longer obvious that an aircraft was FIM equipped/eligible. The '#' symbol should remain in the radar label;
    - Show the '#' symbol also in the sequence list on the EDD, so the controller gets a better awareness of the amount of IM (or non-IM) aircraft that are approaching the TMA;
    - The ground-based predicted spacing computation needs to be improved. The spacing marker symbol on the radar screen regularly showed jumping behaviour, which made it less useful. Though in principle the spacing marker was considered a good feature to monitor the IM (and non-IM) Operations; and
    - In the future the spacing marker may also be used to monitor and control non-IM Operations. However, the simultaneous use of the spacing marker and merge tool needs to be reconsidered. The two information elements are basically used for the same purpose and if both are displayed the radar display quickly becomes cluttered.
    - The spacing marker was hardly used in the RTS because of afore-mentioned cluttering and jumping behaviour.

6.1.5 Observations

The bullet list below gives a summary of observations as gathered during the IM RTS and later on during the data analysis. Although it is not tied to controller acceptance, it was considered useful to put it close to the controller feedback section (paragraph 6.1.3).

- IM was performed on procedures that included a (long) segment with a nominal speed of 240 KIAS, in these cases the speed limit of 250 KIAS below FL100 is too restrictive. Prior to the merge point SOKSI, one transition experienced a headwind and the other transition a tailwind. For the same speed and altitude this results in a groundspeed difference. In order to correct a spacing error, the aircraft with the headwind sometimes had to increase its speed but could only increase its airspeed by 10 kts (i.e., the difference between the nominal speed and the speed limit). As a consequence the groundspeeds became more or less equal and the inter-aircraft distance (observed through the merge tool) did not decrease and had to be corrected in a relatively short time between the merge point and FAP (see also the second bullet of the controller feedback). It is recommended either to delete the speed limit or to adjust the nominal speed to a lower value (e.g., 230 KIAS). Alternatively, the controller may also inform the flight crew that they could disregard the speed limit (e.g., 'high speed approved'), provided that the IM implementation supports the deletion of the speed limit.
- Without explicit discussion or requests from the experiment leads, one controller suspended and later on resumed an IM Operation. This occurred when several aircraft were vectored off the

route (near the merge point). The IM Operation was initially cancelled by means of a speed instruction, but it was resumed when the target aircraft rejoined the route of the transition.

- IM was sometimes used in situations where a large gap was present. The controller knew in advance that the IM Aircraft would not make the Assigned Spacing Goal, but wanted the aircraft to fly high speeds because of a tight sequence behind it. With IM, the aircraft would fly at its nominal speed + 10%, exactly what the controller wanted. It should be noted that on-board the aircraft, at a certain moment, the IM system would inform the flight crew that the IM Operation has become infeasible (this function was not fully implemented during the RTS).
- The aircraft did not always respect the vertical profile due to a simulation implementation issue. Aircraft with a headwind typically flew below the published altitude profile and aircraft with a tailwind typically flew well above the profile. At the merge point, altitude differences of 1000-1500 ft between two succeeding aircraft have been observed. This most likely has had an impact on the spacing performance and the separation between aircraft.
- When flying standard speeds, aircraft did not always comply with the speed constraints on final approach because of a simulation implementation issue. Too low speeds have been observed (-20 kts). This was also seen for IM Operations, i.e., IM Speeds on final approach well below the nominal speed minus 10%. This erroneous behaviour has had an impact on the spacing performance and separation between aircraft.
- Different working methods for issuing the IM target selection and actual IM Clearance have been used; this became clear for aircraft flying the ARTIP2X transition and being sequenced behind an aircraft on the SUGOL2X transition. Due to the large difference in path length, the ‘ARTIP’ aircraft could not be given an IM Clearance immediately after handover (near the IAF), but the controller had to wait for the ‘SUGOL’ aircraft to be handed over (thus ensuring that ACC would not vector them anymore). The working methods were:
    - IM target selection almost immediately after handover from ACC and then waiting a long time (in the order of 1-2 minutes) before issuing the IM Clearance for aircraft on the ARTIP2X transition;
    - Target selection just prior to the IM Clearance, at a moment when the aircraft had already flown a part of the ARTIP2X transition.

  It was found that the better working method was the one where the target selection was almost immediately followed by the IM Clearance itself. This working method did not cause confusion about whether or not an IM Clearance was already given, which the other working method sometimes did.
- If a (target) aircraft was vectored off the route, the controller typically did not cancel the IM Operation of the succeeding aircraft. Moreover, the pseudo-pilot did not query the continuation of the IM Operation in these conditions. In the future, this needs more emphasis during training for both controllers and pilots.
- No modifications to the inbound sequence or any Assigned Spacing Goal suggested by the system have been made. The suggested Target Aircraft and ASG were always used. One controller would have preferred the ASG in more rounded numbers, i.e. 95 instead of 96 seconds, whereas another controller preferred the non-rounded 96 seconds because it creates a clear distinction with heading and speed instructions
- Traffic was normally handed over to the tower near the IF instead of the FAP. The FAP was the anticipated handover point and was selected as the Achieve-by Point. Placing the Achieve-by Point at the IF seems to be more in line with the working method of the APP controllers. Moreover, the handover to the tower was performed while the IM Operation was normally still in progress. The procedures in this RTS weren’t designed to cover a handover with IM still active.

6.1.6 Number of R/T Instructions

The number of R/T instructions was recorded for each aircraft. As can be seen in Figure 24 and Figure 25, the average number of ATC instructions does not vary much between IM and non-IM operations. However, when an IM aircraft is taken off the IM operation and has to continue by radar vectors, the number of instructions effectively doubles.

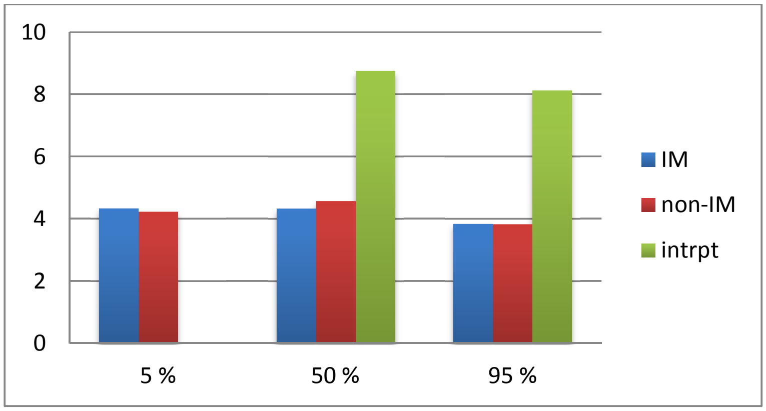

Figure 24. Average number of RT calls per aircraft for each FIM-equipage level. Data is shown for IM-traffic, non-IM traffic and IM-traffic that was interrupted.

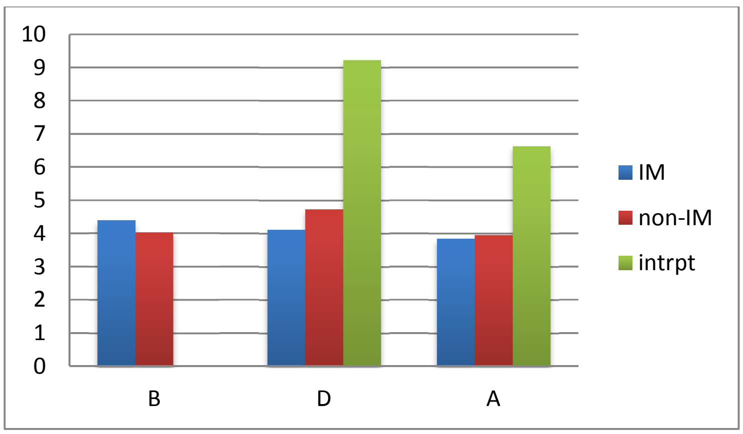

Figure 25. Average number of R/T instructions per aircraft, divided by traffic sample.Data is shown for IM-traffic, non-IM traffic and IM-traffic that was interrupted.

This is further investigated in Figure 26. On average, traffic that remains on the fixed arrival route receives on average about four R/T instructions. (4.0 for IM and 4.0 for non-IM). IM traffic that was instructed to stop IM operations, but remains on the fixed arrival route received an average of 6.6 instructions. This was traffic where the controller intervened mostly by issuing speed instructions and sometimes intermediate altitude restrictions.

The cases where the controller intervened by taking aircraft off the fixed routes, by issuing heading and direct-to instructions, required the most R/T commands, 8.8 for IM and 7.9 for non-IM traffic.

It can be concluded that the introduction of interval management in itself does not increase the average number of R/T commands, but that not using the fixed arrival routes by issuing radar vectors effectively doubles the number of R/T instructions.

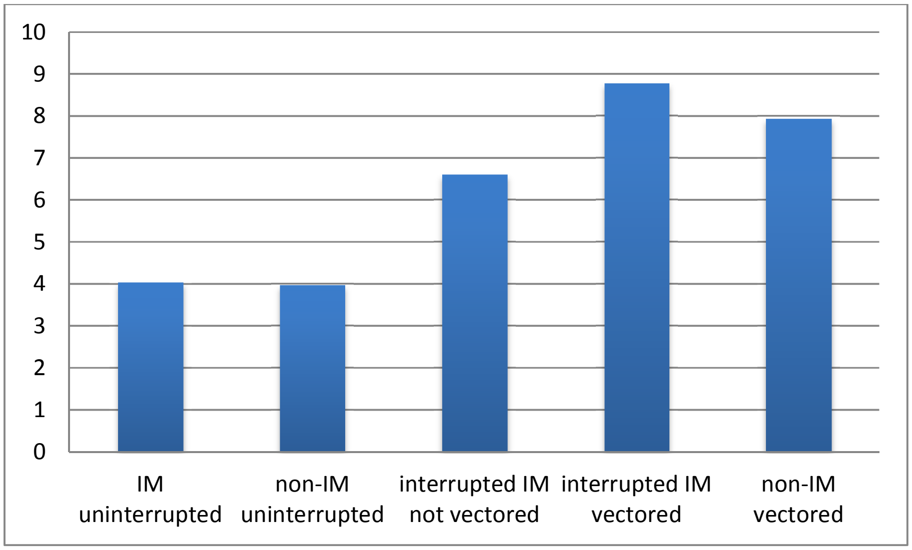

Figure 26. Average number of RT instructions per aircraft. Data is shown for uninterrupted IM and non-IM traffic, interrupted IM traffic that remaind on the fixed arrival route and traffic that received radar vectors, both IM and non-IM

6.2 Number of violations of the Separation Standard

The number of separation violations is presented below. As can be seen, a number of runs had multiple separation losses. All of these occurred close to the Achieve-by Point, or close to the merge point.

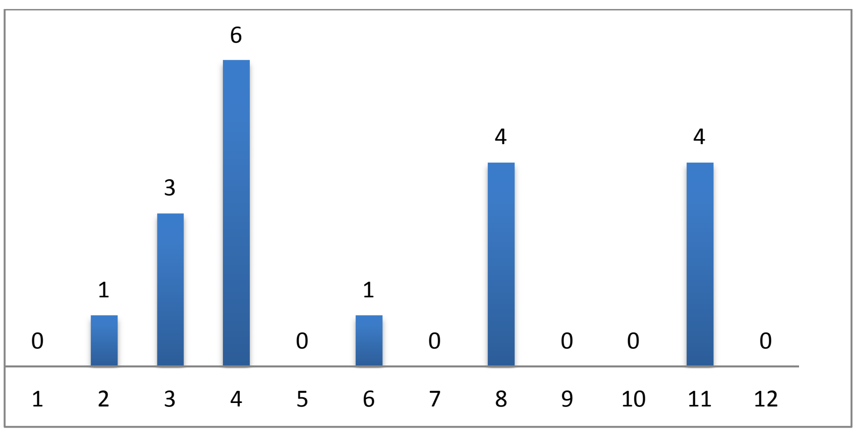

Figure 27 The number of separation losses for each run.

Most of the separation violations are less than 0.5 NM and are due to spacing the aircraft just a little too close. To give an indication of the severity of the separation losses, Figure 28 shows the number of times the separation was violated with more than 0.5 NM.

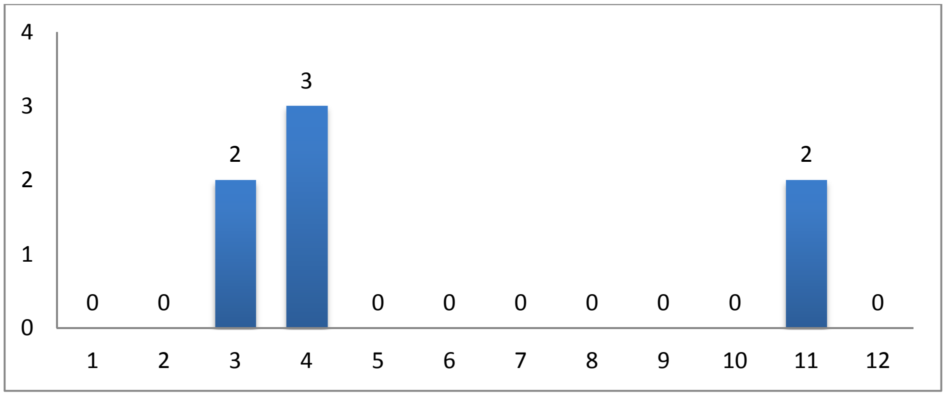

Figure 28. The number of separation violations by more than 0.5 NM.

During run numbers 3, 4 and 11 a non-nominal event was included, which forced the ATCo to deal with a sudden unexpected situation. As can be seen in the figure, this led to problems in these runs. Two separation losses occurred at the merge point, and five on final approach. These separation losses are described in more detail in 6.4.2.
Runs 6, 7 and 12 also contained non-nominal events, but were dealt with without serious separation violations.

6.2.1 Effect of Traffic Sample and FIM Equipage Level

Figure 29 shows the average number of separation violations per simulation run for the different traffic scenarios and FIM equipage levels. Traffic scenario A had the highest traffic density, which caused the controllers to space the aircraft more closely, resulting in the highest number of minimum separation violations.
The FIM equipage level did not show a significant effect. During the simulation runs, it was observed that the controller would typically interrupt the IM Operation when the spacing seemed to get too close, so it cannot be concluded that IM-spacing results in a similar separation violation rate to radar vectoring.

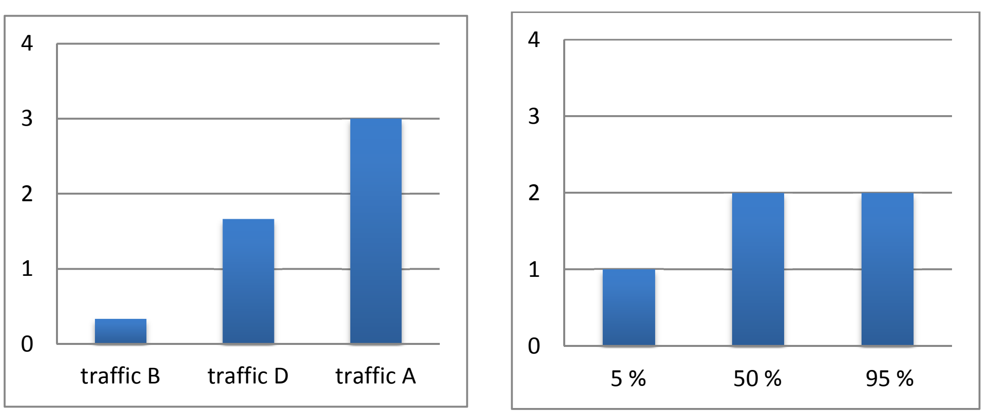

Figure 29. Average number of separation violations per run, split for each traffic scenario and FIM equipage level.

6.3 Assigned Spacing Goal Conformance

The Assigned Spacing Goal for each wake vortex combination is presented in Table 4 (page 22). The actual achieved in-trail spacing in seconds was recorded over the Achieve-by Point for all aircraft that were flying *uninterrupted* during their IM Operation. This metric can be seen as a measure of safety versus capacity, as a spacing below the assigned spacing goal may infringe wake vortex or radar separation minima, while a spacing larger than the assigned spacing goal may result in a lower runway throughput number.

6.3.1 Effect of Traffic Sample

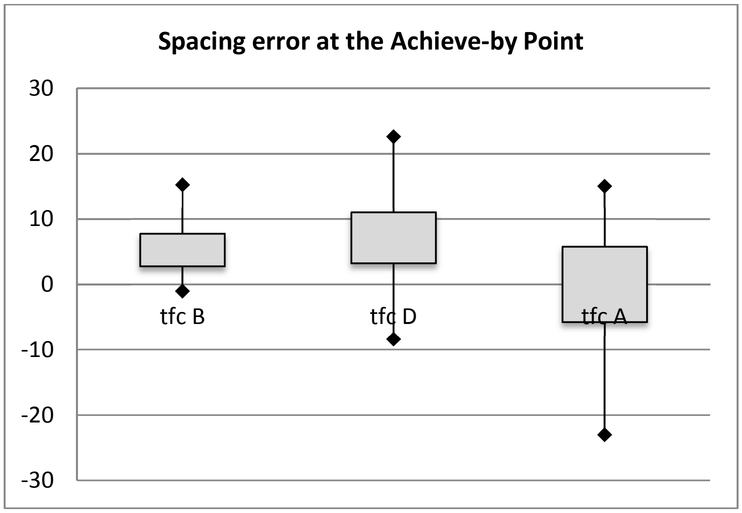

Figure 30. Average spacing error and standard deviation (in seconds) for each traffic scenario.

As can be seen in Figure 30, the traffic scenario had a large effect on the average spacing error. This is to be expected, as scenarios B and D were relatively low traffic density (25.7 and 32.6 aircraft per hour, respectively), which resulted in gaps that could not be closed by the IM algorithm. In the highest traffic density scenario A (36.3 aircraft per hour), there are fewer gaps, and the throughput is maximized.

This effect is visualized in Figure 31. It can be seen that the average spacing error is increased by a small number of very large positive spacing errors (gaps, capacity loss) in traffic scenarios B and D. The higher traffic density of scenario A allows the IM-algorithm to close the gaps and minimize the spacing error. On the other hand, the higher traffic density also causes an increase in the number of cases where aircraft end up *below* the target spacing (negative spacing error, spacing too close). While 0% and 8% of the IM-aircraft arrive more than 10 seconds early in scenarios B and D respectively, this number increases to 20% for scenario A.

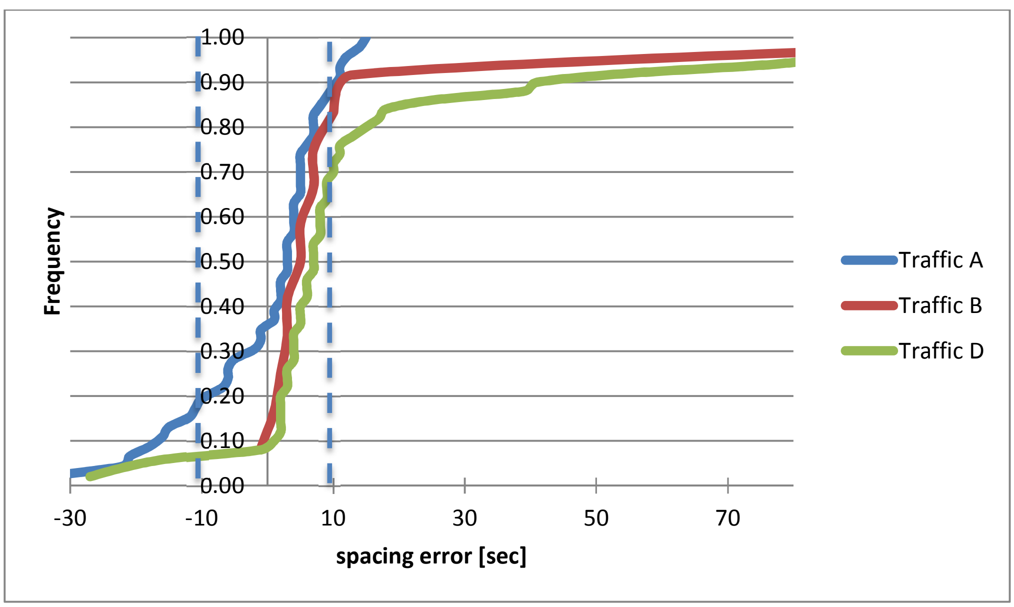

Figure 31. Distribution of the spacing error for the different traffic scenarios.

6.3.2 Effect of FIM Equipage Level

The effect of the FIM equipage level of the traffic mix did not have an effect on the average spacing error, as shown in Figure 32. This indicates that the IM-algorithm worked equally well on equipped and non-IM equipped target aircraft.

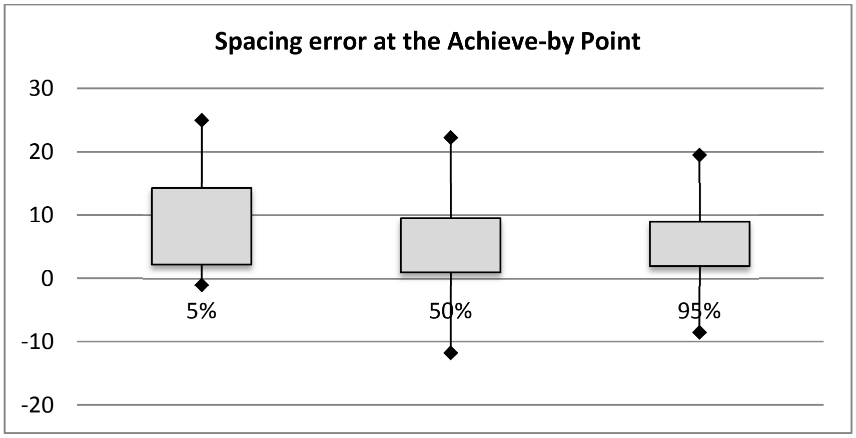

Figure 32. Average spacing error and standard deviation (in seconds) for FIM equipage levels.

However, Figure 33 does show a small effect of the FIM equipage level on the distribution of the spacing error. The 95% equipage level shows a better performance for the negative spacing errors. It was observed during the runs that the controllers would typically issue large speed reduction when aircraft were approaching the Achieve-by Point, especially during higher traffic densities. Since the IM-algorithm is restricted to ± 10% speed changes, a possible explanation for the slightly worse performance of the 50% equipage scenario over the 95% equipage, is that the more gradual speed reductions of IM-aircraft, facilitate the following by other IM-aircraft.

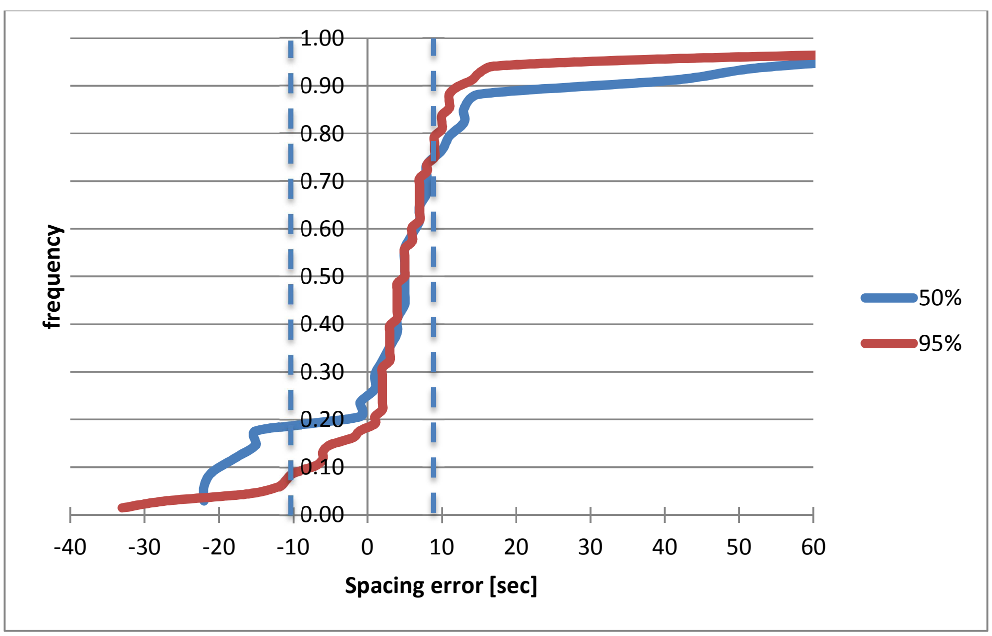

Figure 33. Distribution of the spacing error for different equipage levels.

6.4 Excessive Spacing at the Achieve-by Point

All figures in this section present the excessive spacing between two consecutive aircraft in the sequence, when the lead aircraft crossed the Achieve-by Point (= Final Approach Point and Planned Termination Point). The excessive spacing is the actual slant range distance minus the wake vortex or radar separation minimum applicable for the aircraft pair, see Figure 34. For example, the actual distance between two Heavies was 5.1 NM and, given that the separation distance for that pair is 4 NM, the normalized distance, as displayed in the figures, is therefore 1.1 NM.

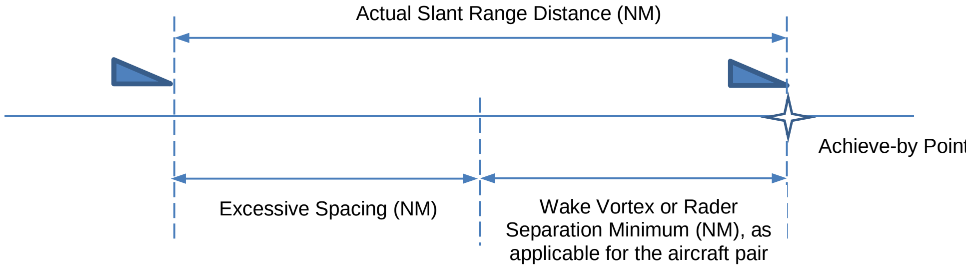

Figure 34. Excessive Spacing at the Achieve-by Point

6.4.1 Effect of IM Operations

Figure 35 and Figure 36 present the overall results for non-FIM equipped and FIM equipped traffic. In general FIM equipped aircraft performed IM Operations. These results are for all runs performed during the RTS. It may be concluded that, as anticipated, the FIM equipped traffic performs more consistently than non-FIM equipped traffic, i.e. a steeper curve in Figure 36. However, as not all FIM equipage levels were tested for all three Traffic Samples and both wind conditions, a more credible comparison is given in paragraph 6.4.3.

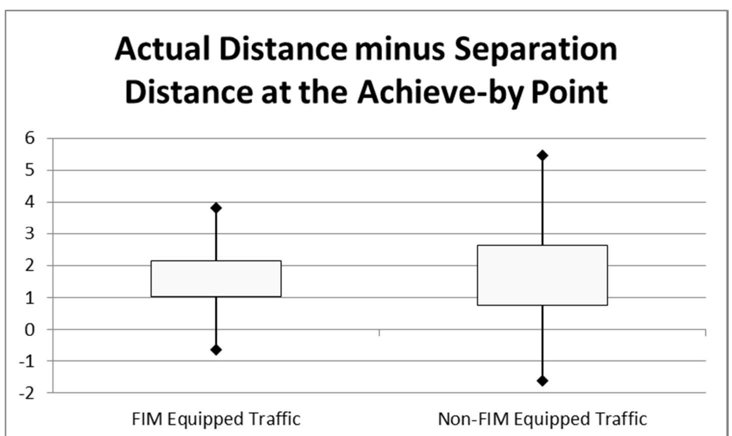

Figure 35 Box plot[2] of Excessive Spacing (in NM) at the ABP - FIM equipped versus Non-FIM equipped traffic

[2] The box represent the middle 50% of the data (25% of the data is lower and 25% is higher) and the whiskers (defined as lowest/highest data within 1.5 times the Interquartile Range) represent the 'upper limit' and 'lower limit' of the data.

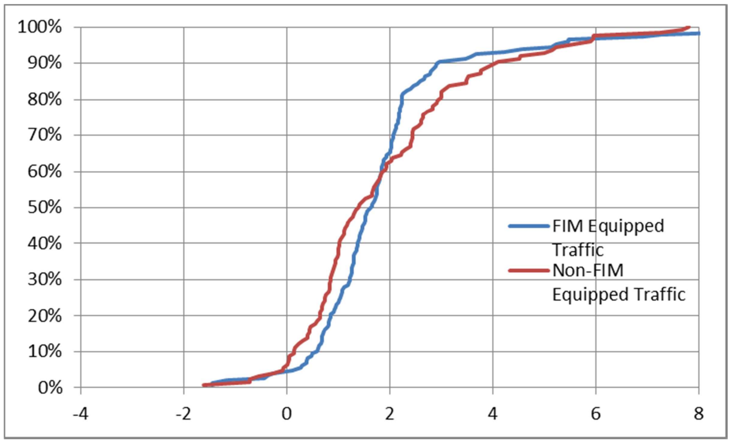

Figure 36 Distribution of Excessive Spacing (in NM) at the ABP - FIM equipped versus Non-FIM equipped traffic

6.4.2 Separation Standard

Eleven aircraft out of 269 (4.0%) violated the separation standard by more than 0.1 NM at the Achieve-by Point. These cases have been categorized as follows: IM performance related, IM usage related, and not related to IM. Note that sometimes a case has been put in two categories. Furthermore, one special case has been added, case 12 describes a separation loss near the merge point; however, on final approach the separation had been restored.

In summary:

- Five cases (1, 3, 5, 6 and 11).are related to IM performance. Cases 3 and 6 involved simulation errors.
- Three cases (2, 5 and 10) are related to the usage of IM.
- Five cases (4, 7, 8, 9 and 12) are not or not primarily related to IM Operations. Case 4 involved a pilot error, case 7 and 8 involved simulation errors, and case 9 involved a controller error.

The table below discusses each case in detail.

All cases where the separation was less than 2.5 NM, as identified in section 6.2, are also included in the table below. Most occurrences coincide with the violations of the separation standard at the Achieve-by Point. One specific case has been added at the end of the table below (case 12), it involved a separation loss near the merge point but it did not result in a spacing below the separation standard on final approach. During three runs (out of twelve) a total of seven losses of separation (<2.5 NM) occurred.

- Two losses of separation occurred near the merge point (once between two IM aircraft in combination with an incorrect target selection and once between two non-IM aircraft)
- All five losses of separation on final approach were related to an aircraft performing IM and an aircraft not performing IM. In 3 out of 5 cases in combination with vectoring. In all of these cases IM Operation was continued where it should have been cancelled (due to vectoring or a very low speed instruction to the target aircraft). In 2 out of 5 cases a non-IM aircraft trailing an IM aircraft didn't reduce speed in time, due to a 'late' instruction in combination with a slow deceleration on the continuous descent path.

It is concluded that improvements are needed in terms of guidance (and training) to the controllers on when to suspend or terminate IM Operations, especially in relation to vectoring operations and (very) large speed reductions of a target aircraft. Furthermore, additional controller support with respect to their monitoring task might sometimes be helpful (e.g., continuous display of the spacing marker and/or continuous display of the actual IAS). Special attention in terms of controller support is deemed necessary for non-IM aircraft behind an IM aircraft.

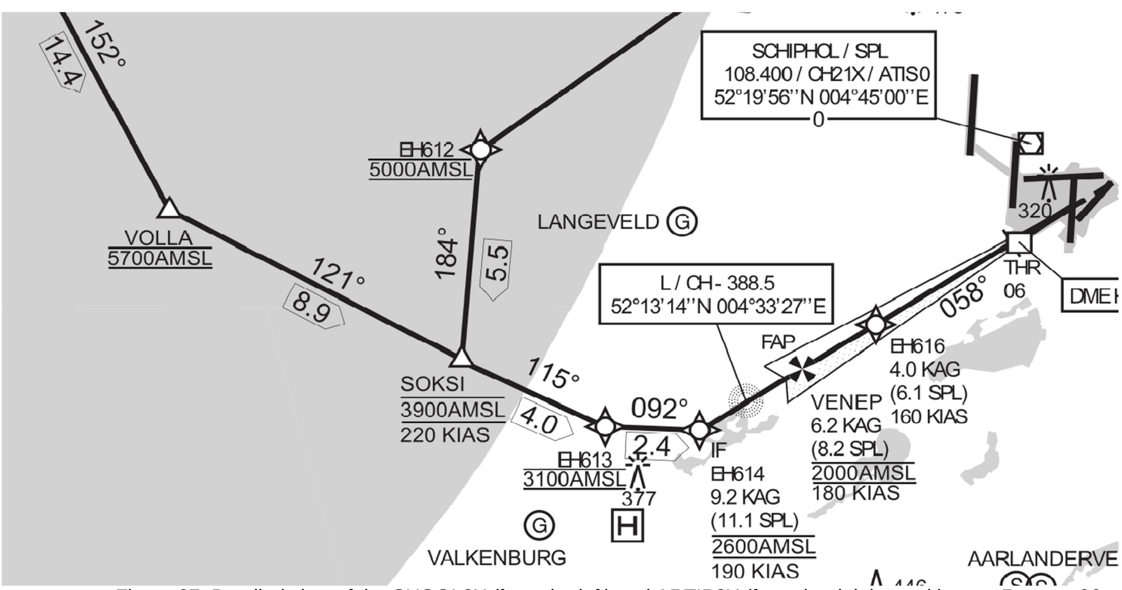

Figure 37 Detailed view of the SUGOL2X (from the left) and ARTIP2X (from the right) transitions to Runway 06

Table 11 Violations of the separation standard by at least 0.1 NM, lead aircraft crosses the FAP (= ABP, PTP)

Case	Violation of separation standard (NM)	Separation distance (NM)	Aircraft Pair (Lead, Trail)	Discussion	Event ID
1	-0.27	3	KLM84F, KLM1362	Sequence (initial): - EZY215A B737, S2X, IM - RRR1701 B461, S2X, IM - KLM84F F70, S2X, IM - KLM1362 E190, A2X, IM - FIN841Q A320, A2X, IM This was a sequence of three aircraft on the SUGOL2X transition, KLM84F was last in this sequence. KLM1362 flew the ARTIP2X transition and was sequenced behind KLM84F. All aircraft, incl. KLM1362, were performing IM Operations. This was a Wind 1 (light) scenario. All aircraft on SUGOL2X (headwind) passed the merge point SOKSI (constrained at 3900ft) too low at approx. 3100ft, whereas KLM1362 on ARTIP2X (tailwind) passed SOKSI too high at approx. 4700ft. So both the tailwind and higher altitude contributed to a high groundspeed for KLM1362. This behaviour was also observed during other runs and is considered to be a simulation error. Both aircraft were flying rather slow (at or close to their -10% limit), correcting their spacing errors. The aircraft were flying very similar groundspeeds, and the consistent altitude difference of more than 2000 ft had an adverse effect. Consequently, KLM1362 was not able to increase the gaps sufficiently prior to the Achieve-by Point, and it resulted in the observed minimum distance of 2.73 NM. It should also be noted that the controller did not intervene.	A1
2	-1.45	3	FIN841Q, KLM678	Sequence (initial): - KLM1362 E190, A2X, IM - FIN841Q A320, A2X, IM - KLM678 A332 (H), S2X, IM Directly related to a planned non-normal event: Incorrect target aircraft ID readback and subsequent incorrect target aircraft selection by FIN841Q. As a consequence, close to the merge point SOKSI, FIN841Q was becoming too closely spaced behind its lead (KLM1362) and therefore was given a speed of 180 kts and a heading of 170 (i.e., a path extension). Minimum horizontal separation was 2.0 NM; vertical separation was within 1000 ft between FIN841Q and KLM1362 around the merge point. FIN841Q was turned back late to CH, and eventually ended up too close in front of KLM678. KLM678 initially continued IM Operation (while FIN841Q was being vectored well off the transition, slightly more than 3 NM off route), with a high speed to close the initial large gap, however as FIN841Q 'intercepted' the transition with a large angle (by flying the final approach course) the distance between the two aircraft decreased very rapidly.	A1

				At a certain point the controller intervened, giving KLM678 a speed of 180 KIAS, but it took too long to decelerate. Consequently, the aircraft were only separated by 1.55 NM when FIN841Q crossed the FAP. It should be noted that IM Operations should have been suspended or terminated by both the controller and flight crew due to the vectoring of FIN841Q. Note that the associated indication to the flight crew and flight crew procedure were not yet implemented in the RTS.	
3	-0.36	3	SAS557, GWL8732	Sequence (initial): - BTID9 B735, A2X, IM - SAS557 B736, A2X, IM - GWL8732 B744 (H), A2X, IM The aircraft in front of SAS557 was put on a speed of 180 KIAS prior to the localizer intercept and also the aircraft behind SAS557 was put on a speed of 180 KIAS near the merge point SOKSI (the merge was not relevant as the aircraft were flying the same transition). SAS557 continued the IM Operation; however it was flying extremely slow when on the intercept course to the localizer. As observed during other runs, sometimes the reference speed profile at this point was 170 KIAS instead of 190 KIAS (a simulation error). Together with the minus 10% IM limit SAS557 was indeed flying 150-155 KIAS. Whereas the other aircraft were flying 180 KIAS. The controller instructed SAS557 to fly 180 KIAS and GWL8732 170 KIAS. It finally resulted in a separation of 2.64 NM near the FAP (at the point also the vertical separation had just been lost).	D2
4	-0.71	3	KLM1480, KLM1290	Sequence (initial): - KLM1026 F70, S2X, ATC speeds - KLM1480 F70, S2X, IM - KLM1290 E190, S2X, ATC speeds - CFE76A B462, S2X, ATC speeds KLM1480 initially flew IM, but still near IAF SUGOL the controller started to instruct speeds, initially 240 and later on 200 KIAS. So, this sequence was fully controlled by ATC through speed control. After the merge point SOKSI, KLM1480 is instructed to resume IM. Shortly thereafter the groundspeed of KLM1480 drops by 45 knots. In response the controller, somewhat later, reduces the speed of the trailing aircraft KLM1290 from 210 to 180 KIAS. But after this speed reduction the groundspeed difference was still 15 kts closing. It resulted in a separation of just 2.29 NM when KLM1480 crossed the FAP.	D2
5	-1.45	5	BCS730, KLM78B	Sequence (initial): - KLM1024 B737, S2X, IM - GWL8732 B744, A2X, IM - BCS730 A30B, S2X, IM - KLM78B E190, A2X, IM	D1

				KLM1024 was delivered 2 minutes late at the IAF, just ahead of GWL8732 (based on distance projection). Due to the mainly tailwind for GWL8732 and headwind for KLM1024, the groundspeed remained quite similar. About 10 NM before the merge point, SOKSI, GWL8732 was put on a heading. And immediately thereafter BCS730 was also put on a heading and was instructed to fly 200 KIAS. When GWL8732 flew off the transition at EH612, it was also given a speed instruction (190 KIAS). Shortly thereafter, GWL8732 was instructed to re-intercept the transition. Somewhat later, also BCS730 was instructed to re-intercept the transition (this occurred at SOKSI). Again somewhat later, KLM78B was instructed to cancel IM and fly 200 KIAS (about 15 NM before SOKSI) When BCS730 re-intercepted the transition at SOKSI, KLM78B was instructed to resume IM, however KLM78B was too close to correct the spacing error (note: the lead aircraft BCS730 flew standard speeds). The controller intervened when KLM78B crossed EH613, and instructed it to reduce to FAS. It should be noted that the performance was also affected by a sustained altitude difference, initially 3000 ft.	
6	-0.55	3	BTI6D9, SAS557	Sequence (initial): - BAW442 A320, S2X, ATC speeds - BTI6D9 B735, A2X, IM - SAS557 B736, A2X, ATC speeds - GWL8732 B744, A2X, ATC speeds BAW442 flew standard speeds, however, when approaching the Intermediate Fix (IF), EH614, and its airspeed was approx. 172 KIAS instead of the published 190 KIAS. As a consequence, BTI6D9 also had to reduce speed (still under IM). When approaching the IF, BTI6D9 flew approx. 155 KIAS (~172 KIAS minus 10%). Instead of the expected minimum value of 171 KIAS (190 minus 10%). ATC instructed SAS557 to fly 180 KIAS, this resulted in a closing groundspeed of 23 kt. While the BTI was sufficiently spaced behind the BAW, the SAS came too close despite the controller instruction to the SAS aircraft (just prior to the IF) to reduce from 180 to FAS. It should be noted that vertical separation was maintained throughout the operation.	D2
7	-0.27	3	KLM1026, KLM1480	Sequence (initial): - SAS553 MD82, A2X, ATC speeds - KLM1026 F70, S2X, STD speeds - KLM1480 F70, S2X, STD speeds KLM1026 reduced and reached approx. 173 KIAS at EH613 (waypoint prior to the IF). At this point the expected speed is 190 KIAS due to the 190 kt speed constraints at the IF. The controller thereafter instructed KLM1026 to reduce to 170 KIAS, the deceleration was rather slow due to the descending flight and the resulting spacing was 2.73 NM when KLM1026 crossed the FAP.	D2

8	-0.72	3	CFE76A, KLM1396	Sequence (initial): - KLM1290 E190, S2X, ATC speeds - CFE76A B462, S2X, STD speeds - KLM1396 B738, A2X, ATC speeds CFE76A is low on the profile (2700 ft at SOKSI) and KLM1396 is high on the profile (5300 ft at SOKSI). Furthermore, CFE76A reduces and reaches approx. 173 KIAS at EH613 (expected speed was at least the published speed of190 KIAS at IF). The controller reduced KLM1396 in a few steps (220 → 180 → 160) between SOKSI and the IF, and reduced it to FAS just after passing the IF. However, in combination with the descending flight the deceleration was rather slow. Consequently, the two aircraft came too close together. It should be noted that vertical separation was maintained throughout the operation.	D2
9	-1.61	5	SQC7879, KLM1396	Sequence (initial): - KLM1386 B738, A2X, ATC speeds - SQC7879 B744 (H), S2X, IM speeds - KLM1396 B738, A2X, STD speeds When SQC78679 crossed SOKSI, it was flying at approx. 200 KIAS (220 minus 10%) to achieve the assigned spacing. Its lead KLM1386 was reduced from 250 to 220 to 180 KIAS prior to SOKSI. KLM1396 was held on standard speeds. As a consequence, the spacing that was initially 7 NM, reduced to 3.4 NM when SQC crossed the FAP, well below the 5 NM standard.	D1
10	-1.17	3	FIN841Q, SAS1553	Sequence (initial): - KLM1362 E190, A2X, IM speeds - KLM84F F70, S2X, IM speeds - FIN841Q A320, A2X, IM speeds - SAS1553 MD82, A2X, IM speeds - KLM678 A332 (H), S2X, IM speeds - MPH0640 B763 (H), S2X, IM speeds When KLM84F crossed SOKSI (merge point) it was 4 NM behind KLM1362 and had a similar groudspeed. The controller decided to reduce KLM84F (low on the profile) and FIN841Q (high on the profile) to their FAS. SAS1553 was continued on IM. As a consequence, the SAS aircraft came close to the FIN aircraft. The SAS was vectored off route (and immediately also the KLM678 was vectored off route). SAS was turned back to intercept the ILS at slightly more than 3 NM behind the FIN. Due to the extremely slow speed of the FIN aircraft, and the SAS still performing IM, the spacing quickly reduced well below 3 NM. It should be noted that IM Operations should have been suspended or terminated by both the controller and flight crew due to the vectoring of the SAS aircraft. The KLM678 is vectored on to the localizer well behind SAS1553; however, its trailing aircraft MPH0640 continued IM Operation on the SUGOL2X transition. Consequently, MPH0640 and KLM678 came as close as 2.4 NM (with a separation standared of 4 NM). Again, because KLM678 was vectored well off route (~3 NM) both controller and flight crews (of KLM678 and MPH0640) should have suspended or terminated IM	A2

				Operations	
11	-0.43	5	LCO1506, KLM365	Sequence (initial): - SQC7879 B744 (H), S2X, IM speeds - EZY163K A319, S2X, IM speeds - LOC1506 B763 (H), S2X, IM speeds - KLM365 B734, A2X, IM speeds EZY163K, LOC1506 and KLM365 have to fly for a prolonged period of time at nominal speeds minus 10%. This isn't an issue for the pairs SQC-EZY. EZY-LOC because they are flying the same transition (same wind impact), however, for the LOC-KLM pair it is more problematic. The KLM aircraft has initially a much higher groundspeed than the LOC aircraft due to the wind (tailwind on ARTIP2X, headwind in SUG2X), and as a consequence these aircraft are too close around the merge point (approx. 4 NM). The spacing was 4.57 NM when LOC1506 crossed the FAP, and later on it had increased to 5 NM when KLM365 crossed the IF (i.e., localizer intercept). It should be noted that vertical separation was maintained throughout the operation.	D1
(12)	N/A	3	SAS553 KLM1026	Sequence (initial): - BAW8119 B734, S2X, STD speeds - SAS553 MD82, A2X, ATC speeds - KLM1026 F70, S2X, ATC speeds Due to the large groundspeed differential and a spacing less than 3 NM, between the BAW and SAS aircraft near SOKSI, the controller puts SAS553 on a heading. (The aircraft were vertically separated). When horizontal separation is well established, SAS553 is given a direct to CH. Due to a relatively late direct to, the spacing between SAS and BAW aircraft is now approx. 7 NM, but between the SAS and KLM aircraft only 4 NM and reducing because the SAS is flying a longer path due to the vectoring. Despite a speed reduction of 20 kts for KLM1026, the horizontal separation reduces to 2.3 NM before the aircraft become vertically separated.	A1

6.4.3 Effect of FIM Equipage

The results of the excessive distance spacing metric at the Achieve-by Point are presented in Figure 38 through Figure 48.

Figure 38 and Figure 39 show that the excessive spacing becomes more consistent with an increase in FIM equipage level. However, it should be noted that not all FIM equipage levels have been tested for all conditions.
Traffic Sample D is the only traffic sample for which all combinations of FIM equipage levels and wind conditions have been tested. Therefore, real comparative results are available for this traffic sample only. Figure 40 shows that the performance (for Traffic Sample D) with 95% equipage is better than the performance with the other two equipage levels. This is supported by Figure 43, it shows that the 95% FIM equipage level has a steeper curve, indicating that it performs better than the other FIM equipage levels. This is also clearly visible in the scatter plots providing the 'individual' results for Traffic Sample D and the various FIM equipage levels, compare Figure 44, Figure 45 and Figure 46. It indicates that if the traffic density is increased, this performance benefit may actually be realized (i.e., shifting the Trfc D 95% curve slightly to the left). This is indeed visible for Traffic Sample A with the highest throughput, see Figure 41. Note that also the 50% case now shows a better performance compared to the other two traffic samples with lower throughputs. It is also illustrated by the scatter plots for Traffic Sample A, see Figure 47 and Figure 48

The figures below show that IM becomes effective:

- In the scenario with the highest traffic density (36 ldg/hr), for both 50% and 95% FIM equipage; and
- In the scenario with the second highest traffic density (32 ldg/hr) and 95% FIM equipage.

For the other cases, the 50% and 5% FIM equipage show very similar results for the excessive distance spacing at the Achieve-by Point'.

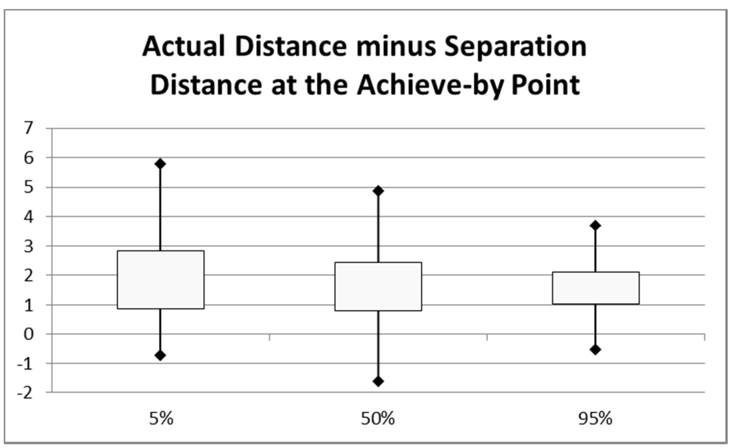

Figure 38 Box plot of Excessive Spacing (in NM) at the ABP - Level of FIM equipage

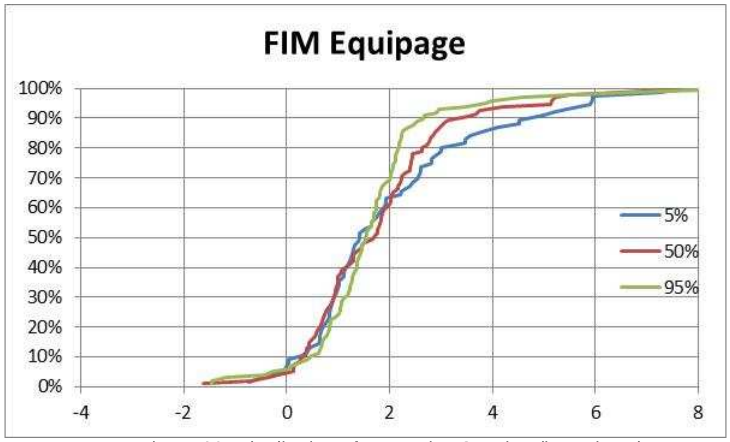

Figure 39 Distribution of Excessive Spacing (in NM) at the ABP - Level of FIM equipage

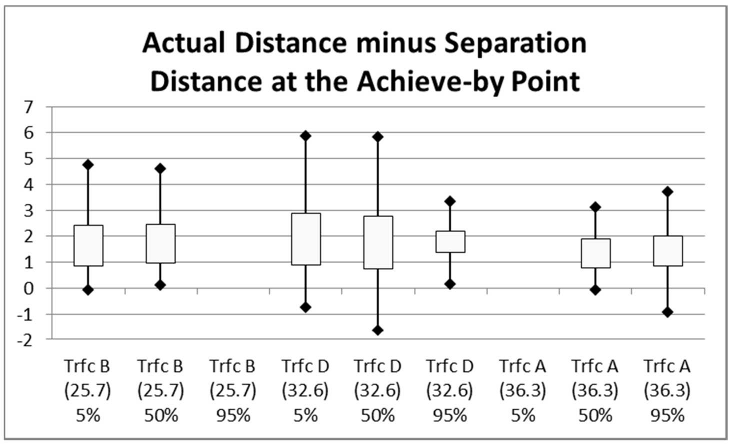

Figure 40 Box plot of Excessive Spacing (in NM) at the ABP - Traffic Sample and FIM equipage

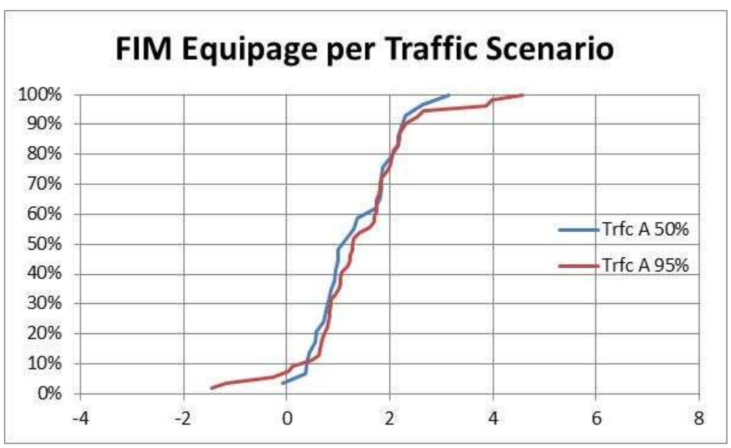

Figure 41 Distribution of Excessive Spacing (in NM) at the ABP - Traffic Sample A (36.3 ldg/hr), FIM equipage

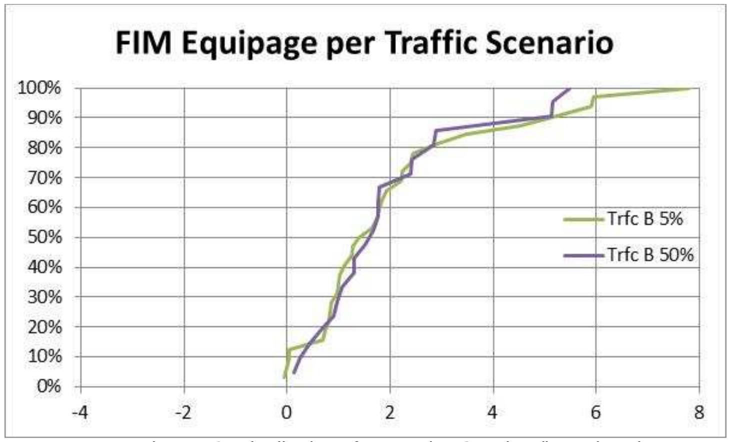

Figure 42 Distribution of Excessive Spacing (in NM) at the ABP - Traffic Sample B (25.7 ldg/hr), FIM equipage

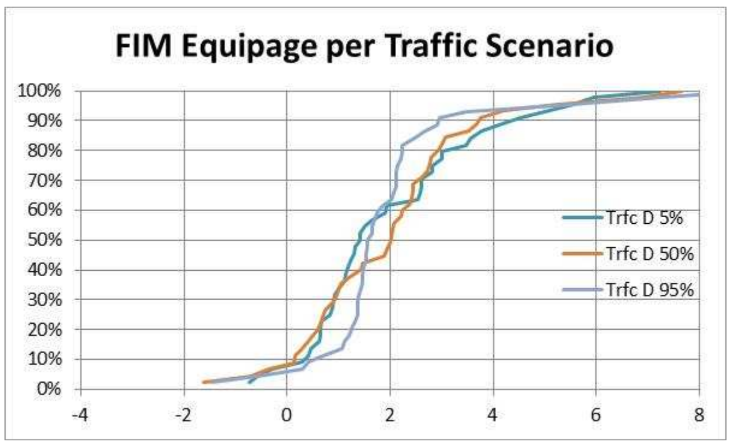

Figure 43 Distribution of Excessive Spacing (in NM) at the ABP - Traffic Sample D (32.6 ldg/hr), FIM equipage

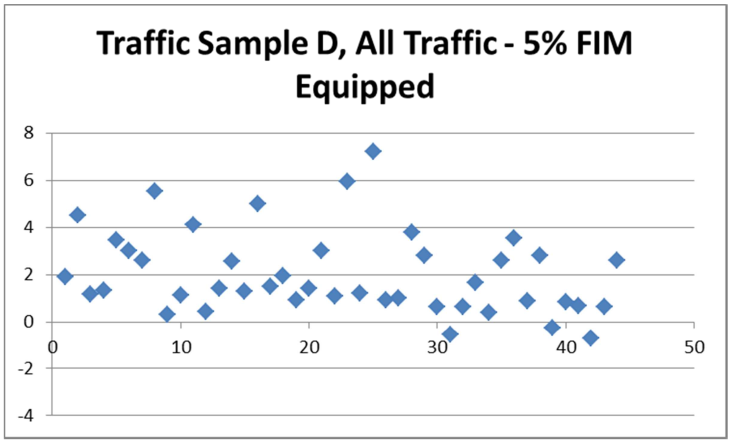

Figure 44 Individual data points of Excessive Spacing (in NM) at the ABP - Traffic Sample D (32.6 ldg/hr), 5% FIM equipage

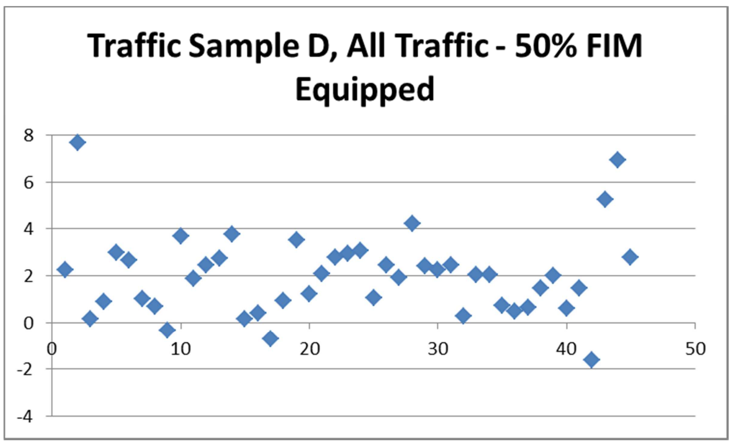

Figure 45 Individual data points of Excessive Spacing (in NM) at the ABP - Traffic Sample D (32.6 ldg/hr), 50% FIM equipage

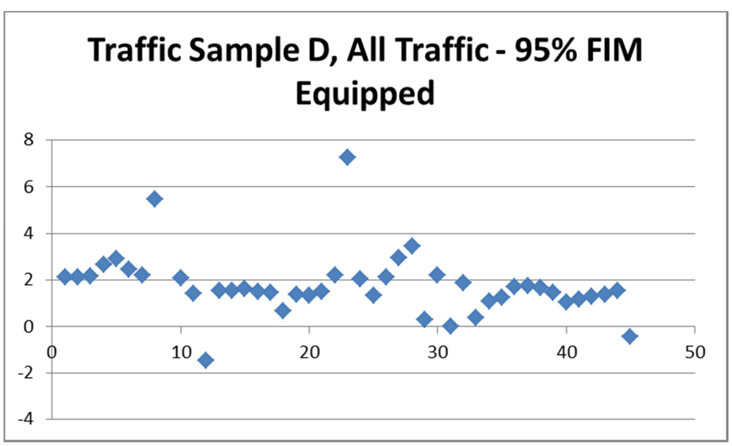

Figure 46 Individual data points of Excessive Spacing (in NM) at the ABP - Traffic Sample D (32.6 ldg/hr), 95% FIM equipage

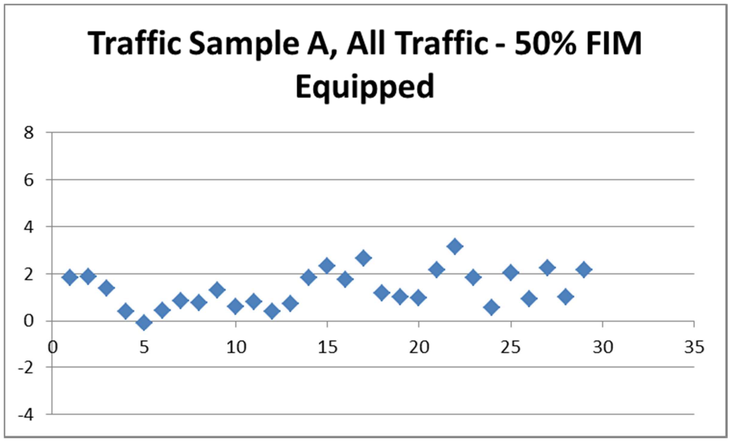

Figure 47 Individual data points of Excessive Spacing (in NM) at the ABP - Traffic Sample A (36.3 ldg/hr), 50% FIM equipage

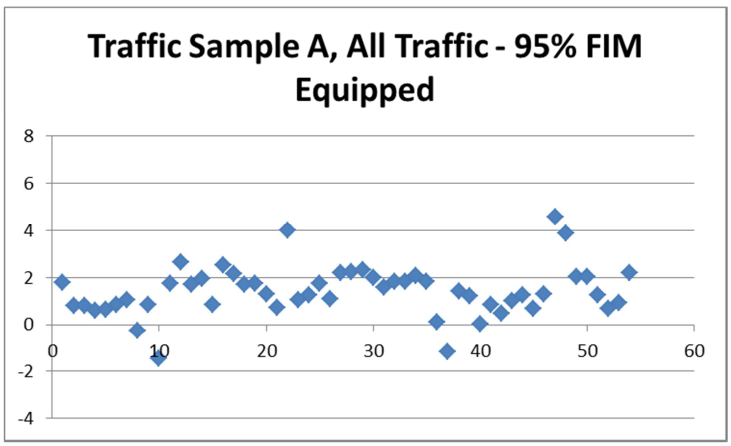

Figure 48 Individual data points of Excessive Spacing (in NM) at the ABP - Traffic Sample A (36.3 ldg/hr), 95% FIM equipage

6.4.4 Effect of Wind

Figure 50 show that the performance is very similar for Wind 2 (moderate winds) over the Traffic Samples, this is confirmed by Figure 52. The performance varies considerably for Wind 1 (light winds), also this is confirmed by the cumulative distribution in Figure 51. It is concluded that under light wind conditions the required performance is not influenced by the wind field, but for moderate wind conditions a similar performance is required for the three traffic densities up to 70 percent, the remaining 30 percent needed to be spaced closer for the highest traffic density only (see W2 - Trfc A curve in Figure 52).

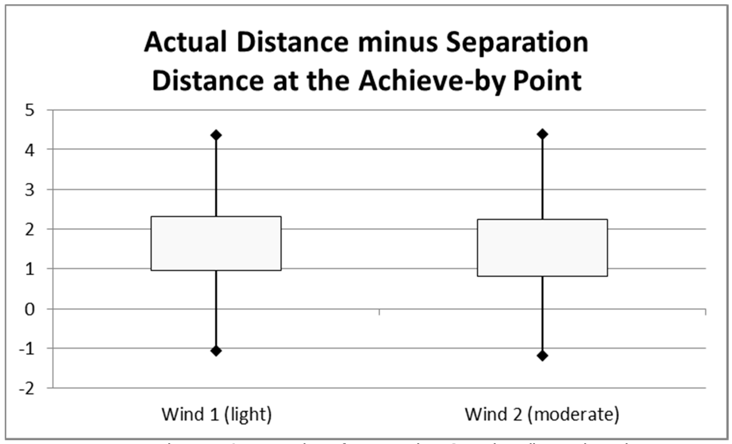

Figure 49 Box plot of Excessive Spacing (in NM) at the ABP – Wind (1 Light, 2 Moderate)

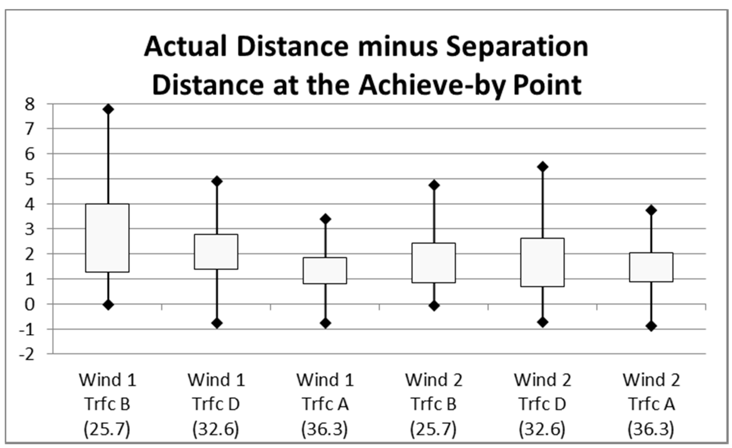

Figure 50 Box plot of Excessive Spacing (in NM) at the ABP - Traffic Sample and Wind

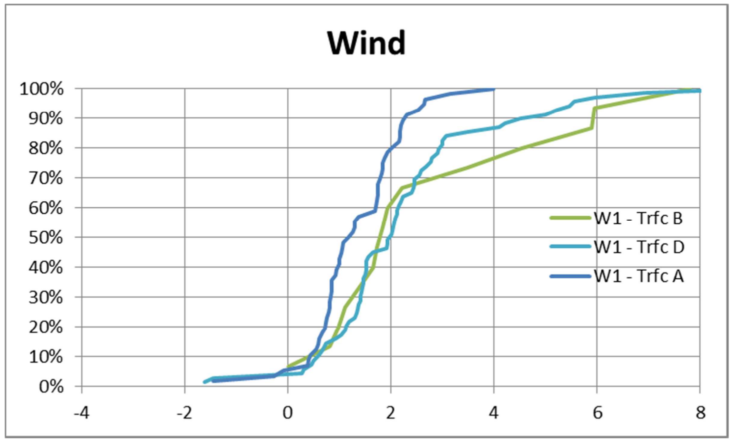

Figure 51 Distribution of Excessive Spacing (in NM) at the ABP - Traffic Sample and Wind 1 (light)

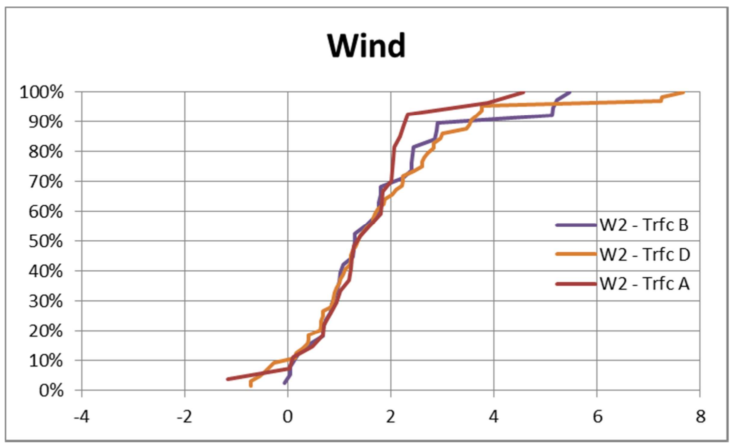

Figure 52 Distribution of Excessive Spacing (in NM) at the ABP - Traffic Sample and Wind 2 (moderate)

6.4.5 Effect of HMI

It can not be concluded that the HMI itself is or isn't making a difference. The difference between the two HMI variants, as shown in Figure 53 and Figure 54, could very well be caused by the traffic samples (see Figure 55). Traffic Sample A is the highest traffic density, and therefore requires a better performance compared to the other Traffic Samples (see upper 60% for Trfc A in Figure 55).

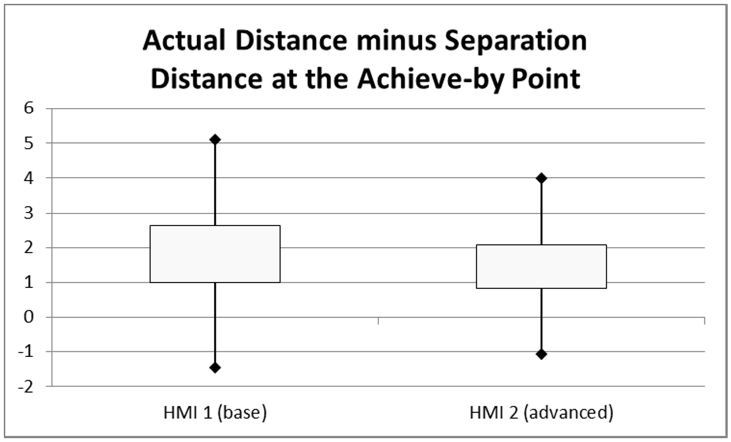

Figure 53 Box plot of Excessive Spacing (in NM) at the ABP – HMI (1 Baseline, 2 Advanced)

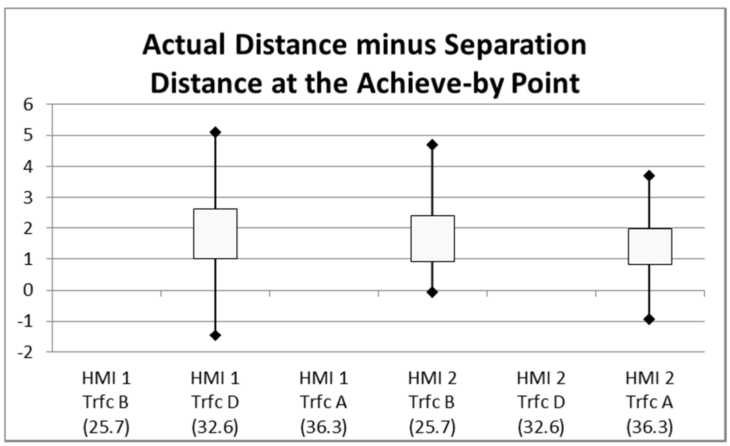

Figure 54 Box plot of Excessive Spacing (in NM) at the ABP - Traffic Sample and HMI

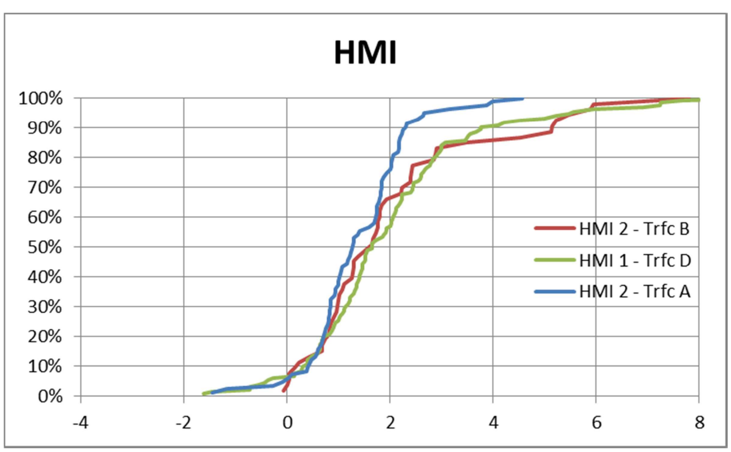

Figure 55 Distribution of Excessive Spacing (in NM) at the ABP - Traffic Sample and HMI

6.4.6 Effect of Traffic Sample (traffic density)

The figures for the Traffic Samples are the same as presented for the two HMI conditions, since there was a one-to-one link between the HMI condition and Traffic Sample.
It is shown that in particular the highest traffic density resulted (and required) the best performance. See the box size of Trfc A in Figure 56 and the Trfc A curve in Figure 57.

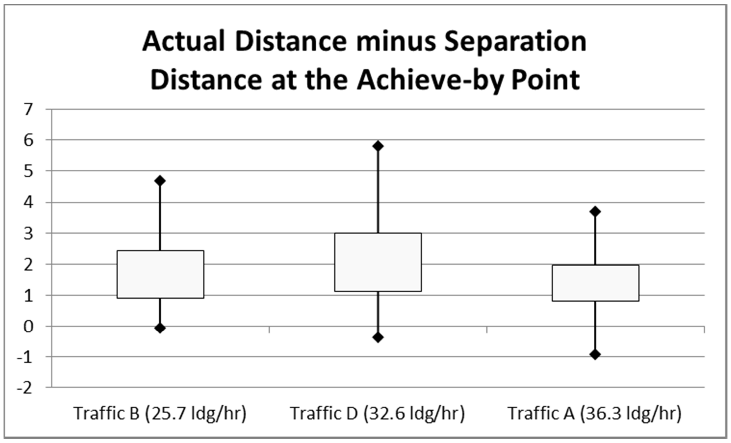

Figure 56 Box plot of Excessive Spacing (in NM) at the ABP - Traffic Sample (B 25.7, D 32.6 and A 36.3 ldg/hr)

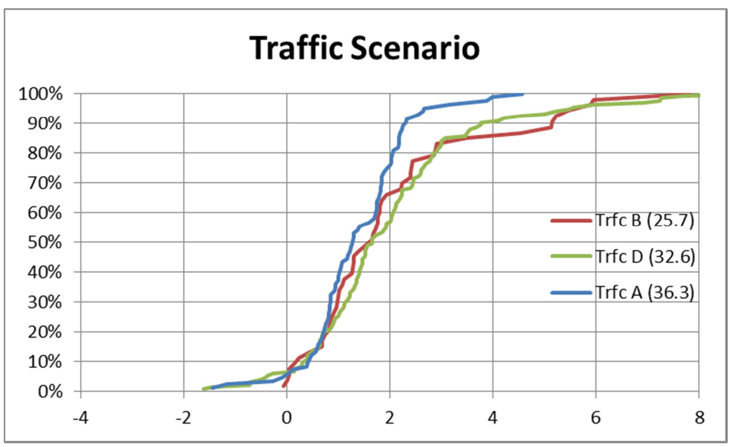

Figure 57 Distribution of Excessive Spacing (in NM) at the ABP - Traffic Sample

6.5 IM Usage and Success Rate

Table 12 presents the number of IM Clearances and the number of (un)interrupted IM Operations for each run and in total. The number of IM-equipped aircraft that actually got an IM Clearance was 132 out of 145 (91.0%). If the very first aircraft of a run was IM-equipped, then this one was discarded in the calculations since no target aircraft was present.

The number of IM-cleared aircraft that continued IM Operations until the Achieve-by Point (FAP) was 110 of out 132 (83.3%). The number of IM Operations that were interrupted due to non-normal events was 19 out of 132 (14.4%) and the number of IM Operations that were interrupted not related to any non-normal event was 3 out of 132 (2.3%).

The 2.3% is the interruption rate of interest and this number is acceptably low. Note that strings up to 20 consecutive IM aircraft have been cleared.

Table 12 Number of IM Clearances and number of interrupted IM Operations

Run ID	# of IM Cleared	# of IM Operations still ongoing at end of run	# of IM Equipped that crossed FAP	# of IM Cleared that crossed FAP	# of uninterrupted IM Operations	# of IM Interruptions	# of IM Interruptions - not related to non-normal events	# of IM interruptions - related to non-normal events
p1r1	2	0	2	2	2	0	0	0
p1r2	14	3	13	11	11	0	0	0
p1r3	23	3	23	20	18	2	0	2
p1r4	7	0	9	7	3	4	1	3
p2r1	1	0	1	1	1	0	0	0
p2r2	15	4	12	11	11	0	0	0
p2r3	23	3	20	20	15	5	0	5
p2r4	2	0	2	2	2	0	0	0
p3r1	1	0	1	1	1	0	0	0
p3r2	13	2	13	11	10	1	1	0
p3r3	29	5	25	24	18	6	1	5
p3r4	23	1	24	22	18	4	0	4
Total	153	21	145	132	110	22	3	19

The three cases where the IM Operation was interrupted by the controller, without a direct relation to a non-normal event, are characterized as follows:

1. Near SUGOL, KLM1480 was put on a speed. No clear reason was found based on a playback of the run.
2. The speed of CFE76A (non-IM Operation) was reduced from 220 to 180 KIAS prior to the merge point due to traffic ahead (the merge point itself is not relevant, as all aircraft in the string were coming from SUGOL). ELY163, who was performing an IM Operation relative to CFE76A and had a similar groundspeed as CFE76A, was immediately thereafter instructed to fly the same airspeed of 180 KIAS. Note: the nominal airspeed is 220 KIAS for the part of the route the aircraft were flying on, therefore ELY163 –if IM had remained active- would have had a closing airspeed of at least 20 KIAS.
3. The target aircraft KLM1108 was performing an IM Operation, and flew between the merge point and localizer intercept with a very low groundspeed of 146 kt (this seems to be caused by the sometimes incorrect nominal speed profile, see also paragraph 6.4.2). The trailing aircraft, KLM410, was also performing IM and came too close to KLM1108. The controller did put KLM410 on heading vectors for a short time and on standard speeds.

7 Conclusions and Recommendations

Main Conclusions

Controller acceptance (para. 6.1.1 and 6.1.4)

- All controllers readily accepted and appreciated the IM Concept of Operations and were able to safely and efficiently manage the arrival traffic in all scenarios with the newly developed HMI.
- All controllers showed a high level of trust for the IM concept, working procedures and HMI.

Controller workload (NASA TLX metric) (para. 6.1.2)

- Perceived controller workload was well within predefined targets in all scenarios, with the exception of one of the six workload components (frustration) during one run.
- There appears to be a trend that workload slightly increases in scenarios with non-normals.
- For 50% FIM equipage level, perceived workload seems to be slightly higher than for 5% and 95% FIM equipage.
- Perceived controller workload seems to slightly increase with increased traffic density.
- For all other experimental variables, no effect on perceived workload has been observed.

Number of R/T transmissions (para. 6.1.6)

- The average number of R/T instructions per aircraft does not vary much between IM and non-IM operations. However, if an IM-aircraft is taken off the IM-operation and has to continue with radar vectors, the average number of instructions effectively doubles.

Situation Awareness (EUROCONTROL SASHA metric) (para. 6.1.3)

- Perceived situation awareness was rated as good by all controllers. One controller had difficulties coping with some non-normals which resulted in a lower perceived situation awareness and a higher perceived workload for those runs.

IM Usage / Success rate (para. 6.5)

- The percentage of IM clearances as function of FIM equipped aircraft is very high (>90%).
- The percentage of (unanticipated) IM cancellations by the controller is very low (<3%).

Spacing Performance at the Achieve-by Point (para. 6.3)

- The spacing performance improves with FIM equipage level (95% equipped versus 50% equipped).
- With increasing traffic density, the average spacing is more closely packed around the spacing goal, however the percentage of aircraft arriving too close to their lead increases.

Excessive Distance Spacing at the Achieve-by Point – Performance (para. 6.4)

- IM Operations show the best accuracy for:
    - the highest density traffic sample (36 ldg/hr) with both 50% and 95% FIM equipage levels; and
    - the second highest density traffic sample (32 ldg/hr) in combination with a FIM equipage level of 95%.

  In these cases the inter-aircraft distance at the ABP/FAP is showing a better, more consistent performance.
- HMI had no effect on inter-aircraft distance at the ABP
- Moderate wind conditions resulted in a more consistent performance for all traffic samples.

Excessive Distance Spacing at the Achieve-by Point – Safety (para. 6.2 and 6.4.2)

- The number of violations of the separation distance (4%) is relatively high, they only occur in the higher density scenarios (32 and 36 ldg/hr).
    - Out of the twelve cases, five were related to IM performance, three were related to IM usage, and five were not related to IM Operations.
- During three runs (out of twelve) a total of seven losses of separation (<2.5 NM) occurred.
    - Two losses of separation occurred near the merge point (once between two IM aircraft in combination with an incorrect target selection and once between two non-IM aircraft)

  - All five losses of separation on final approach were related to an aircraft performing IM and an aircraft not performing IM. In 3 out of 5 cases in combination with vectoring. In all of these cases IM Operation was continued where it should have been cancelled (due to vectoring and a very low speed instruction to the target aircraft). In 2 out of 5 cases a non-IM aircraft trailing an IM aircraft did not reduce speed in time, due to a 'late' instruction in combination with a slow deceleration on the continuous descent path.

Secondary Conclusions (para. 6.1.4 and 6.1.5)

- The R/T phraseology to initiate IM Operations should be improved to make the target selection a shorter and more naturally spoken phrase. Suggestions for improvement were provided.
- The speed limit of 250 kt below FL100 in relation to the nominal speed of 240 kt had an impact on the spacing performance, either waiving the speed limit (at least for IM Operations) or applying a lower nominal speed (e.g., 230 kt) should be considered.
- The lower bound of the IM speed range at the Achieve-by Point, co-located with the Planned Termination Point, needs to be raised in order to not lose throughput. A lower limit of 180 KIAS was proposed.
- The capability to suspend and later on to resume an IM Operation was used a number of times (without explicit discussion or requests).
- The working method in which the target selection and IM Clearance were separated in time regularly caused confusion about whether or not the target selection or IM Clearance had been given. It is recommended to use a working method in which the target selection is immediately followed by the IM Clearance itself.
- The spacing marker was hardly used because it showed jumping behaviour on the radar screen and resulted in a cluttered display. Though, in principle it was considered a good feature to monitor the IM (and non-IM) Operations.

Recommendations (para. 6.1.4, 6.1.5 and 6.4.2)

- Improvements are needed in terms of guidance (and training) to the controllers on when to suspend or terminate IM Operations, especially in relation to vectoring operations and (very) large speed reductions of a target aircraft.
- Additional controller support with respect to their monitoring task may in some situations be helpful (e.g., continuous display of the spacing marker and/or continuous display of the actual IAS). Special attention in terms of controller support is deemed necessary for non-IM aircraft behind an IM aircraft.
- Traffic was normally handed over to the tower near the IF instead of the FAP. The FAP was the anticipated handover point and was selected as the Achieve-by Point. Placing the Achieve-by Point at the IF seems to be more in line with the working method of the APP controllers. Moreover, the handover procedures need to be readdressed when IM is continuing after the handover.
- Controllers need confirmation of the correct selection of the Assigned Spacing Goal and Target Aircraft Ident. These are included in the IM Clearance and could be set incorrectly without the controller knowing it.

Disclaimers

- This initial RTS was limited to three controllers, performing twelve runs in total.
- The controllers were not familiar with operating fixed arrival routes or with continuous descents at the used traffic densities. Current practice in the Schiphol TMA is vectoring and stepped descents.
- During each run, only one APP controller controlled all inbound traffic, from handover by Amsterdam ACC near the IAF down to handover to Schiphol Tower on final approach. Normally, two APP controllers would control the higher traffic densities as simulated in the RTS, one Feeder/Departure controller and one Arrival controller.
- All runs with 95% FIM equipage and half of the runs with 50% FIM equipage included three non-normal events. This most likely has had an impact on the performance of these runs.
- Due to the limited scope of the RTS not all combinations of the independent variables were tested. Traffic Sample D --with on average 32.6 landings per hour-- was tested for all combinations of FIM equipage levels (5%, 50% and 95%) and wind conditions (1 light wind, 2 moderate wind). The other traffic samples were only tested with a subset of these combinations.

- Despite the number of test and shakedown sessions, the simulation environment still had some, previously unnoticed, flaws. In particular, the vertical guidance along the two-degree descent path was incorrect and the nominal speed profile near and on the final approach was sometimes incorrect.

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9 Acronyms

The following acronyms and symbols for units of measure are used in this document.

Acronym	**Description**
ABP	Achieve-by Point
ACC	Area Control
ADEP	Departure Aerodrome
ADS-B	Automatic Dependent Surveillance- Broadcast
AGL	Above Ground Level
AIRB	Basic Airborne Situation Awareness
AMAN	Arrival Manager
APP	Approach Control
ARR	Arrival
ASA	Aircraft Surveillance Applications
ASAS	ASA System
ASG	Assigned Spacing Goal
A-SMGCS	Advanced Surface Movement, Guidance and Control Systems
ASPA	Airborne Spacing
ASTAR	Airborne Spacing for Terminal Arrivals
ATC	Air Traffic Control
ATM	Air Traffic Management
CAS	Calibrated Airspeed
CDA	Continuous Descent Approach
CDO	Continuous Descent Operation
CPDLC	Controller Pilot Data Link Communication
CTA	Controlled Time of Arrival
DCO	Departure Controller
EAT	Expected Approach Time
EDD	Electronic Data Display
EHS	Enhanced Surveillance
ETA	Estimated Time of Arrival
FAP	Final Approach Point
FCU	Flight Control Unit
FDR	Feeder
FIM	Flight-Deck Interval Management
FL	Flight Level
FMS	Flight Management System
H	Hypothesis
HDG	Heading
HiRLAM	High Resolution Limited Area Model
HMI	Human Machine Interface
IAF	Initial Approach Fix
IAP	Instrument Approach Procedure
IAS	Indicated Airspeed
IBP	Inbound Planner
ID	Identification
IF	Intermediate Approach Fix
IFPI	Intended Flight Path Information
ILS	Instrument Landing System
IM	Interval Management
KDC	Knowledge and Development Centre – Mainport Schiphol
KIAS	Knots Indicated Airspeed
Lat	Latitude
Lon	Longitude
MCP	Mode Control Panel

MOPS	Minimum Operational Performance Standards
NARSIM	NLR ATC Research Simulator
NM	Nautical Mile
Nom	Nominal
OPA	Operational Performance Assessment
ORL	On-Request Line
OSED	Operational Services and Environment Definition
PBN	Performance Based Navigation
PSL	Pilot Selected Level
PTP	Planned Termination Point
RF	Radius to Fix
RFG	Requirements Focus Group
RFL	Requested Flight Level
RNAV	Area Navigation
RP	Reporting Point
RQ	Research Question
RT, R/T	Radio Telephony
RTS	Real Time Simulation
RWY	Runway
SARA	Speed And Route Advisor
SASHA	Situation Awareness for Shape
SESAR	Single European Sky ATM Research
SID	Standard Instrument Departure
SPD	Speed
SSR	Secondary Surveillance Radar
Std Dev	Standard Deviation
TAS	True Airspeed
TID	Touch Input Device
TIS-B	Traffic Information Services - Broadcast
TLX	Task Load Index
TMA	Terminal Manoeuvring Area
Trfc	Traffic
TTG	Time To GO
VQ	Validation Question
W	Wind
WTC	Wake Turbulence Category
XFL	Exit Flight Level
deg	degree
ft	foot
hPa	hecto Pascal
intrpt	interrupted
kt, kts	knot
s	second
μ	Mean
σ	Standard deviation

10 Document Information

Document information	
Start of process	
Document type	Test Result Report
Title	Real Time Simulation (RTS) Test Results for Interval Management in the Schiphol TMA
Part	-
Started by	KDC
Related to	-
Document number	KDC/2014/0055
Version number	V1.0
Version date	21-11-2014
Status	First Release

Summary
This document provides the results of a Controller-In-The-Loop Real Time Simulation of a proposed IM concept of operation for Schiphol Airport. The aim of the RTS is to validate working procedures and support tools and to assess controller workload and acceptance.

Key words			
ASAS Spacing	Controller Acceptance		
Interval Management			
Fixed Arrival Routes			
High Capacity			
CDO			
Real Time Simulation			

Security classification
Unclassified

Version Management

Version	**Version date**	**Section**	**Remarks**
1.0	21-11-2014	All	First release

APPENDIX A WIND PROFILES

Schiphol TMA currently uses wind data at the following five altitudes:

- FL10 (304.8 m)
- FL30 (914.4 m)
- FL50 (1524.0 m)
- FL70 (2133.6 m)
- FL90 (2743.2 m)

Amsterdam ACC currently uses wind data at the following five altitudes:

- FL50 (1524.0 m)
- FL100 (3048.0 m)
- FL160 (4876.8 m)
- FL220 (6705.6 m)
- FL280 (8534.4 m)

For the FIM Equipment the forecast wind data is used at three altitudes (preliminary minimum requirement from draft FIM MOPS). The following altitudes, including the planned altitude at the Achieve-by Point, are proposed:

- FL20 (609.6 m)
- FL50 (1524.0 m)
- FL90 (2743.2 m)

The tables below provide the actual and forecast wind data for two conditions. Condition #1 is the 40th percentile of the average wind speed between the surface and FL100 (based on KNMI HiRLAM data for the entire year of 2013, with a sampling of three hours); condition #2 is the 78th percentile. Note: condition #2 is the most severe wind condition in 2013 when runway 06 could have been used.

Interpolation is required to acquire the forecast wind data from Table B.2 and Table B.4 at the above-mentioned altitudes for ATC systems (e.g., AMAN) and at the three altitudes for the FIM Equipment.

Note that the International Standard Atmosphere is assumed in this RTS, including a QNH of 1013.25 hPa.

Table B.1 Wind Profile #1 - actual

HiRLAM wind profile 2013-08-25 09:00		
Altitude, geometric	Wind direction	Wind speed
(m)	(deg)	(m/s)
0	50	3.8
32.2	50	3.8
96.1	50	4.1
161.8	51	4.2
230	52	4.3
299.7	55	4.7
371	62	5.2
444.8	69	5.2
521.5	71	5.4
601.3	77	5.8

684.7	77	6.3
772	82	6.7
863.5	85	7.2
959.5	82	7.3
1060.3	83	7.3
1166.2	85	7.4
1277.5	86	7.8
1394.5	88	8.3
1517.6	90	9.1
1647	91	9.8
1783	94	10.5
1925.9	95	11
2076.1	95	11.4
2233.9	94	11.6
2399.5	94	11.6
2573.4	96	11.5
2755.7	97	11.6
2946.9	100	11.4
3147.4	106	11.1
3357.6	107	10.9
3577.9	102	10.8
3808.9	97	11
4051.4	95	12
4305.7	93	12.8
4572.5	91	13.2
4852.1	90	13.4
5145.1	92	13.8
5452	94	14.4
5773.5	94	14.5
6109.7	94	13.7
6461.1	101	13
6829.3	110	14.5
7216.3	110	17.6
7622.9	106	19.7
8050	110	20.6
8499.3	116	20.3
8973	129	20.2
9473.3	143	25.3
10002.5	146	23.6
10571	90	13.1
11193.8	80	13.6
11882.6	41	10
12649.5	40	9.2
13507	31	7.6

14479.9	27	8.1
15608.2	45	4.8

Table B.2 Wind Profile #1 - forecast

HiRLAM wind profile 2013-08-25 06:00		
Altitude, geometric	Wind direction	Wind speed
(m)	(deg)	(m/s)
0	68	3
32	68	3
95.5	117	4.1
161.1	121	4.1
229.2	103	4
298.9	111	4.8
370.3	121	4.6
444.1	126	5.1
520.7	130	5.6
600.4	129	5.6
683.6	124	6
770.6	123	6.3
861.8	116	7.2
957.6	113	7.7
1058.3	111	8
1164	113	7.9
1275.1	115	7.8
1391.9	116	7.5
1514.7	117	7.1
1643.8	118	6.9
1779.5	118	6.9
1922.1	116	7
2072	115	7.4
2229.4	114	8
2394.9	112	8.6
2568.6	112	9.4
2750.9	112	9.7
2942.1	112	9.7
3142.5	113	9.4
3352.6	111	9.3
3572.6	108	9.4
3803.2	107	9.7
4044.7	107	9.9
4297.9	106	10.1
4563.5	106	9.7
4842	109	9.3

5133.9	111	8.9
5439.7	116	8.7
5760.1	120	9.2
6095.9	119	9.5
6447.5	115	9.9
6815.7	110	10.4
7201.8	106	11.2
7607.2	106	13.1
8033.4	105	16
8481.6	106	17
8953.6	110	18
9452.9	102	17
9987.3	71	18.7
10562.8	64	22.3
11186.5	65	16.7
11871.9	63	11.5
12634.6	47	8.1
13490.8	24	6.1
14464.1	355	6.3
15595.8	359	6.5

Table B.3 Wind Profile #2 - actual

HiRLAM wind profile 2013-02-25 21:00 (modified)		
Altitude, geometric	Wind direction	Wind speed
(m)	(deg)	(m/s)
0	55	7.9
30.5	55	7.9
91	55	9.2
153.3	56	9.9
217.9	57	10.8
283.9	60	11.4
351.6	61	12.2
421.7	64	12.7
494.6	67	13.3
570.6	71	13.9
650	76	14.5
733.1	82	15.1
820.5	84	15.7
912.4	83	16.2
1009.4	80	16.8
1111.8	79	17.4
1220	80	18
1334	80	18.7

1454	80	19.2
1580.2	79	19.6
1713.1	78	19.8
1853.2	78	19.9
2000.7	83	20
2155.4	87	20
2317.7	88	19.9
2487.7	89	19.8
2665.8	86	19.7
2853.5	79	19.6
3051.4	77	19.4
3259.3	76	17.9
3477.2	80	16.8
3705.4	86	17.5
3944.3	87	19.2
4194.4	83	20.5
4456	79	21.1
4729.4	76	21.4
5015.1	75	21.5
5313.6	75	21.5
5625.5	75	21.9
5951.8	75	22.8
6293.2	75	24.3
6650.7	74	26.1
7025.1	74	27.1
7417.6	76	27.1
7829.9	76	27.3
8263.8	76	27.2
8721.1	76	26.4
9204.5	76	25.3
9718.4	75	24.4
10270.9	71	23
10874.8	67	20.7
11546	66	19.3
12298.7	60	18.5
13145.7	57	15
14104.3	43	13.9
15204.9	47	13.2

Table B.4 Wind Profile #2 - forecast

HiRLAM wind profile 2013-02-25 18:00 (modified)		
Altitude, geometric	Wind direction	Wind speed
(m)	(deg)	(m/s)
0	45	8.6

30.6	45	8.6
91.2	47	9.6
153.6	47	10.2
218.3	47	10.6
284.5	48	11.4
352.2	50	12.1
422.3	52	12.7
495.2	53	13.2
571.2	56	13.6
650.7	60	13.8
733.8	63	13.9
820.9	67	14
912.5	70	14.1
1009.3	68	14.2
1111.3	66	14.2
1219	65	14.2
1332.4	64	14.2
1451.8	65	14.2
1577.7	65	14.4
1710.3	65	14.7
1849.9	65	15.3
1997	64	15.7
2151.6	63	16.1
2314.1	63	16.5
2484.7	63	16.9
2663.8	64	17
2851.8	68	17
3049.1	71	17.8
3255.9	70	18.9
3472.2	69	19.4
3698.3	67	19.7
3935.1	68	19.6
4183.5	71	19.3
4443.7	74	18.8
4715.8	79	19.6
5000.4	80	21.6
5298.4	77	23.2
5610.2	75	23
5936.3	75	21.9
6277.3	78	21.8
6634.2	83	23
7008.1	86	24.3
7400.2	86	25
7811.8	86	25.1

8244.8	85	24.8
8701	84	23.2
9183.7	80	21.3
9697.6	73	20.1
10251	70	19.4
10856.4	66	17
11529.1	50	17.3
12281.9	52	16.9
13127.5	57	14.2
14085.1	51	12.6
15184.6	38	11.9

APPENDIX B Run Definitions

Table 13 Day 1

Run ID	FIM equipage (%)	Wind	HMI	Segment 1 non-normal	Segment 2 non-normal	Segment 3 non-normal	Traffic sample
1T	50	1	2	-	-	-	T
1E1	5	1	1	-	-	-	D
1E2	50	2	2	-	-	-	B
1E3	95	1	2	2	8	3	A
1E4	50	2	1	5	6	9	D

Table 14 Day 2

Run ID	FIM equipage (%)	Wind	HMI	Segment 1 non-normal	Segment 2 non-normal	Segment 3 non-normal	Traffic sample
2T	50	1	2	-	-	-	T
2E2	5	2	2	-	-	-	B
2E3	50	1	2	2	8	3	A
2E1	95	1	1	5	6	9	D
2E4	5	2	1	-	-	-	D

Table 15 Day 3

Run ID	FIM equipage (%)	Wind	HMI	Segment 1 non-normal	Segment 2 non-normal	Segment 3 non-normal	Traffic sample
3T	50	1	2	-	-	-	T
3E3	5	1	2	-	-	-	B
3E1	50	1	1	-	-	-	D
3E2	95	2	2	2	8	3	A
3E4	95	2	1	5	6	9	D

FIM equipage levels:

- 5%
- 50%
- 95%

Wind conditions:

1. light wind
2. moderate wind

HMI variants:

1. need to have only
2. need to have plus spacing marker and IM information in the third line of the on-request line

Non-normals:

1. Incorrect Target Aircraft selection (correct readback) → separation issue
2. Incorrect readback of Target Aircraft
3. Unable Target Aircraft selection (e.g. due to out of ADS-B range)
4. Unable to accept IM Operations (e.g. due to equipment failure, data quality)
5. Unable to continue with IM Operations (e.g. due to equipment failure, data quality, IM speed too low/high)
6. IM or Target Aircraft delivery at IAF well outside +/- 30 seconds
7. Incorrect spacing (e.g. aircraft flies profile speeds instead of IM speeds → with or without separation issues)
8. Incorrect spacing (e.g. aircraft follows different spacing goal than the assigned one → with or without separation issues)
9. A Target Aircraft is unable to continue the transition (e.g. due to an RNAV equipment failure)

Non-normals: one in every 15 min segment. Total duration of a run is 45-50 min.

Traffic samples (throughput RWY 06):

T. <25 landings/hour (training)
A. 36 landings/hour
B. 25 landings/hour
D. 33 landings/hour

Traffic samples (general):

- 12% Heavies, 2% 757, 86% Mediums (for landing runway 06).
- Throughput landing runway 36R: 30-35 a/c per hour (scripted).
- Throughput take-off runway 36L: in total 25 a/c per hour, of which 10-15 aircraft depart via TMA-West (controlled) and another 10-15 aircraft depart via TMA-East (scripted).
- Metering accuracy: Inbound traffic towards their assigned IAF will be scripted to represent an organized flow that is sequenced and arrives within +/- 30 sec (99%) of their assigned time, i.e. Expected Approach Time (EAT).

APPENDIX C **NASA TLX**

The NASA Task Load Index (TLX) questions used in this Real Time Simulation are given below.

- How mentally demanding was the task?

○ ○ ○ ○ ○ ○ ○

Very low Very high

- How physically demanding was the task?

○ ○ ○ ○ ○ ○ ○

Very low Very high

- How hurried or rushed was the pace of the task?

○ ○ ○ ○ ○ ○ ○

Very low Very high

- How successful were you in accomplishing what you were asked to do?

○ ○ ○ ○ ○ ○ ○

Perfect Failure

- How hard did you have to work to accomplish your level of performance?

○ ○ ○ ○ ○ ○ ○

Very low Very high

- How insecure, discouraged, irritated, stressed, and annoyed were you?

○ ○ ○ ○ ○ ○ ○

Very low Very high