Use of master Air Traffic Management (ATM) European validation plan (MAEVA) guidelines in the INTENT project

J.L. Farges (ONERA), A. Nuic (EUROCONTROL) and R. Ruigrok (NLR)

1. Abstract

Accurate information on the future trajectory of an aircraft may be used to increase the maximum number of aircraft that can be safely and efficiently handled through a sector of airspace. The objective of the INTENT project is to answer the research question: "How does the level of aircraft INTENT information, shared among ATM users and actors, relate to the air traffic system capacity, the avionics system design and the ATM system design? ".

The INTENT project addresses ATM en-route concepts based on the communication of information about intended aircraft trajectories calculated by the aircraft's Flight Management System (FMS) to other aircraft and the ground ATM system. A variety of operational scenarios are considered based on:

- different levels of intent information (0 to 20 minutes)
- location of separation assurance process (ground or airborne based)
- type of airspace (fixed routes or unstructured routes)
- different traffic densities (1 to 3 times year 2000 traffic levels)

During the preparation of INTENT's simulation exercises, the Master ATM European VAlidation plan (MAEVA) approach to validation was adopted. This paper describes how the MAEVA Validation Guideline Handbook (VGH) was used to structure the INTENT project validation plan for three distinct types of simulation exercises:

(i) Part task real time simulations for calibrating human operator (air traffic controller and pilot) workload models for use in fast time simulations.
(ii) Fast time simulations for producing statistically significant data on airspace capacity for the different operational scenarios under investigation.
(iii) Full scale real-time simulations to validate the most promising results of the fast time simulations.

Details of the validation plan are given for each type of simulation exercise. Discussions follow on how such a structured approach resulted in a commonly understood framework for developing 15 versions of a document with a low level of ambiguity. This allowed efficient discussion and rapid consensus among partners of an international consortium. An extra unforeseen iteration in the planning and execution of the part task real-time simulation exercises, so far, resulted in underestimation of resources by about 30 %.

The INTENT project is a Research, Technology development and Demonstration (RTD) project aimed at the development of Critical Technologies, contributing to the work programme for Competitive and Sustainable Growth of the European Union. It is co-funded by the European Commission and a Consortium(1) of research organizations and industry.

(1) The consortium comprises Stichting Nationaal Lucht- en Ruimtevaartlaboratorium (NLR), QinetiQ, Office National d'Etudes et de Recherches Aerospatiales (ONERA), Eurocontrol, Delft University of Technology, Rockwell-Collins France, Smiths Aerospace, AIRBUS, European Cockpit Association, Association of European Airlines.

2. Introduction

Validation is a key stage in the development of new Air Traffic Management (ATM) concepts. The objective of validation is to ensure that the concept addresses the problem for which it was designed, achieves its stated aims and presents no undesired impacts.

Nowadays, the research and development in Air Traffic Management is structured and performed in various projects. Each project is dedicated to specific sets of concepts, areas of study and stages of development which may lead to different approaches taken once the validation activity is performed.

In order to gather the knowledge on air traffic management at a global level, a minimum set of definitions and methods common to all projects is needed. A standardised framework for conducting validation exercises would be an enabler for achieving this goal. Some actions have already been taken in this area and the work has been done through conferences, workshops, thematic networks and several cross project actions. Various cross project actions have been sponsored and supported by the European Commission. For example:

- the guidelines for field trials in road transport [2] during the Third Framework Programme,

- the CONVERGE validation quality support action for all modes of transport [3][4] during the Fourth Framework Programme,
- the Master ATM European VAlidation plan (MAEVA) of the Fifth Framework Programme.

The INTENT project [1] addresses ATM en-route concepts based on the communication of information on intended aircraft trajectories calculated by the aircraft's FMS to the other aircraft and the ground ATM system.. Different operational scenarios are defined by an experiment matrix considering:

- Different levels of intent information (0 to 20 minutes)
- Three combinations of airspace structure and location of the traffic separation assurance process:
    - Airborne located traffic separation assurance process, unstructured airspace (no routes)
    - Ground located traffic separation assurance process, unstructured airspace (no routes)
    - Ground located traffic separation assurance process, structured airspace (fixed routes)
- Different traffic densities (1 to 3 times year 2000 traffic levels).

The techniques chosen for validation are:

- real-time part-task human-in-the-loop simulations, to establish human workload models and demonstrate acceptability on the use of a conflict detection and resolution tool incorporating aircraft intent,
- fast-time simulations, to produce experimental data (statistically significant) over a larger airspace and larger set of traffic scenarios,
- full-scale real-time human-in-the-loop simulations to validate the results from the fast-time simulation.

MAEVA work has proved to be relevant and beneficial for the validation of the concepts under study in the INTENT project. Namely, MAEVA Validation Guideline Handbook (VGH) [5] which proposes a five-step process for conducting a validation exercise. Those steps are as follows:

Step 1 Definition of validation aims, objectives and hypotheses.
Step 2 Planning and preparation of the validation exercise runs.
Step 3 Execution of the exercise runs and the measurement.
Step 4 Analysis of the results.
Step 5 Development and dissemination of conclusions.

However actual practice may differ from guidelines and an analysis of this difference can contribute to the improvement of guidelines in terms of applicability and enable better use of guidelines by projects in the future. This paper describes and analyses how the guidelines for the two first steps are taken into account in the production of a validation plan for the INTENT project. Steps 3, 4 and 5 of the VGH are considered in the other work packages of the INTENT project, but their implementation is not covered by this document.

3. Approach

3.1. Use of the VGH

Steps 1 and 2 of the VGH were used in the Definition work package of the INTENT project, within a task named "Experiment design". As shown on figure 1 this task is scheduled in parallel with the beginning of the "Experiment" task. The "Experiment" task includes preparation and running of three validation exercises. The deliverable [12] of the "Experiment design" task, called "Validation plan" integrates not only the result of the work conducted in this task but also contributions from the "Experiment" task.

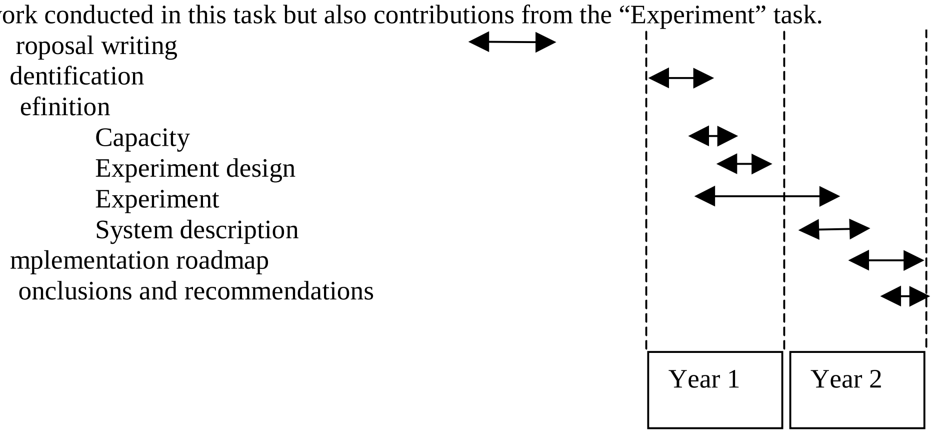

Figure 1: Simplified time schedule of the INTENT project (from [6])

3.2. *Fitting project work plan and guidelines*

At the highest level, VGH recommends to describe the validation strategy and to present it by a Validation Route Map. Such a validation strategy defines for each stage what type of validation should be used and what may be a preferable validation technique that delivers the most useful results. It can be given in the form of a graph where the nodes are the validation techniques and where the links indicate the possible techniques for the next validation exercise. The validation techniques in VGH are grouped in four “families”:

- Literature studies;
- Judgmental techniques;
- Fast time techniques (fast time simulation and analytic modelling);
- Real-time techniques (real time simulation, field test, shadow mode and operational trials).

The VGH five step process was applied to each validation exercise. This approach induces a rigour in the whole validation process.

For the INTENT project, the guidelines were taken into account at the level of the experiment design, after having completed the following tasks:

- Writing the project proposal.
- Identifying the ATM problem through a refined scope, a literature analysis and an analysis of stakeholders and their benefits.
- Studying the airspace capacity in terms of applicable metrics, reasons for limitations and maximum theoretical capacity.

A part of the work already performed can be qualified as literature studies and analytic modelling, but it was too late to usefully apply the guidelines to this part. Moreover, the proposal and the contract [6] indicate a fixed sequence of three simulations:

- A real-time part-task simulation.
- A fast-time simulation.
- A real-time full-scale simulation.

It is difficult to deviate from a contract, thus most of the flexibility of the whole validation process is lost and a simple validation road map shown on figure 2 was obtained.

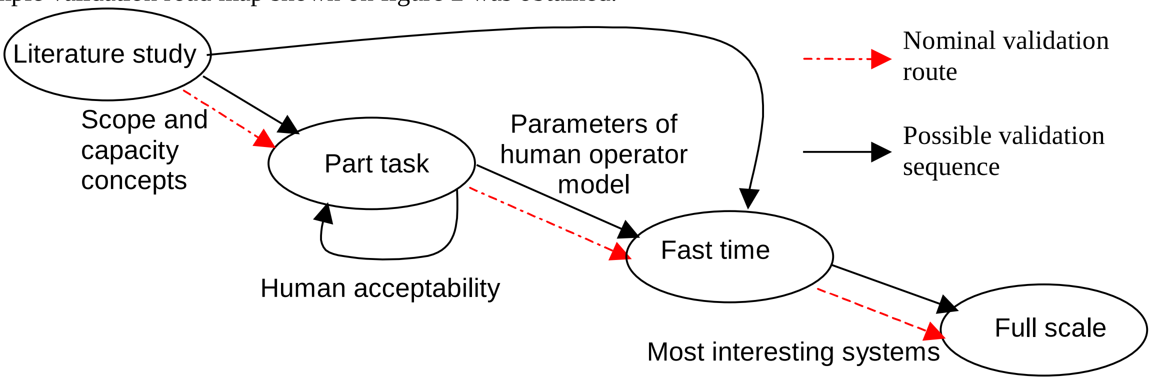

Figure 2: Validation road map for the INTENT project

For each validation exercise, the steps of the validation process are broken down in activities. For Step1, Definition of validation aims, objectives and hypotheses, the activities are:

(1a) Understanding the ATM problem and operational concept.
(1b) Identification of stakeholders.
(1c) Identification of validation aims.
(1d) Identification of high-level, low-level and subsidiary validation objectives.
(1e) Establishing validation platform requirements.
(1f) Identification of metrics and indicators.
(1g) Identification of hypotheses.
(1h) Definition of high-level experimental design.
(1i) Operational and statistical significance.

Step 2, Planning and preparation of the validation exercise runs, assumes the following activities:

(2a) Selection of the technique and facility and definition of the detailed experiment design.
(2b) Preparation of outline plan.
(2c) Scenario specification.
(2d) Production of the overall validation management plan.
(2e) Preparation for the exercise runs.

However, for the INTENT project all validation exercises address the same ATM problem with the same operational concepts for the same stakeholders. Moreover, an analysis of the stakeholders and their benefits is available [7]. Finally, in order to maintain consistency between the different validation exercises, there is a need to construct their scenario using a common source. For these reasons, the activities 1a, 1b and 1c are performed only once for all the simulation exercises.

4. Deriving INTENT validation plan from MAEVA VGH

4.1. Common activities for all simulation exercises

(1a) Understanding the ATM problem and operational concept

The ATM problem addressed in INTENT is the en-route capacity limitation and flight inefficiency. In order to solve this problem several approaches are studied:

- Increase of human operator productivity through automation by introduction of Conflict Detection and Resolution (CD&R) tool and transmission of aircraft intent information,
- Increase of flight efficiency through the use of direct routes and,
- Delegation to the separation assurance to the crew.

The operational concepts selected for the study are shown on table 1. The operational concept A is similar to current operational practice and is the reference. The expected impacts of other operational concepts with respect to the reference are presented in table 2.

Type of separation assurance	Level of automation		
	State	State + CD&R	State + Intent + CD&R
On the ground with structured routes	Yes : Concept A	Yes : Concept B	Yes : Concept C
On the ground with direct routes	Yes : Concept D	Yes : Concept E	Yes : Concept F
Airborne with direct routes	No	Yes : Concept G	Yes for intent horizon of 5, 10 and 20 minutes : Concepts H5, H10, H20

Table 1: Ten operational concepts studied in the project

Impact	Pilot workload	Controller workload	Flight efficiency	Capacity
B / A	0	-	0	+
C / A	0	--	0	++
D / A	0	+	+	-
E / A	0	0	+	0
F / A	0	-	+	+
G / A	+	Not applicable	+	++
H / A	0	Not applicable	+	+++

Table 2: Expected magnitude of impacts of operational concepts B, C, D, E, F, G and H with respect to operational concept A (-- large decrease, - decrease, 0 no change, + increase, ++ large increase, +++ very large increase)

(1b) Identification of stakeholders

The stakeholders identified in [7] are airlines, air traffic service providers, national governments, Eurocontrol, the general aviation, airports, avionics manufacturers, aircraft manufacturers, air traffic control system manufacturers, passengers and military.

(1c) Identification of validation aims

The global validation aim of the project is to answer to the following question: “How does the level of aircraft INTENT information, shared among ATM users and actors, relate to the air traffic system capacity, the avionics system design and the ATM system design?”.

(2c) Scenario specification

The airspace for validation exercises is presented in figure 3. Namely, a region of Western Europe bounded by the meridians at 1° and 14° East, and by the parallels at 47° and 52° North, with nine measured sectors. The sector definition of this airspace is inspired from the south part of the free route sector plan defined by the Free Route Airspace Project (FRAP) [8].

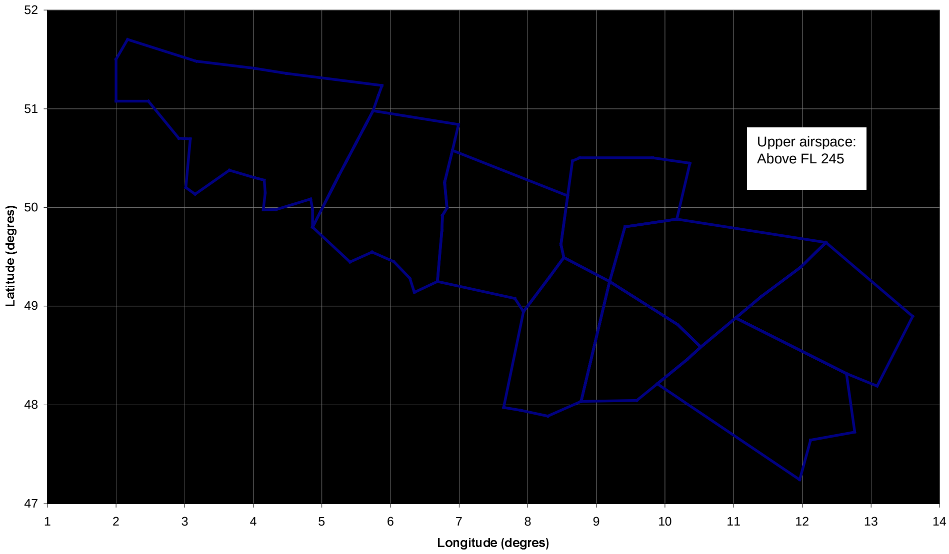

Figure 3: Validation site

Actual traffic data for the period of July to August of the year 2000 is provided by the Eurocontrol Central Flow Management Unit (CFMU) for this airspace. Statistics on hourly flows for each origin-destination couple and each aircraft type are computed and used for scenario generation [11]. For the simulation of flows exceeding the present day capacity, the demand is multiplied by a factor. It has been planned to run the experiments for three levels of traffic demand.

Several factors were considered when the suitability of the airspace and the traffic demand to the validation exercises was assessed:

- some sectors under the study are currently considered as main bottlenecks,
- summer weekdays present high traffic levels,
- the flight time to cross the area is consistent with the largest conflict detection horizon,
- some controllers were already trained for the chosen airspace.

4.2. Simulation specific activities

Part task real time simulation

(1c) Identification of validation aims

The aims of this validation exercise were to calibrate and validate human operator models that can be integrated in fast time simulation and to assess acceptability and workload for the pilots and controllers.

(1d) Identification of high-level, low-level and subsidiary validation objectives

The high level objectives are related to capacity either directly such as “to determine human operator limits in terms of workload” or indirectly such as “to correlate metrics that can be computed in fast time simulations with the human-in-loop responses”.

(1e) Establishment of validation platform requirements

The fact that for some operational concepts under study the separation assurance function is performed on the ground and for others in the air, leads to the requirement of having two separate validation platforms. As shown in figures 4, the core part of the platform used for the ground based separation assurance is radar and data controller (tactical and planner) working positions.

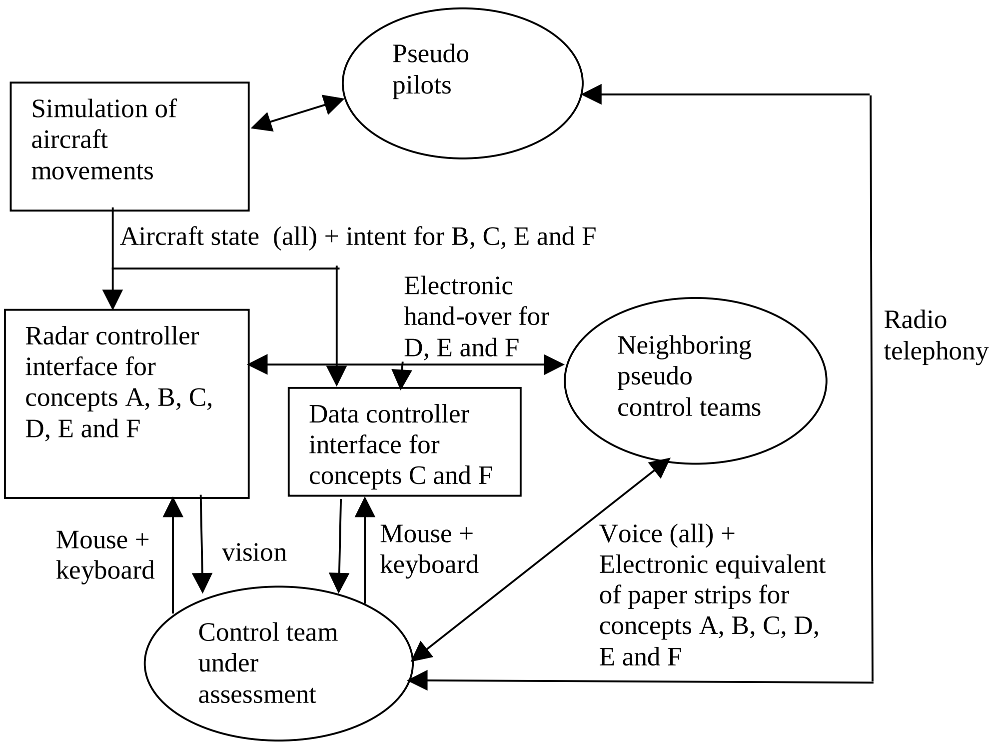

Figure 4 : Specification of real time validation platform for ground based separation assurance

Figure 5 depicts the validation platform for airborne separation assurance where conflict detection and resolution is performed in the cockpit.

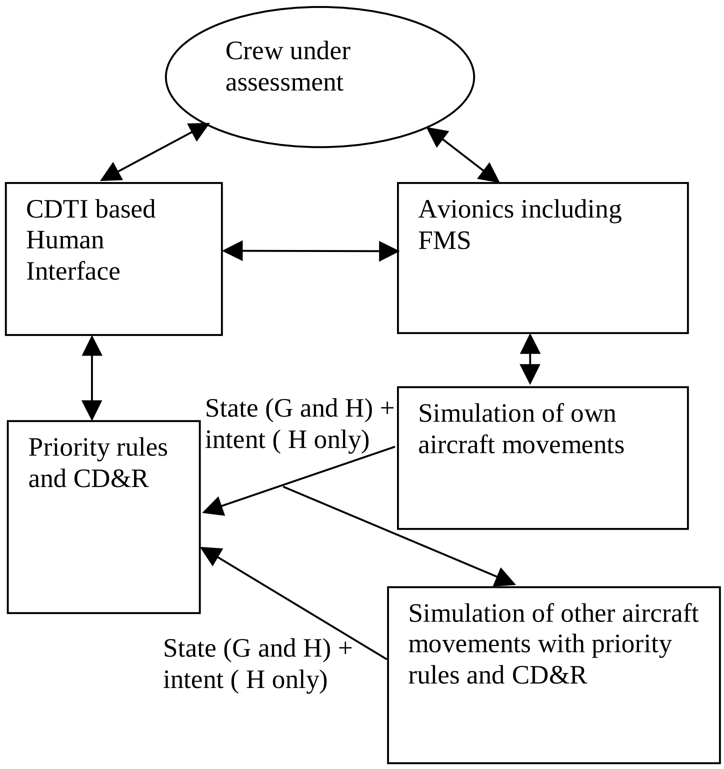

Figure 5: Specification of real time validation platform for airborne separation assurance

(1f) Identification of metrics and indicators

Several metrics and indicators were identified for each validation objective. For example the correlation coefficient with the Instantaneous Self Assessment (ISA) is an indicator associated to the objective “to correlate metrics that can be computed in fast time simulations with the human-in-loop responses". The rating scale of mental effort is an indicator associated to the objective "to determine human operator limits in terms of workload".

(1g) Identification of hypotheses

Hypotheses concerning the comparison indicators against limits or comparisons of means of indicators of different operational concepts were formulated.

(1h) Definition of high-level experimental design

The high level experimental design proposed 144 runs for the control team platform and 96 runs for the crew platform. These runs correspond to several different combinations of operational concept and –traffic demand for successive teams.

(1i) Operational and statistical significance

The operational significance of the validation exercise is limited by the maturity of the concept and by the fact that flights are simulated at level for the crew platform. Statistical analysis is performed taking into account the sample sizes. Depending on the indicator the sample size is:

- The number of runs.
- The number of 2 minutes period.
- The number of conflicts.

Statistical significance of the validation exercise is checked against rules of thumb for parameter estimation of random variables and either using distribution properties or assumption on variance.

(2a) Selection of the technique and facility and definition of the detailed experiment design

NLR's ATC Research SIMulator (NARSIM) and NLR's Research Flight Simulator (RFS) were selected as test facilities. However, in order to comply with platform requirements, some updates were planned.

(2b) Preparation of outline plan

For each platform the objective and subjective measurements to be made were identified. Objective measurements include events and related information, choices made by the human operator, traffic characteristics, conflict characteristics, deviations and separation. Subjective measurements are based on questionnaires.

(2d) Production of the overall validation management plan

For each platform the test of updates were planned. For NARSIM the update activities were to be completed on November 9th 2001, tests and experiment preparation were planned from November 12th to November 16th

For each platform a measurement and analysis plan was given. There were three types of analysis; after each run, after each team and at the end of the experiment

NARSIM experiments were planned to start on November 19th 2001 and to continue until December 21st. RFS experiments were planned in January and February 2002.

(2e) Preparation for the exercise runs.

The experiment planning encompassed a period of testing that finalised the implementation activities and the actual experiment execution.

Fast time simulation

(1c) Identification of validation aims

The aim of the fast time simulation is to produce results on the capacity related measurements for the different operational concepts using the human operator models developed, calibrated and validated with the data collected during part-task real-time simulations.

(1d) Identification of high-level, low-level and subsidiary validation objectives

The main validation objective is the assessment of traffic handling capacity. Subsidiary validation objectives are safety, economy and environmental impact analysis.

(1e) Establishment of validation platform requirements.

Validation platform requirements are presented in Figure 6. As shown in the figure, it is required that the platform produces the indicators taking into account dynamically the reactions of the control system and human operators to the movements of the aircraft. The software module concerning system behaviour is taken from the real-time part-task platform. The software concerning human operator behaviour integrates the findings of real time part-task simulations.

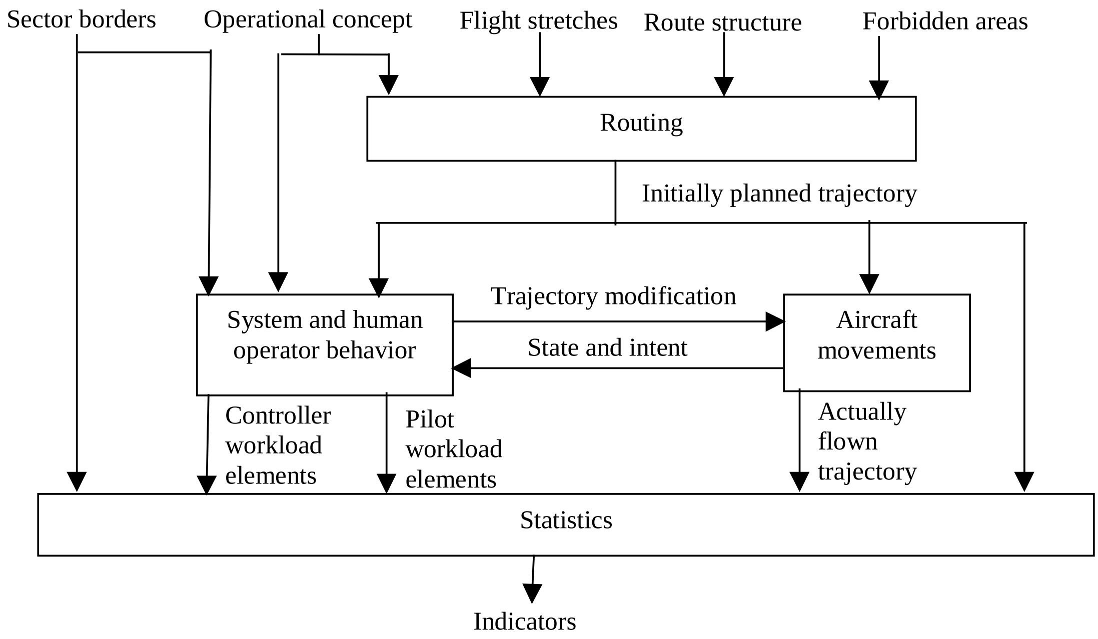

Figure 6: Specification of the validation platform for fast time simulation

(1f) Identification of metrics and indicators

The indicators for flight handling were the workload models that were correlated with ISA data in the part-task experiment. The indicators for economical and environmental impacts were the flying time and the path length. Number of intrusions and workload were taken as the main safety indicators.

(1g) Identification of hypotheses

For capacity assessment, a hypothesis was made in order to check either the maximum value or the quantile of order 0.95 against a pre-specified limit. For impact assessment, a hypothesis on difference of means between operational concepts was performed.

(1h) Definition of high-level experimental design

The experimental design led to a factorial plan where the factors were the 10 parameterised operational concepts, the three levels of demand for each operational concept and two different busy periods. This plan was repeated three times leading to 180 runs.

(1i) Operational and statistical significance

Statistical significance was analysed by computing the sample size by different sampling methods. Significance for the maximum value against a limit is analysed using a binomial distribution. Significance for the 0.95 quantile against a limit and for comparison of means is analysed. The analysis is performed assuming that:

- distributions are Normal,
- it exists a specific relation between mean and standard deviation and
- a relative difference of 0.1 has to be detected.

(2a) Selection of the technique and facility and definition of the detailed experiment design

QinetiQ's FLexible Airspace Modelling Environment (FLAME) was selected as the test facility. It has the advantage of being a set of software modules from which simulations for particular applications can be constructed rather than a monolithic simulation program.

(2b) Preparation of outline plan

Measurements of workload and flight efficiency were planned.

(2d) Production of the overall validation management plan.

A time period of three months was planned for the implementation of CD&R, human operator models and, collection of measurements.

(2e) Preparation for the exercise runs.

Test runs were planned to be performed over a period of one month. It was planned that validation runs would take place over an elapsed time of two months.

Real time full simulation

(1c) Identification of validation aims

The aim of real time full simulation is to give confidence in the results obtained from the fast time simulations.
(1d) Identification of high-level, low-level and subsidiary validation objectives
The objectives of this validation exercise are:

- To produce data on acceptance for the most interesting operational concept.
- To verify the outcome of fast time simulation.
- To perform measurement allowing a deeper analysis than in part task simulation.
- To confirm the impact difference obtained with the fast–time simulation between the most interesting and the "baseline" operational concepts.

(1e) Establishment of validation platform requirements
The fact that for the base-line concept the separation assurance function is performed on the ground implies that a part of the platform is centred on radar and data controller working positions. Part-task simulation results indicate that the capacity potential of airborne separation assurance is higher that the one of ground based separation assurance. It is likely that the fast time simulation results confirm that the most interesting concept is based on airborne separation assurance. For these reasons, two separate platforms were foreseen in the real-time full simulations: a ground platform (NARSIM) and an airborne platform (RFS).
(1f) Identification of metrics and indicators
The metrics for this validation exercise are identical to the capacity and acceptability metrics used in the part-task real-time simulations.
(1g) Identification of hypotheses
Hypothesis are formulated about acceptation or rejection of the most interesting operational concept, about the fact that a demand exceeds the capacity, about the difference between real-time and fast-time results and about the comparison of indicators for different operational concepts.
(1h) Definition of high-level experimental design
For the high level experimental design it is not possible to define the variation of factors before knowing the results of the fast-time simulations. However the dimensioning constraints due to the available platforms, NARSIM and RFS, were well understood.
(1i) Operational and statistical significance
Strong statistical significance is not searched in this case
(2a) Selection of the technique and facility and definition of the detailed experiment design
Like in the part-task real time simulation, NLR's ATC Research SIMulator (NARSIM) and NLR's Research Flight Simulator (RFS) were selected as test facilities. Following the results of the part-task some additional updates were planned.
(2b) Preparation of outline plan
Measurements to be made are similar to the measurements for the real-time part-task simulation and no updates are planned for NARSIM and RFS. Validation runs are planned for July and August 2002.
(2d) Production of the overall validation management plan
Validation runs are planned for July and August 2002.

5. Discussion of INTENT experiences using the VGH

5.1. A framework for stable evolution

The application of the process described in the VGH to the writing of a validation plan for the INTENT project has resulted in fifteen versions of the document. Nevertheless, the structure of the validation plan that fits to the decomposition of the VGH in the steps and activities was stable. The main change in the structure occurred at version five where the commonalties for the different validation exercises in terms of ATM problem, operational concept, aim and scenario were structured as a single chapter.
Changes to the validation plan are indicated in the document change log. However, it is not possible to have a view of the main options chosen during the preparation of the validation exercise.
During preparation of the INTENT validation plan, the document was used as an explicit reference among the partners and provided a framework for discussion. This framework could also be used for cross project exchanges, but no action of that type is on going.

5.2. Technique and validation platform selection

For INTENT, the selection of validation technique and platform was biased. The main reason for that was that the choices are actually made during the project's proposal preparation. Requirements for the validation were defined from the ATM problem under study, the concept and the validation aims, keeping in mind that NARSIM, RFS and FLAME were directly available in the consortium. Selection of the platform was not made from the MAEVA proposed list of platforms, but the pre-selected platforms were checked against the requirements.

It is likely that this bias occurs for many projects involving a partnership. Partners may join the consortium with tools that are considered as basis on which the consortium can built a research proposal.

5.3. Feedback from execution of validation exercises

Practice has shown that some of the relevant and highly important issues for the validation process, not covered and included by the actual version of the validation plan in use, may occur during the actual execution of the validation exercises. Some of the INTENT project's experiences that were encountered during the first run of the real-time part-task simulation (December 2001) for ground based separation assurance are briefly described below:

Simulation exercise iterations
Some simulation problems associated with the simulation of the differences between operational concepts based on flight plan processing and operational concepts based on FMS intent data were not recognised and addressed in the applied version of the validation plan. After analysing the results of December's simulation runs, a new definition of the variation of factors was performed. That led to the second step of the real-time part-task simulations, as were performed during March 2002.

Evolution of Validation plan
Some originally planned levels of traffic demands were found to be too high and not workable during the real-time human-in-the-loop experiment. Furthermore, it was found difficult to simulate the difference between operational concepts with intent and operational concepts without intent information.

These findings had to be taken into consideration in the execution of the following steps of the project. As they certainly affected and influenced the other, already planned, validation exercises in terms of operational concepts and traffic demand levels, corresponding updates of the validation plan were made. To maintain consistency between different validation exercises the feedback should also be used to modify the validation plan of the current exercise. This seemed to be unfeasible with the available resources.

No protection against optimism (Re-planning of resources)

The actual execution of the real-time part task simulation showed that the resources needed to conduct the validation exercise were underestimated by of 30% in the validation plan. Continuous up-date of the validation plan would require additional resources as well.

5.4. Flow of data on the validation route

The result of a validation exercise not only provides indications for deciding the technique for the next validation exercise but may also produce data that is needed to define more precisely the exercise itself. For example in the INTENT project:

- The models to be used in fast time simulation were the result of the analysis of the data recorded during the part task real time simulation.
- The most interesting operational concepts to be assessed in the full real time simulation were selected on the basis of the results of the fast time simulation.

A lesson learned from this experience is that it might not be possible to define the detailed plan for some validation exercises before the end of other validation exercises.

5.5. Level of detail

For each activity detailed information was given in the final validation plan. However, as the validation plan may change after discussions inside the consortium, some resources may be unnecessarily spent if detailed information is produced using an unstable basis. The control of the level of detail with respect to the type of activity and the time to validation could improve the efficiency of the preparation of validation exercises.

6. Conclusion

The INTENT project has followed the MAEVA methodology for planning three validation exercises; a part task real time simulation, a fast time simulation and a full scale real time simulation. This approach has led to a

structured validation plan that describes the validation exercises with a low level of ambiguity and was useful for reaching a consensus among international partners at multiple sites and conducting experiments.
Additional guidelines on the interaction between validation exercises and on the requested level of detail as a function of the time to the actual validation exercise could be very valuable.

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8. Abbreviations

ACC	Air Traffic Control Centre
ADS-B	Automatic Dependant Surveillance – Broadcast mode
ASAS	Airborne separation assurance system
ATC	Air Traffic Control
ATCo	Air Traffic COntroller
ATM	Air Traffic Management
CDTI	Cockpit Display of Traffic Information
CD&R	Conflict Detection and Resolution
CDU	Control & Display Unit
CFMU	Central Flow Management Unit
CWP	Controller Working Position
ECAC	European Civil Aviation Conference
FLAME	FLexible Airspace Modelling Environment
FMS	Flight Management System
FRAP	Free Route Airspace Project
FTS	Fast Time Simulation
FUA	Flexible Use of Airspace
ISA	Instantaneous Self Assessment
MAEVA	Master ATM European VAlidation plan
NARSIM	NLR Air traffic control Research SIMulator

RFMS	Research Flight Management System
RFS	Research Flight Simulator
R / T	Radio Telephony
RSME	Rating Scale of Mental Effort
SUA	Special Use Airspace
TCP	Trajectory Change Point
TMX	Traffic and experiment Manager
TPD	Traffic Pattern Description
VGH	Validation Guideline Handbook