ATS SYSTEMS

Tactical Controller Tool
TCT Real Time Simulation
Final Report

FASTI

Making change in En-Route Air Traffic control

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D2 – TCT RTS
FINAL REPORT
09-110142-C

TACTICAL CONTROLLER TOOL
TCT REAL TIME SIMULATION
FINAL REPORT

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FASTI Programme Manager	Christopher Brain	Signature:
TCT Project Manager	Angelo Scorciarino	Signature:
Think Research Project Manager	Marinella Leone	Signature:

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Document title	TCT Real Time Simulation Evaluation Report
Author	Marinella Leone
Produced by	Think Research Cromwell House 64-68 Calvin Road Bournemouth Dorset England BH9 1LN
Produced for	TCT Project
Think Research contact	Marinella Leone Tel. +32 279 3519 Email: marinella.leone@eurocontrol.int
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Christopher Brain	FASTI Programme Manager
Angelo Scorciarino	TCT Simulation Manager
Christopher Costelloe	TCT RTS Operational Expert
Poul Jorgensen	TCT Expert

Table of Contents

List of Figures

List of Tables

Abbreviations

A

ACC	Area Control Centre
AFL	Actual Flight Level
ATC	Air Traffic Control
ATM	Air Traffic Management

C

CB	Cumulonimbus
CFL	Cleared Flight Level
CWP	Controller Working Position

D

DCT	Direct
DFL	Dynamic Flight Level

E

EATM	EUROCONTROL Programme for Performance Enhancement in European Air Traffic Management
EATMP	European Air Traffic Management Programme
EC	Executive Controller (also known as Tactical Controller)
EEC	EUROCONTROL Experimental Centre
EFL	Entry Flight Level
ELW	Extended Label Window
EPT	Sector Entry Point
ETO	Estimated Time Over

F

FL	Flight Level
FMS	Flight Management System

G

GSP	Group-sector Planner

H

HMI	Human-Machine Interface

M

MIW	Message In Window
MM	Missed-manoeuvre
MONA	Monitoring Aids
MOW	Message Out Window
MTCD	Medium Term Conflict Detection

N

NM	Nautical Mile

P

PC	Planning Controller
PEL	Planned Entry Level
PFL	Planned Flight Level
PPD	Potential Problems Display
PVD	Plan View Display

R

RPVD	Radar Plan View Display

S

SA	Situation Awareness
SIL	Sector Inbound List
SME	Subject Matter Expert
SNET	Safety Nets
SPO	Single-person Operations
STCA	Short-Term Conflict Alert
SWIM	System Wide Information Management
SYSCO	System Supported Co-ordination

T

TC	Tactical Controller (also known as Executive Controller)
TCT	Tactical Controller Tool
TP	Trajectory Prediction

V

VAW	Vertical Aid Window

X

XFL	Exit Flight Level

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1 Introduction

This document reports the findings and output from the Real-Time Simulations (RTS) carried out in the context of the Tactical Controller Tool (TCT) Integration Project launched by the First ATC Support Tools Implementation Programme (FASTI). Two Real-Time Simulations were run for one week in October and one week in December 2008. The aim of the experiments was to evaluate the impact of introducing the Tactical Control Tool as conflict detection tool supporting the Tactical Controller's work. The validation work of the TCT project is between the scoping and the prototyping phase, which relates to the levels V1 and V2 of the E-OCVM concept maturity scale. Further work is required to bring the validation work from the scoping and prototyping stage, which is more a pre-validation phase, to V3, where TCT would be integrated in a more realistic environment and tested in all its aspects.

The FASTI TCT Integration Project has focused the evaluation on a prototype for the first two operational levels of the TCT concept (i.e. TCT Resolution Advisory - TCT level 3 - is excluded). The current project was an exploratory exercise aimed at validating the integration of the conflict detection tools, TCT & MTCD supporting tactical and planner controllers respectively, in concert with MONA, SYSCO and Safety Nets (STCA) in a realistic operational environment.

The simulation objectives, the experimental plan, the exercise descriptions and the results are described herein.

1.1 Background

EUROCONTROL has developed and validated a Medium-Term Conflict Detector (MTCD) to support controllers in identifying potential conflicts. This tool targets activities of the Planning Controllers and conflicts are detected up to 20 minutes in advance. The objective of the TCT tool is to provide automated support to the Tactical Controller in the form of conflict detection in a shorter time-frame (e.g. up to 8 minutes).

The operational need for developing such tools has already been identified by projects of European stakeholders (i.e. NATS I-FACTS and MUAC NFDPS). TCT Concept and tool development and their validation are closely linked to these and other European projects sharing similar objectives.

1.1.1 ATM Problem Description

The Air Traffic Management Strategy for 2000+ (ATM2000+) has identified that controller workload is a major constraint to capacity improvement and that increased automated support will assist controllers to handle more flights (ATM 2000+ vol. 1, 6.4.3).

The search for increased ATM capacity will translate into controllers managing more aircraft per sector per hour. As traffic demand continues to rise, the peaks and troughs in traffic demand that used to exist are slowly disappearing to be replaced by a constant high plateau of demand. Thus, the pressure builds on controllers to deliver peak performance over longer and longer time periods. The result is that the vigilance and skill of the individual controller to maintain safety in the ATC system is coming under increasing pressure.

A core part of the ATC task undertaken by controllers is the identification and resolution of potential future conflicts, carried out through planning and tactical roles. In most current ATC systems the mechanism of identifying and resolving conflicts is driven by a process, which the controller follows in scanning and analysing a radar display and manipulating a collection of paper strips.

Future ATC systems have the potential to improve this process with the introduction of computer-based assistance tools including trajectory prediction (TP), medium term conflict detection (MTCD), monitoring aids (MONA) and an advanced graphical interface.

In many sectors today, the Tactical Controller is overworked and spends a high proportion of his available effort monitoring traffic. The computer-based assistance tools cited above provide support, but mainly to the Planning Controller and for the most part related to planned trajectories.

The Tactical controller needs support in the near term to help him/her cope with the dynamic and stressful situation in the sector.

1.1.2 Proposed Solution

The Tactical Controller Tool(s) will help the Tactical Controller detect conflicts in his/her sector. In high traffic the controller has little reaction time and needs immediate assistance. The prime aims of TCT are to give support to the controller work, where needed, to gain efficiency and to maintain safety in instances where the controller's workload is approaching saturation.

The aim is to reduce the dependency on the vigilance of the controller for conflict prediction and resolution by providing an additional barrier.

- TCT tools will provide accurate support in the vertical and horizontal profiles. TCT will not be solely dependent on efficient trajectory update (as is the case for MTCD planning trajectory).
- TCT will help to maintain the plan and provide stability for the ATC system.
- TCT will be aware of the traffic situation in terms of aircraft observed behaviour (surveillance) and forecast behaviour (planned trajectory). The tool will operate within the confines of the sector and compliments the planning controller's MTCD tool.
- TCT will alert the controller to conflicts (separation standard infringements), that are likely to occur in the near term, based on the traffic situation. In making this judgement the tool will consider both the planned trajectory and the aircraft's current behaviour. Conversely, this feature may be regarded as a separation assurance aid.
- Missed-manoeuvre detections will detect cases in which a failure of a planned aircraft manoeuvre will cause an associated separation threshold to be infringed. Awareness of critical missed-manoeuvre is expected to allow minimisation of such occurrences through judicious planning.

1.1.3 Conclusion

TCT will complete the 'package' of automated support tools to the sector controllers. A system incorporating the automated tools already foreseen (and mentioned in the "introduction" to this project plan will allow for more stability in the planning phase (e.g. MTCD, MONA, TP etc.). This will provide a more adaptive approach when compared to current operations which is mainly reactive ATC combined with a number of static constraints, static airspace organisation and flow distribution.

Apart from the enhancements in the planning phase, with the addition of TCT it is perceived that the Tactical Controller will be given support and full flexibility within the "tactical window" (up to 8 min) from the event time. It will reduce the Tactical Controller workload using present and planned ATM system capabilities and in addition, steer the tactical interventions in line with overall enhanced planning approach to the extent possible. TCT is expected to bring safety benefits in that when Tactical Controllers are under high pressure they will be offered a solution (which they may struggle to identify under pressure).

1.2 TCT Project Scope

The scope and emphasis of the study was limited to TCT and its interaction with Medium Term Conflict Detection (MTCD), Monitoring Aids (MONA), Safety Nets (STCA only) and

SYSCO. The project focused on system technical TCT integration and derivation and optimisation of controller working methods and procedures associated with the target environment.

Enablers such as integrated HMI and TP are within the scope of this project to the extent that they affect the performance of the MTCD, TCT and the controller working methods. This activity lasted about 16 months and was completed with the delivery of this report.

The project scope was to:

- Develop:
  - Within a dedicated small scale simulation platform (i.e. eDep) TCT integration with the current FASTI tools (MTCD, MONA, SYSCO).
  - The software development should result in a stand-alone product that can subsequently be implemented on the current FASTI demonstrator platform.
- Conduct:
  - *RTS1 on 13-17 October 2008*. An exploratory small scale real time simulation (max 2 controlling sectors within the same ATSU) performed on the developed platform aimed at proving the usability and acceptability of the tools integrated.
  - *RTS2 on 1-5 December 2008*. A small scale real time simulation with the specific aim to assess the acceptability, usability and operability of the TCT tool in a generic environment, plus examining the conditions to gain the expected benefits.
- Produce:
  - Preliminary assessment of the operational acceptability, technical usability and domain usability.
  - Preliminary benefit analysis mainly focused on the contextual factors that may impede or favourite those benefits.
  - Preliminary safety assessment of the TCT tool.
  - Recommendations for experimental follow-up activities.

To achieve the project goals and provide the information necessary to complete this report, several data collection methods and tools were used. Qualitative data was collected during RTS1 to scope the concept and the RTS2 investigation goals. Qualitative and quantitative measurements were applied during the RTS2.

1.3 Document Structure

This Final Report summarises the findings and output of the two experiments, focusing particularly on RTS2. The document contains:

- Preliminary assessment of the operational acceptability, technical usability and domain suitability.
- Preliminary benefit analysis mainly focused on the contextual factors that may impede or favour those benefits.
- Preliminary safety evaluation of the TCT tool.
- Conclusions and recommendations for experimental follow-up activities.

2 Tactical Controller Tool (TCT)

2.1 Operational Concept

The main thrust of the FASTI Operational Concept is that the PC is empowered by the provision of the FASTI tools and thus enabled to identify, analyse and resolve some of the MTCD conflicts for traffic that is in Advanced State (Pending sector entry). The TC is expected to be less reactive in performing tasks because of the extra support of the PC and the addition of the MTCD tactical conflicts. The advent of TCT, which is directed at providing separation assurance support for the TC, necessitates deliberation of the controller Working Methods.

2.2 System and HMI

The system or platform (hosted on the eDEP platform) that was used was the EATMP front end HMI and the FASTI tools MTCD, MONA and SYSCO for the baseline exercises. The addition of TCT and the associated functions were the main enhancements for the TCT project study.

2.3 Roles and Working Methods

The Working Methods (WMs) description encompasses the Baseline and the TCT system used by the controller teams. In broad terms, the Baseline Working Methods are similar to those provided in the FASTI Operational Concept.

2.3.1 Working methods in RTS1

All participants were used to working in the classical PC/TC sector team with modern trajectory based systems. They came from environments which could be described as en-route and eTMA type airspace. This facilitated adaptation of working methods for RTS 1 that were not radically different to what controllers were familiar with in their own environments. The main changes were the HMI, the addition of TCT and the functionality of the system. It was decided to give the controllers some latitude in deriving their own working methods based on the FASTI operational concept (refer Figure 1 and Figure 2) while rotating the pairings to ensure optimum variation of the approaches by the different pairs. The PC was tasked with providing planning support to the TC and additional support where needed in managing the traffic.

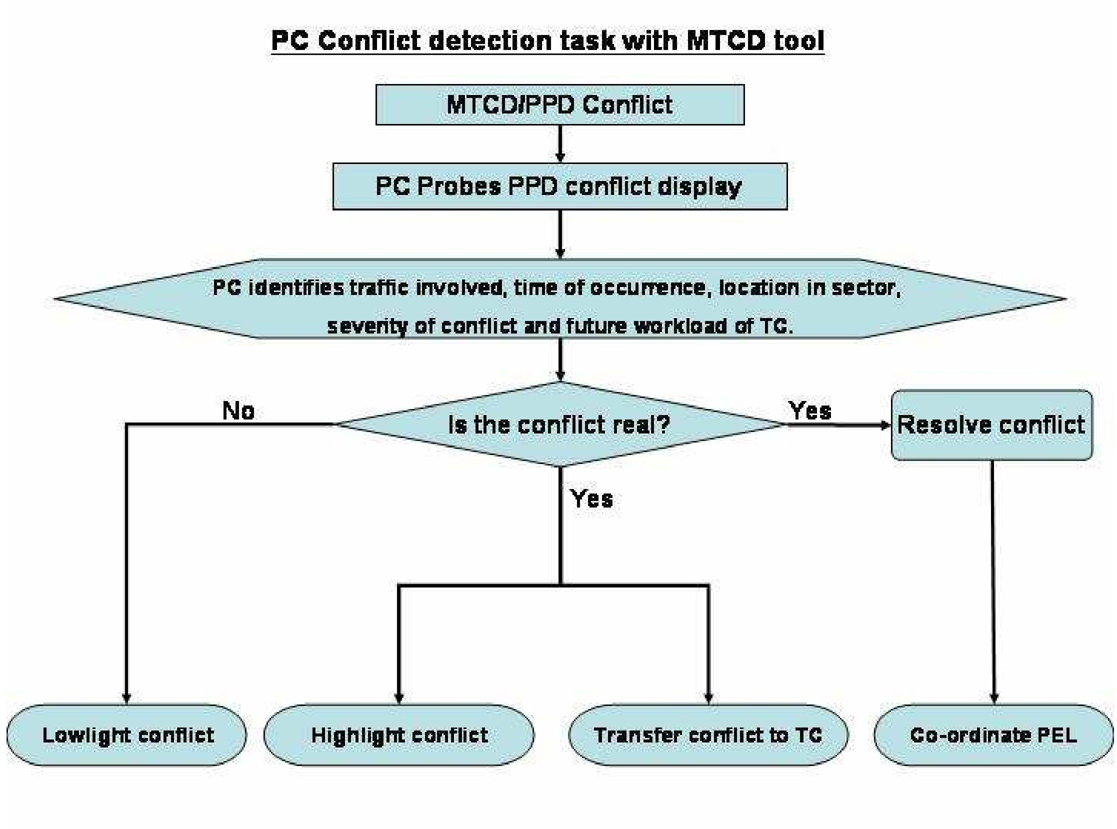


Figure 1: PC Conflict detection task

The resulting working methods enabled analysis of the system use and the variety of system configurations by the controllers. This output was subsequently used to prescribe working methods for RTS 2.

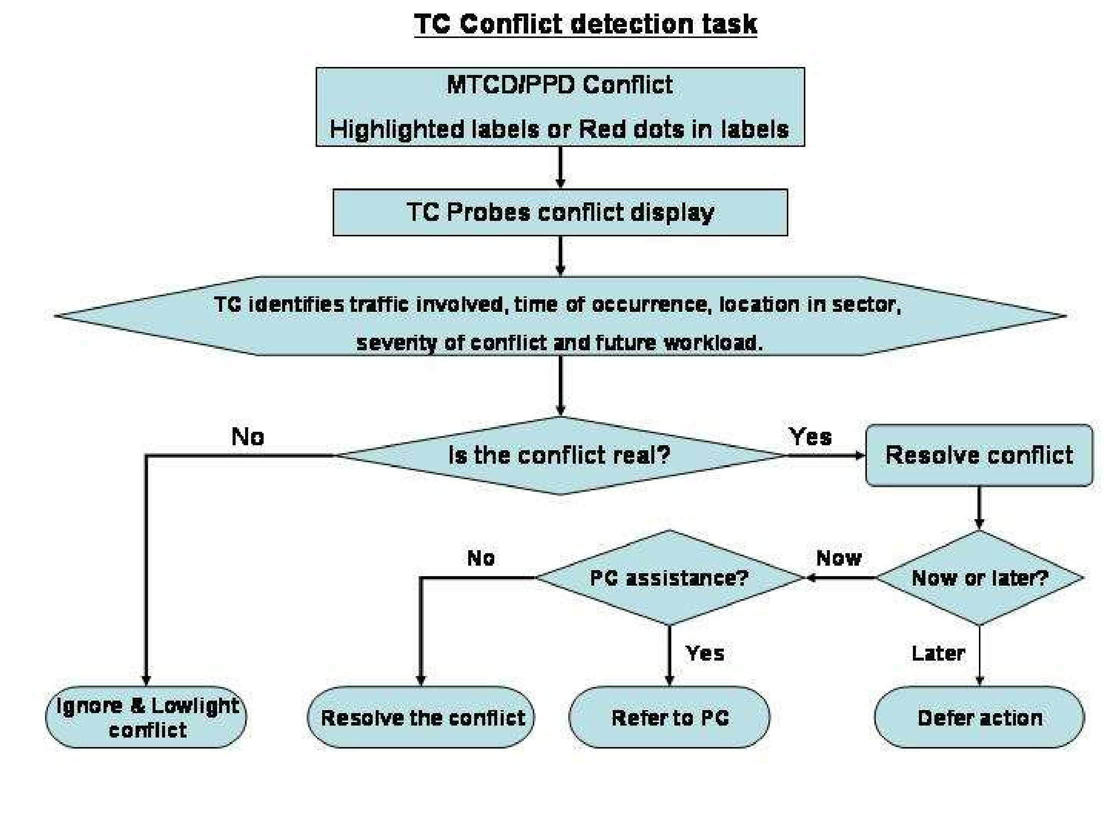


Figure 2: TC Conflict detection task

2.3.2 Working methods in RTS2

In order to comprehensively assess the impact of TCT on the work of the Tactical controller it was decided to prescribe specific working methods for the controller team for the duration of RTS 2 when controllers were using the complete set of tools including TCT. The major change for the controllers was that the PC was working with MTCD and SYSCO and was tasked with conflict resolution and management for traffic that was notified or in advanced state. The PC was asked to make a sector plan and to assess impact of system detected conflicts and either resolve them or pass them to the TC. The main challenge for the controllers was that they were requested to rely on the tools and focus on their own particular areas of responsibility. This facilitated the TC gaining the full support of the system and in particular the TCT tool. The impact of TCT could then be more clearly assessed.

3 Real Time Simulations

The validation process consisted of real time simulation (human-in-the-loop) exercises with the capability of simulating generic airspace with two sectors of the same ATC centre. In a real time simulation the interaction between the actors and the system together with the integrated tools could be observed and validated. Operational Air traffic controllers were enabled to assess the usability of the new tool. The need for two interactive real time simulations of one week each was identified.

In order to make a statement about the operability of the concept with the predicted traffic increase a low to higher traffic load was required.

3.1 Simulated Airspace

The air traffic scenarios used in the experiment were dynamic – the controllers interacted with the traffic in a real time environment. A scenario lasted for one (measured) hour and defined the air traffic in the adjacent sectors that were operated by independent TC/PC controller teams. These sectors were said to be measured because controller responses were recorded by rating scales, questionnaires, and written protocols. Furthermore, the scenarios involved feed sectors that were operated by individual controllers (feeders) in the RTS1 and automatically in the RTS2. The feeders managed traffic to and from the measured sectors. Feeders were included in the experiment to emulate realistic air traffic management and co-ordination (SYSCO) with the measured sectors and they were not exposed to the experimental manipulations.

An environment containing a classical en-route and en-route but with E-TMA like traffic sectors was deemed suitable (i.e. higher level of vertical evolutions) for the project. The two measured sectors were originally taken from the MUAC Delta and Münster (a merged Ruhr and Munster sector) sectors. The route networks and the Coordination procedures were simplified to reduce the training for the participating Controllers and to ensure focus on the tools usage. Three hybrid sectors (RTS2 only) fed the flights into the measured sectors.

3.2 Traffic Samples

Traffic samples used for the simulation were created from real traffic, recovered from CFMU radar data, cut from 08:00 to 09:20 and from 18:25 to 19:45 thus ensuring morning and afternoon traffic samples.

All traffic samples were engineered to create particular “situations/conflicts”

All the resulting samples were validated on completion, in excel format first, then in IPAS and e-DEP for the technical tests and then they were evaluated by operational experts.

The traffic load was defined by the number of aircraft in the sector and the number of conflicts that occurred in the sector taking the characteristics of the sectors into account (size, number of descending/climbing aircraft, coordination with adjacent sectors etc.). The operational engineering of traffic load was conducted so that each level of traffic load consistently imposed a certain task demand on the controllers. Higher traffic loads meant a higher task demand. Thus, the three levels of traffic loads can be interpreted in the following way:

- Low load: There was 20% less traffic than normal rush hours. Low task demand.
- Medium load: There was normal rush hour traffic in the sector. Medium task demand.
- High load: There is 20% more traffic than normal rush hours. High task demand.

Note: A training traffic sample was prepared with 50% less traffic than normal rush hour and with a very low task demand.

In RTS1, which had a more exploratory and instructive approach, the three levels of traffic loads were tested. RTS2 focused more on recording of quantitative metrics. So a more steady and challenging traffic load was chosen for the 6 exercises and these were repeated in baseline and with TCT.

When designing the validation exercises the following operational scenarios were assessed in addition to the nominal use of the tactical controller tool:

- Multiple conflict situations in the tactical phase (more than 2 aircraft involved in a conflict).
- Potential measurements of the STCA occurrence level in a TCT environment (Critical miss-manoeuvre).

3.3 Technical Context

The eDEP platform was selected to run the TCT experiments. This platform was capable of running exercises in real-time to test the TCT while recording controllers' interaction with the tool to detect behaviour and performances.

The TCT module integrated into the platform consisted of:

- The regular calculation of a Tactical Trajectory which starts at the current aircraft position and rejoins (if necessary) and follows the flight plan.
- The regular calculation of a State Vector Trajectory which extends 8 minutes along the current track of the aircraft, and whose vertical profile is constructed using the aircraft performance model up to the CFL.
- The calculation of conflicts along the set of Tactical Trajectories
- The calculation of conflicts along the State Vector Trajectories
- The possibility to calculate conflicts between a State Vector Trajectory and a Tactical Trajectory, indicating that if an aircraft doesn't turn it would be in conflict with the Tactical Trajectory of another Flight (the so-called Missed-Manoeuvre conflict).
- A modified HMI where the different types of problem (conflict or risk) may be visualised in order of priority: STCA, State Vector conflict, Tactical conflict, MTCD conflict, Missed-Manoeuvre conflict.
- A modified PPD to show/hide conflicts based on the time-to-go to the conflict and the minimum separation of the conflict.

Two sectors were available to manage the Delta (DD) and Munster (HH) sectors according to the sitting scheme in Figure 3. Two further positions have been arranged for the feed sectors which were automated. These positions were used only for demonstrations to visitors.

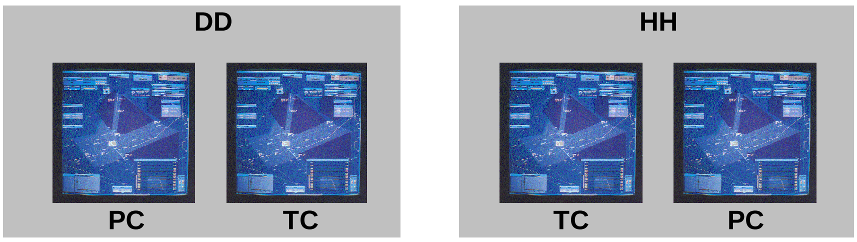


Figure 3: Simulation set-up: 2 sectors (DD and HH) and TC/PC positions

The major limitations were related to the integration of the MTCD already available on the ACE platform (a commercial MTCD), instead of emulating the MTCD by using the TCT module with a different setting and look-ahead for the planner controller. The MTCD used during the simulation could benefit of the same TP updates of the TCT. Then, the algorithm of the used MTCD was different with respect to the MTCD available on the ACE platform. The algorithm of the adopted MTCD was able to make more accurate predictions because conflicts and risks were detected within a tube of +- 1000 ft along the aircraft trajectory, instead of using level bounds. As expected, the MTCD performances were higher than they would have been with the use of the previous MTCD.

3.4 Experimental Design

3.4.1 Experimental Variables and Conditions

The simulation followed an experimental plan. This meant that different system versions were contrasted with each other. These different system versions were (1) the baseline system (EATMP Baseline) and (2) the TCT system with tactical conflict detection. This facilitated evaluation and improvement of the TCT HMI design. Three different traffic loads were used and the two controller roles (i.e. PC and TC) were investigated separately in the simulated sectors.

For controllers participating in the experiment, this meant that they worked:

- With two different organisations (i.e. the baseline and TCT).
- With three different traffic levels (medium, high and very high) in RTS1
- With very high traffic levels in RTS2
- In both controller roles (PC and TC).
- Permutation of positions in RTS1 rotations.
- Change couples of controllers with a permutation of their positions in RTS2 rotations.
- In measured sectors (Delta-DD and Münster – HH)
- As feeders (Feed East – FE, Feed West – FW and Feed Low – FL) in RTS1.

Real time simulations are generally conducted to identify and assess specific human performance issues as a result of new ATM initiatives. Within the context of an exploratory assessment this validation method was used to assess the validity of the concept and to ensure the possibility of TCT coexistence with the other FASTI tools and safety nets (STCA). The set up of the simulation platform will facilitate the assessment of the tools, enablers, system performance requirements as well as subjective assessment of the proposed concept and HMI.

Given the proposed deployment environment, the simulation explored the integration of the TCT tool in a realistic operational airspace environment. The aim was to evaluate the integration of TCT in a typical en-route and E TMA environment, while considering the traffic characteristics for this airspace.

This initial TCT validation experiment was a pure prototyping session that aimed mainly at exploring the role of the TCT in the operational working environment, its functionality and some “look and feel”. RTS1 focused on the definition of the working methods as well as the revision of the TCT system requirements (performance requirements). RTS2 completed the picture by assessment of all the validation objectives.

3.4.2 Participants and Rotation

The controllers that took part in the experiment were selected according to specific criteria. They were from different ANSPs, i.e. Skyguide, LFV, HungaroControl, IAA and FINAVIA to determine the impact and applicability of the tool in different operational environments. These control centres have an environment in common where the MTCD is integrated and the controllers had good level of air traffic control experience.

The Real Time Simulation 1 had an exploratory approach. The simulation aimed at evaluation of the possible working methods to be adopted with the use of the TCT tool. The idea was not to impose a prescribed set of working methods thus stimulating more natural and probably unexpected approaches. Therefore, the pairing of controllers was not frozen to avoid the development of three different approaches as working methods. The fixed pairing option would not have allowed accurate understanding of the pros and cons of different approaches, so the participants working at each position did not follow a rigid scheme. The rotation of people in each team was important to test the greatest number of combinations to avoid the consolidation of three different practices, which would have hindered the analysis.

In RTS2 the rotation was fixed according to a balanced roster where pairings were frozen for each specific exercise and arranged in a manner to ensure people changed positions during the day and allowed the assessor to have a full rotation of spare people available for SME observation support and interviews.

3.4.3 Training

Training is the most critical element of transition to new ATM systems or the introduction of new Decision Support tools. The background and operational experience of the participants was such that the approach to training was similar to that of a conversion training exercise.

The training programme consisted of some short classroom tutorials on the system tools and HMI elements and the philosophy of the HMI design. The classroom work was followed by hands-on sessions where participants actively used the tools and interface in rotation and familiarised themselves with the variety of functions available. There were similarities in the functionality provided and that of the controllers' current operational systems. The main issues addressed in training were:

- The aircraft states and colour coding;
- Representation of the variety of flight legs and their meaning;
- The PPD, VAW and other windows;
- Use of the 3 button mouse for input, information display and special function activation;
- SYSCO co-ordination message activation.

3.5 Data collection

The data collection in RTS1 was different to that of RTS2. Given the exploratory nature of RTS1, the data required for assessment of the objectives of the simulation were collected by the means of subjective assessments by the participants through: end of the day debriefings and interviews. For post run activities a simple and qualitative technique based on post-it notes was used to collect feedback on acceptability and usability especially in relation to satisfaction, engagement and motivation of the users. The only quantitative tool used was an end of simulation questionnaire subject to validation at the same time. The interaction and data collection sessions were organised as follows:

- Day 1: (Social & Familiarisation Exercises) + Post-Training questionnaire
- Day 2: (Exercise preparation for debriefings) + Post-it exercise + End-of-the-day Debriefing
- Day 3: Individual Interviews (30 minutes each) + Post-it exercise + End-of-the-day Debriefing
- Day 4: End-of-the-simulation Questionnaire + End-of-the-day Debriefing
- Day 5: Overall final feedback + End-of-the-simulation Debriefing

The RTS1 Simulation Plan in paragraph 5 displays the timetable of these activities in parallel with the experimental activities.

The RTS2 plan achieved a more structured validation approach with the use of the techniques presented in a complementary manner to satisfy the objectives. The RTS2 interaction and data collection sessions were organised as follows:

- Day 1: Expert Observation and Evaluation of three baseline exercises carried out by the Human Factors engineer and two controllers acting as Subject Matter Experts. Each observation session was followed by debriefings between the HF and the SME, while the trial controllers complete the post-run questionnaires.
- Day 2: Expert Observation and Evaluation of three TCT exercises was carried out by the Human Factors engineer and two controllers acting as Subject Matter Experts. After each run the HF and the two SMEs discussed the observed factors in debriefings. The trial controllers completed the post run questionnaires. The second day ended with the End-of-the-day De-briefing, followed by a Focus Group on roles and working methods.
- Day 3: At each run, one trial controller focused on the observation task as SME, while the other was involved in a semi-structured individual interview of about one hour duration with the HF Engineer. After each run the trial controllers filled in the post run questionnaires, while the SME discussed observations with the HF Engineer. The End-of-the-day de-briefing was followed by a focus group on the Human Machine Interface.
- Day 4: During the runs, the two spare controllers completed the end-of-the-simulation Questionnaire. After each run the trial controllers completed the post run questionnaires. The End-of-the-day De-briefing was followed by a focus group on safety and human factors issues.
- Day 5: The last day was dedicated to a final end-of-the-simulation debriefing aimed at verifying the overall picture of the final results.

The Simulation Plans are available in Annex A – Chapter 7, they detail the timetable of all the activities described so far in parallel with the experimental schedule.

Data required to assess the performance of the system (which do not require participant's subjective assessment) were recorded directly on the platform. In order to support the subjective assessment there was a requirement that each exercise was recorded and all the controller inputs were logged. The data were then analysed with the support of the INTEGRA tool.

In summary, the validation methods and tools used are listed in the present Table 1. The table describes the objective of the applied methods and tools and when they have been used.

Data Collection methods and tools		
METHODS & TOOLS	**OBJECTIVE**	**Completed**
Post-Training Debriefing	The debriefing after the training was to appreciate the level of confidence gained by the controllers in working with the Conflict Detection Tool.	After RTS1 training on 13 October 2008
Training Questionnaire	A questionnaire was distributed to collect information about the completeness of the training session and the developed controllers' expectations.	After RTS1 training on 13 October 2008
Observation by a Subject Matter Expert (SME), i.e. an operational expert	Gather information concerning the participants' strategy and efficiency; discuss the concepts, procedures, and tools under study.	During RTS2 runs
Observation by a human factors specialist	Gather information about HMI usability, Human errors, stress, workload, motivation, confidence, "learnability", skills, etc…	During RTS2 runs
Post-run questionnaire	Assess participants' ratings of overall workload across the run, situation awareness, team work …	After RTS2 runs
Post-run Debriefing with SME	The post-run de-briefing with the SME lasted only 15 min to collect some quick feedback "to strike when the iron's hot" and collect material for further discussion in the end-of-the-day de-briefing after the SME observation of a specific run.	After each RTS2 run
End-of-Simulation Questionnaire	Gather information regarding User Acceptability, Usability and Suitability of the concept, plus Safety and Capacity vs. Efficiency in environments of different complexity. RTS1 questionnaire differed from that in RTS2.	During day 4, towards the end of the simulation
Individual Interviews	The interviews complemented the information gathered by other tools, going into the specificity of each individual experience. The questions were designed	During runs of the third day of RTS1 and RTS2

Data Collection methods and tools		
METHODS & TOOLS	**OBJECTIVE**	**Completed**
	to cover all the simulation objectives, i.e. User Acceptability, Usability and Suitability of the concept, plus Safety and Capacity vs. Efficiency in environments of different complexity.	
End-of-day Debriefing	Assess participants' ratings of the impact of the tools and/or procedures on system or human performances such as safety, workload and situation awareness during that run.	After set of three runs at the end of the day (RTS1 and RTS2)
Focus Groups	End-of-day debriefing in RTS2 were complemented by three different focus groups, addressing respectively: 1. Applicability: Assessment of working methods and roles + TCT Parameters in different conditions 2. HMI Usability with the use of templates for the HMI Elements Evaluation and a Usability Questionnaire. 3. HAZOP: HF and Safety Issue Analysis	End of day 2, 3 and 4 in RTS2
End-of-Simulation Debriefing	The post simulation de-briefing was structured according to the output of the post-simulation questionnaire. The conclusion was discussed with the controllers to verify their agreement.	End-of-Simulation
Video, audio recording	Gather information to be used for post analysis of efficiency, HMI usage and better understand human behaviour while interacting with the tool. Videos recorded during the runs and debriefings were analysed to derive valuable evidence.	During RTS2 runs
System log recording	System log recordings gather information used to assess separation performances, workload and capacity with the support of the INTEGRA tool that would perform the elaboration of data. The data were analysed by the focus groups.	During RTS2 runs
INTEGRA tool	The scope of the INTEGRA tool was to provide quantifiable metrics for the determination of capacity, safety, efficiency and environmental impact in real and fast time simulations. The output of INTEGRA Safety metric was analysed	After RTS2 runs – during the analysis phase

Data Collection methods and tools		
METHODS & TOOLS	**OBJECTIVE**	**Completed**
	after RTS2 to evaluate capacity and to supplement the adopted methods to assess safety.	

Table 1: Data Collection methods and tools

4 Evaluation Focus and Analysis

4.1 FASTI Validation Objectives

The FASTI Programme High Level Validation Objectives can be summarised as follows:

1. ATM KPA: To assess for performance improvements in the following areas:
   a. Safety;
   b. Capacity;
   c. Efficiency;
   d. Economics / Cost Effectiveness;
   e. Environment.

2. To improve ATM system performance through Harmonisation of:
   a. Procedures
   b. Technology

These validation objectives are generic for the whole FASTI programme and are oriented towards the implementation and the deployment of different ATC tools.

Given the development stage of TCT these objectives could not be validated entirely; depending on the maturity of the TCT integration with the other FASTI tools, subsequent validation exercises focused on some specific objectives that were defined after a more exploratory session in the RTS1.

4.2 TCT Validation Objectives

The high level aim of the two Real Time Simulations in the context of this project was to make an initial assessment of the **impact of introducing the Tactical Controller Tool (TCT) as a means of support for tactical control**.

In detail, the validation was focused on the “U.S.A.[1] Assessment” (Harwood,1993) and an initial evaluation of capacity and safety. The U.S.A. Assessment is based on the investigation of three fundamental factors in which fall all the human-centred issues:

- Domain suitability (operability)
- Technical usability and

[1] Usability Suitability Acceptability.

- User acceptance.

These aspects of the human-system interaction are addressed to investigate the human factors issues. This is the first step to be done before measuring the exact benefits of the introduction of new technology. However, the analysis of these three aspects helps verify that safety and efficiency are maintained or introduced as benefits by the system. In particular, the connection between usability and safety, plus usability and effectiveness of service provision are investigated to remove those aspects of the system that might impair safety.

The validation objectives take into account the project aim, which consists of:

- Establishing and collecting the users' view of issues related to TCT usability and TCT functionality within an environment containing the initial MTCD tool as well as safety nets (i.e. STCA)
- Establishing the users view and provide recommendations regarding the TCT HMI,
- Establishing the users view regarding the best adapted environment (airspace, working methods) for TCT integration and deployment
- Establishing the users view with respect to the configuration system parameters (e.g. look ahead time, trajectory types and behaviour, etc) used for TCT implementation
- Assessing benefits of using the system and produce recommendations focussed on a wider implementation and interoperability with the other FASTI tools (mainly focussed on the TP behaviour in the selected environment, traffic characteristics and human machine interface).
- Assessing the compliance of the TP, MTCD, STCA and TCT functions with the EATM operational requirements by evaluating the consequences of items of non-compliance.
- Identifying eventual factors external to the FASTI toolset (including TCT), which may potentially limit system performance (e.g. surveillance requirements, adjacent unit operations and requirements, etc) and evaluate their consequences.
- Assessing the safety issues associated with the use of TCT in the considered environment.

These objectives are encompassed in the validation objectives of the current experiments under the USA assessment and the evaluation of the Key Performance Areas affected by the TCT introduction.

The following elaborates detail of the objective of the TCT RTS1 and RTS2 simulations. Each topic addressed in the simulations was analysed and some low validation objectives were derived. For each area of concern, a validation technique used to make the assessment was matched. In general, the validation techniques used were:

- Human Factors Observation and Evaluation
- Subject Matter Expert (SME) Observation
- End-of-the day debriefings
- Focus Groups
- Post-run Questionnaires
- End-of-Simulation Questionnaires
- Semi-structured interviews with ATCOs
- Debriefings with SME Observers

The description of these validation techniques and the associated tools used for the assessment are provided in a separate annex, together with detailed description of the data collected and analysed.

4.2.1 Operability/Domain Suitability

Analyzing just the usability of a particular set of HMI features available at the controller disposal does not necessarily ensure that the introduced the Tactical Controller Tool will be able to perform its intended function in its designated environment. It is obvious that the "look and feel" of a tool does not guarantee that its role is functional and useful in the specific environment, therefore both of these human factors aspects must be considered. In this specific domain, the concept of suitability refers to the content and appropriateness of the information and display representation in support to controllers' tasks and their cognitive requirements, i.e. the detection aiding algorithms ease the cognitive detection and processing within the ATC environment.

In addition, the suitability of the Tactical Controller Tool is evaluated with respect to the following environment and operational characteristics:

- Environment characteristics:
  - o Different En-route environments, e.g. DD and HH,
    - ▪ Complex route structure,
    - ▪ Simple route structure.
  - o Traffic flow, e.g. mix of traffic and direction of the flow.
- Staffing Options:

    - o Conventional Planning and Tactical Control,
    - o Group-Sector Planner,
    - o Single person operations
- Transition Phase

Assessment method and validation techniques

The domain suitability was mainly assessed by the use of the following methods:

- Semi-structured Interviews to ATCOs
- End of the day debriefings and Focus Group 1 and 2 (FG1 and FG2)
- Questionnaires
- SME Observation and Evaluation

Different ATCOs' provenances help understand the impact of the Tactical Controller Tool in different operational environments. The feedback coming from different experiences can integrate in a more shared and valuable opinion in order to understand how to define an operational concept applicable throughout different contexts.

Operability and Domain Suitability			
High level Objective	**Medium level Objective**	**Low level Objective**	**Data Collection Methods and Tools**
To assess the operability of the TCT procedures and the domain suitability of the Tactical Controller Tool	To evaluate the suitability of the Tactical Controller Tool (including parameter setting) and their related working methods and roles in support of the controllers' tasks and their cognitive requirements		FG2 Interview EoS Q'naire

Operability and Domain Suitability			
High level Objective	**Medium level Objective**	**Low level Objective**	**Data Collection Methods and Tools**
	To evaluate the suitability of the Tactical Controller Tool in different En-route environments	To evaluate the suitability of the Tactical Controller Tool in simple and complex route structure environment in nominal and non-nominal situations	FG2 Interview EoS Q'naire FG3
	To evaluate the suitability of the Tactical Controller Tool in different staffing options	To evaluate the suitability of the Tactical Controller Tool with Conventional Planning and Tactical Control operations	Interview EoS Q'naire FG2
		To evaluate the suitability of the Tactical Controller Tool with Group-Sector Planner operations	Interview EoS Q'naire FG2
		To evaluate the suitability of the Tactical Controller Tool with Single person operations	Interview EoS Q'naire FG2
	To evaluate the impact of the introduction of the TCT tool in the transition period		Interview FG2

Table 2: Operability and Domain Suitability Objectives

4.2.2 Technical Usability

Harwood defines technical usability as: "the perceptual and physical aspects of the human computer interface like display formatting, graphics and human-computer dialog and the anthropometric characteristics of the system". The user interface is usable when the process of using it is effective, efficient and, satisfying, comfortable or engaging. This concept translates in practice in the effort the controller spends to detect the system information, understand it and interact with it. Moreover, the ease of use is affected by the effort that the controller takes to learn how to decode and use the tool. So the technical usability measures assessed include:

- Effectiveness, relating the goals of using the system to the accuracy and completeness with which these goals can be achieved. Specific usability issues evaluated in this context are:
    - Consistency,
    - Coherency,
    - Accurateness – accuracy of the update interval for trajectory required, trying to analyse possible limits to system performances, for example due to trajectory update cycle and surveillance or flight plan data availability.
    - Reliability – detected conflicts stability, no missed conflicts,
    - Flexibility - relating to the capability of the system to adapt to the user use in each operating condition.
    - Prediction – adequate levels of predictions, by setting of look-ahead parameters, taking into account usefulness of the tool and HF issues, for example related to user de-skilling in conflict detection.
- Efficiency, relating to the level of effectiveness achieved to the expenditure of resources such as mental or physical effort. Time efficiency can be measured by the time spent carrying out the task. Human efficiency can be derived from measures of cognitive workload. Economic efficiency takes into account the labour costs of the user's time, the cost of material resources and the cost of required training.
- Learnability, relating to the ease of HMI learning, which is measure by the time required to learn for an inexperienced user.
- Other measures such as satisfaction, engagement and comfort are quality related to the perceived usability of the user. They are more measured by the ratio of comments related to these attributes of the HMI.

The HMI functions of which the usage and usability are evaluated against these measures include:

- Presentation of TCT conflict in the Potential Problem Display (PPD),
- Presentation of TCT conflicts in the Vertical Aid Window (VAW),
- Presentation of tactical conflicts on the horizontal plane of the Radar Plan View Display (RPVD).

In addition to these functions, the urgency mapping of MTCD, TCT and STCA alarms is evaluated as focus of the alarm design matter.

Assessment method and validation techniques

A preliminary Technical Usability evaluation was conducted during the RTS1. Then, it is eventually assessed in RTS2 with a more varied triangulation of validation techniques. The HF observation and the evaluation according to common usability heuristics are coupled by end of the day debriefing and semi-structured interviews that mainly explain the nature and correct the assessment of the observed relationship between usability and operability. The questionnaires should confirm the final conclusions of the usability analysis with some quantitative measures.

- HF Observation and Evaluation
- SME Observation and de-briefing
- Questionnaires
- End of the day debriefings and Focus Group 2 (FG2)
- Semi-structured Interviews to Subject Matter Experts

Technical Usability			
High level Objective	**Medium Level Objective**	**Low Level Objective**	**Data Collection Methods and Tools**
To assess the usage and technical usability of the Tactical Controller Tool HMI in terms of	To assess the efficiency of the interaction of the controller with the TCT while carrying out his tasks	To assess the TCT efficiency in terms of time efficiency (time spent to carry out a task) and human efficiency (cognitive	FG1-2 Interview *Secondary*: Q'naires and Observations interpreted by de-briefings

Technical Usability			
High level Objective	**Medium Level Objective**	**Low Level Objective**	**Data Collection Methods and Tools**
efficiency, effectiveness and learnability		workload)	
	To assess the usage and technical usability of the detected conflict presentation on the horizontal plane of the Radar Plan View Display (RPVD)	To assess the usage and technical usability of the *State Vector* information display	*Primary*: Interview FG1-2
			Secondary: Q'naires and Observations interpreted by de-briefings
		To assess the usage and technical usability of the *Flight leg* information display	*Primary*: Interview FG1-2
			Secondary: Q'naires and Observations interpreted by de-briefings
		To assess the usage and technical usability of the *Tactical Conflict* information display	*Primary*: Interview FG1-2
			Secondary: Q'naires and Observations interpreted by de-briefings

Technical Usability			
High level Objective	**Medium Level Objective**	**Low Level Objective**	**Data Collection Methods and Tools**
		To assess the usage and technical usability of the *Miss-Manoeuvre* information display	*Primary*: Interview FG1-2 *Secondary*: Q'naires and Observations interpreted by de-briefings
		To assess the consistency between MTCD, TCT detected conflicts and their relationship with the safety net (STCA) information	*Primary*: Interview FG1-2 E-o-S Q'naire *Secondary*: Post-run Q'naires and Observations interpreted by de-briefings
	To assess the usage and technical usability of the TCT conflicts presentation in the Vertical Aid Window (VAW)		*Primary*: Interview FG1-2 *Secondary*: Q'naires and Observations interpreted by de-briefings
	To assess the usage and technical usability		Interview FG1-2

Technical Usability			
High level Objective	**Medium Level Objective**	**Low Level Objective**	**Data Collection Methods and Tools**
	of the TCT conflict presentation in the Potential Problem Display (PPD)		*Secondary*: Q'naires and Observations interpreted by de-briefings
	To assess the usage of the menu for HMI selection options, named FlightLeg Mapping Window (FLM)		*Primary*: Interview FG2 --- *Secondary*: Q'naires and Observations interpreted by de-briefings

Table 3: Technical Usability Objectives

4.2.3 User Acceptance

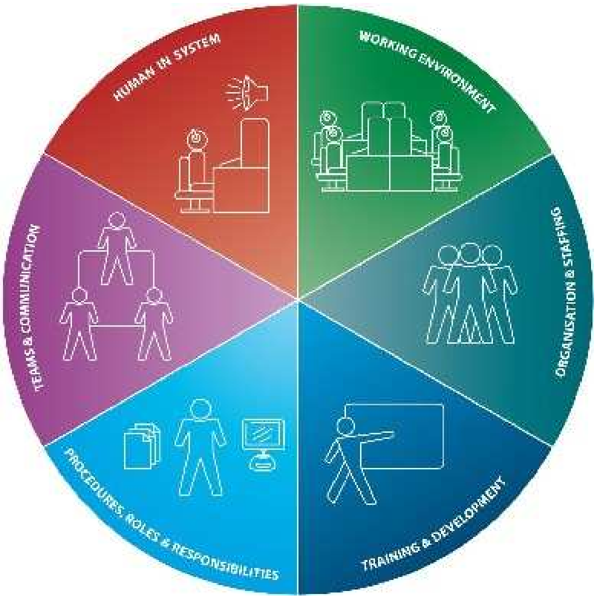
User acceptance concerns the appreciation of the system from the user. The acceptability of a system is highly proportional to its usability and its suitability in supporting the user's physical and cognitive task requirements. However, it is also affected by the job satisfaction as well as the usefulness of tool in the specific context. The usefulness of the tools is generally evaluated on the base of the perceived benefits, e.g. the perceived decrease of workload, the increase in situation awareness, the improvement of teamwork and the perceived increase of system performances, such as safety, efficiency and capacity, impacted by those human performances.

To assess the user acceptance we evaluate the impact of the TCT introduction on the following factors:

We will explore the HF Pie areas by analysing:

- Technical usability
- Domain suitability
- Teamwork and communication

- Training



The investigations of these areas will go through the analysis of the HF impacts on Human Performances, which include:

- Workload
- Situational awareness
- Trust and reliability[2]
- Stress
- Job satisfaction and motivation
- Experience and Skill change

In addition to this assessment, we will get the user acceptability as a result of the perceived improvement of system performances from the controllers.

Assessment method and validation techniques

The factors pertaining to the user acceptance were evaluated by the HF observation and evaluation and coupled with end of the day debriefings and semi-structured interviews. The questionnaires at the end of each run and at the end of the simulation gave some quantitative ranking of the cited areas of interest.

- HF Observation and Evaluation

[2] Reliability pertains to detected conflicts stability, “no” missed conflicts.

- Post run Questionnaire
- End-of-Simulation Questionnaire
- Training questionnaire
- End of the day debriefings
- Focus groups
- Semi-structured Interviews to ATCOs
- Integra for workload

User Acceptance			
High level Objective	**Medium level Objective**	**Low level objective**	**Data Collection Methods and Tools**
To assess the impact of the TCT introduction on the user acceptance	HF Pie	To summarise the assessment of the HMI *technical usability* (Human in System)	E-o-S Q'naire Interviews Observation
		To summarise the assessment of the *domain suitability* (Procedures, roles and responsibilities + Organisation & Staffing + Working Environment)	E-o-S Q'naire Interviews Observation
		To assess the change in *teamwork* and communication (Teams & Communication)	E-o-S Q'naire Interviews Observation
		To evaluate the extent of the required *training* and its compatibility with the current one (Training & Development)	Training Questionnaire Interviews Observation

User Acceptance			
High level Objective	**Medium level Objective**	**Low level objective**	**Data Collection Methods and Tools**
	HF Impacts on Human Performances	To evaluate the physical and cognitive *workload* of the user with the TCT introduction	Post-run Questionnaires Interviews Observation
		To assess the impact of the Tactical Controller Tool on the *situational awareness*	Post-run Questionnaires Interviews Observation
		To evaluate the *trust* and reliability in the Tactical Controller Tool	Interviews Observation Debriefing Q'naires
		To evaluate the resulting *job satisfaction and motivation* after the TCT introduction	Interviews Observation
		To evaluate the resulting s*kill change* with the TCT introduction *into operations*	Interviews Interviews

Table 4: User Acceptance Objectives

4.2.4 Safety

TCT can increase safety through the reduction of safety-related potential errors:

- By alerting controllers to conflicts (predicted separation infringement),
- By identifying potential critical manoeuvre-misses.

The safety levels reached through the use of the TCT combined with MTCD tool were also evaluated considering the increase of situational awareness and the reliance on the system.

Previous work on TCT Safety and Human Factors study was reviewed prior to RTS2 to identify those Safety Requirements that were still valid, those considered for the current simulation design and those missing from the original analysis.

Assessment method and validation techniques

The assessment of the impact of the TCT tool on safety was evaluated in a dedicated focus group. Controllers identified the safety benefits brought by the introduction of TCT and the potential Human Errors and Technical Failures introduced by TCT. As baseline for this focus group the material developed in a previous study (Nicholls, 2007) was adopted. The list of potential safety requirements identified by this study was reviewed.

Topic	**High level Objective**	**Low level objective**	**Data Collection Methods and Tools**
Safety	To assess the impact on safety of the TCT introduction	To evaluate the mitigation of safety-related potential errors occurring the current system and the introduction of any possible safety issues in the future system	FG 2
		To assess overall separation performances of the new system with the introduction of TCT	INTEGRA

Table 5: Safety Objectives

4.2.5 Capacity and Efficiency

The aim of this objective was to investigate if the support of TCT facilitated the work of the controller to ensure an expeditious and orderly flow of traffic as well as increasing the sectors capacity. The effectiveness of the service provided was subjectively judged by the experts as to whether the tools improved the cognitive system performances or not. The aim was to understand if the human and machine were able to work in harmony while taking decisions based on knowledge coming from the two components and the surrounding environment.

The interpretation of the analysis plus some quantitative measurements based on system logs attempted to quantitatively measure the expected increase of sector capacity also in relation to flight efficiency.

Assessment method and validation techniques

Topic	**High level Objective**	**Low level objective**	**Validation Techniques**
Capacity and efficiency	To assess the impact on key performance areas affected by the TCT introduction in relation to airspace complexity	To assess the impact on sector capacity of the TCT introduction in relation to airspace complexity	FG3 INTEGRA Q'naires
		To assess the impact on flight efficiency of the TCT introduction in relation to airspace complexity	

Table 6: Capacity and Efficiency Objectives

5 Validation Results

5.1 Constraints

The TCT experiment was initially intended to be a simple demo-like session. Later, given the maturity of the TCT prototype as determined from the Site Acceptance Tests (SAT) by looking at technical and operational performances, it was decided to perform a more structured validation activity. The simulation sessions were only two of one week duration each. The first simulation session (RTS1) was held in October 2008 and it was organised in an exploratory manner, in order to train controllers on the new airspace as well as on how to use the tools, and in order to scope with the participants some operational concept details. The measurements were performed during the RTS2 in December 2008.

In RTS1 the main change that controllers endured was the new work environment inclusive of airspace, tools and HMI. At the beginning they were unfamiliar with the airspace and with the HMI and they also felt the absence of certain support tools they utilise in their own operational environment. For this reason, the first week with the controllers was limited to training activities and to the exploration and the comprehension of possible TCT implications for controllers. The RTS1 mainly aimed to address the following objectives: 1) to allow controllers familiarisation with the new system, 2) to test, observe and discuss the TCT behaviour to define the working methods and roles to be adopted in RTS2, 3) test the new HMI functionalities and revise them where necessary, 4) set realistic objectives that could be investigated in RTS2. The RTS1 simulation did not give reliable results; it only gave an indication of the hypothesis to be tested in RTS2. Therefore, this report is mainly based on findings of the RTS2 simulation, where a less exploratory approach was adopted and evidence has been systematically retrieved.

In December 2008, the RTS2 took place over 4 days and a half. Only 12 runs were available to perform the experiment. Therefore, it was decided to have just two organisations, which resulted in six exercises with and without TCT. The results were somewhat compromised due to having one software module to simulate both TCT and MTCD, with different look-ahead horizons. The better option would have been to have four organisations. The first organisation with a basic MTCD, the second organisation with the use of an MTCD enhanced by an improved conflict detection calculation, and a third and fourth organisation with the introduction of TCT in the first and second organisation environment respectively. This would have allowed showing more clearly the improvements brought by TCT in a variety of environments. Another alternative would have been to run a baseline with a basic MTCD and an organisation enhanced by the introduction of TCT. Unfortunately, it was decided to improve the calculation of the existing MTCD by using TCT functionalities to reduce the number of nuisance warnings of the MTCD. The MTCD calculation was improved not only by more regular trajectory updating but more importantly due to a dual pass algorithm which searches first for contextual conflicts (i.e. not real conflicts but “blue lines”, using relaxed vertical tolerances), then re-applied the conflict algorithm on the contextual conflicts with the normal 5nm/1000ft criteria to find the real conflicts. In a previous more basic version of the MTCD implementation, the search was done once only with a relaxed vertical separation in order to pick up the contextual aircraft, and these were declared conflicts if there was AFL/CFL/XFL overlap. The result of this was that climbing/descending conflicts had a longer duration than they should have had. Also the enhanced MTCD was improved to use a 'zone of occupancy' whereby a 3D check was done to see if pairs of aircraft can be eliminated without performing a trajectory comparison. This means that the system can produce the contextual and more precise conflict information in a fairly efficient way, even when updating TP on a regular basis.

So the MTCD used during the simulation was very reliable as, in addition to the system trajectory, the calculation was improved to provide more precise and coherent conflict information to TC and PC through MTCD and TCT. This forced enhancement has had an impact on the entire experiment and thus on its results. However, we have to observe that from an experimental view point this may have been a limitation, but from an implementation view point the approach to have the same tool to provide both MTCD and TCT conflict detection could be seen as a key enabler to gain major benefits. The MTCD and TCT full integration would be an ideal situation. Stated that, we have to remark that whether the tools are combined or not, it would be important to have a single system trajectory that provides a sufficient level of performance to support both tools.

5.2 Technical Usability

To assess the usage and technical usability of the Tactical Controller Tool HMI in terms of efficiency, effectiveness and learnability

Primary indicators: Interview, FG1-2

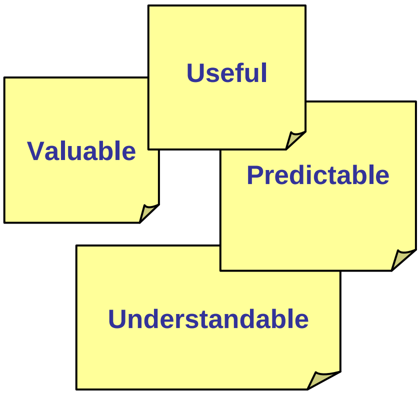
Secondary indicators: Questionnaires and Observations interpreted by de-briefings

The Tactical Controller Tool is an automated support tool that assists air traffic controllers in detecting conflicts between pairs of aircraft on the Radar Plan View Display (RPVD). At the introduction of the concept, the participating controllers quickly appreciated and confirmed the usefulness of the TCT concept. The TCT is a tool that efficiently supports one of their most difficult tasks, which is normally performed by a scanning activity of all traffic presented on the RPVD. The search task to detect conflicts is a cognitive process limited by unstructured and complex information. The TCT alerts draw the right level of controllers' attention when conflicts are detected. The tool also provides controllers with additional information necessary for other ATC tasks such as problem solving, decision making and verification tasks. Thus, TCT increases the level of efficiency of ATC activity achieved with the expenditure of resources, in particular, related to mental effort. Controllers also confirmed the increase in effectiveness of ATC service since TC goals could be achieved by applying planning strategies with the support of accurate and complete system information. The data provided were consistent and coherent throughout all the HMI elements (i.e. the aircraft labels, the alarms on the RPVD, the VAW and the PPD).

TCT support is timely and clear. Data are calculated automatically and systematically by the TCT algorithm to provide an effective and precise detection of all future infringements of the separation minima (as configured by the user). The tool is able to detect conflicts in all vertical and horizontal geometries, this is useful especially when the sectors are particularly complex and the traffic is high to allow the detection on the RPVD. TCT adequately supports controllers where limitations may be surpassed or close to saturation level. The tool helps controllers prevent errors such as forgetting planned instructions or monitoring more complex aircraft evolutions. The information was always reliable; no conflicts operationally relevant were missed thus demonstrating the stability with which conflicts have been detected during the simulation. TCT has demonstrated its flexibility to adapt to the ATC activity. It has been able to detect conflicts in all tested operating conditions, even if non-nominal conditions have not been tested yet.

The Human Machine Interface developed and used during the experiments was easy to learn and to use. TCT elements were all very intuitive, thus reducing the time required to learn for an inexperienced user. However, the logic behind some components of the HMI, particularly the Vertical Aid Window (VAW) and the Potential Problem Display (PPD), were more difficult to understand at the beginning as they require controllers to build new mental models to adapt to these new visualisations. Once ATCOs got used to these views, the benefits they received in terms of use were very much appreciated.

In conclusion, controllers were engaged by the comfort they derived by the usability of the HMI and they were fully satisfied by the quality of the air navigation service increased due to the TCT use. In fact, already during the post-run exercises in RTS1, the adjectives they have often mentioned to define their feeling towards the TCT were useful, valuable, predictable and understandable.



5.2.1 Alarm System

The Tactical Controller Tool is a conflict detection system, which triggers events to attract the air traffic controller attention. By definition we consider it as an Alarming tool, where alarm is meant to be a general term referring to alerts, warnings, reminders, aids, etc. All alarming tools are integrated in an Alarm System where other alarms such as STCA, MTCD and MONA are operating. TCT has been evaluated integrated in a system where other tools are supporting or supervising controllers' tasks. To evaluate TCT and its integration we have used as heuristics the principles derived by a recent EUROCONTROL study on Alarm Design in Air Traffic Management. These principles expand and tailor typical User-centred Design and Cognitive Design principles and cover different important aspects, i.e. tuning of an alarm system, suppression, generation and filtering functions, aggregation and prioritisation of alarms, presentation of alarm information and human behavioural aspects associated to the reaction to an alarm. This study is applied to the TCT case in order to complete the assessment of its usability. The principles for auditory alarms were not applicable since no sound is associated with TCT and, from the observation, it does not seem necessary to associate one.

The statements in bold italic are some of the principles listed in the Alarm Design study. Their relevance for the current validation work is commented subsequently.

5.2.1.1 Alarm Generation

Alarms should be generated by a logic detecting all potential hazards having an operational significance/relevance.

Controllers confirmed that the TCT algorithm has an appropriate operational understanding of what a conflict/risk is (with respect to different types of conflicts – based on different trajectories). TCT is able to detect correctly all hazards that are operationally relevant and it distinguishes between risks and conflicts.

The number of nuisance alarms shall be able to be effectively minimised using tuning and filtering functions and avoiding suppression function.

The number of nuisance alarms was minimised by the tuning performed during the site acceptance tests looking at the technical and the operational aspects of TCT implementation. However, a number of nuisance alarms (1.6 rates on a scale of 5 points) were detected during the experiment. Those nuisance alarms were detected for climbing/descending geometries mainly in MTCD.

Recommendation (follow-up): To evaluate TP performances and accuracy of the MTCD even with constant updating to check if this issue requires more accurate modelling and improved TP performances, or the number of nuisance alarms are within acceptable limits.

The tuning of the alarm system has focused on the reduction of nuisance while avoiding to lose genuine conflicts. The attempt seems to have reached a good balance as the rate associated to the number of missed conflicts is only 0.2 over 6 exercises with TCT. The resulting TCT performances were considered more accurate and reliable than the STCA. It was observed that the TCT detected two alerts that the STCA missed during the exercises.

What tactical and planner controllers can act on is the PPD parameter setting of TCT and MTCD respectively. The PPD parameter setting helps to filter out unwanted alerts. It is particularly important as the TC has to keep the minimum level of warning not to lose the picture and focus only on high risk situations. While the PC cares about all possible conflicts, guaranteeing there is no missed detected occurrence.

During the RTS1, controllers were able to set the PPD parameters as they preferred and the simulation team could observe the use of TCT according to these settings. Where the parameter settings had a greater look ahead, the controllers used it as a monitoring tool instead of using it as a separation assurance tool. Some risks were identified with TCT as a monitoring tool, such as de-skilling of controllers monitoring activities and increase of error risks because of a label cluttering effect and thus the increase of RPVD complexity and decrease of readability. From the analysis of controllers' preferences in RTS1, combined with the required use of TCT (i.e. as separation assistance tool), the TCT parameter setting in RTS2 was defined and fixed to 8 minutes and 6 NM. The time upper bound is set in line with the TCT concept description, while the upper bound setting of the distance is defined with the criteria of getting meaningful alerts still well in advance to allow controllers intervene in an efficient way, thus preventing use of TCT as a monitoring tool. By fixing the parameter data measurements and analysis were also facilitated by reducing variability and allowing easier comparisons.

At the end of RTS2, after working with the fixed setting, controllers were also asked to express their opinion and their preferences about the most adequate TCT parameter settings. The controllers' preferences are listed in Table 1 together with RTS1 preferences.

	NM	min
RTS1	8	8
	7	7
	8	7
	7	8
	8	5
	6	5

	NM	Min
RTS2	6	5
	6	5
	5	6
	8	7
	6	8
	10[3]	8

Table 1: Controllers' preferences for TCT Parameter Settings in RTS1 and RTS2

We can conclude from the discussion and analysis of the data in the table above that the TCT upper bounds of the parameter settings should assume a value in the interval from **5 NM** to **10 NM** and from **5 minutes** up to **8 minutes**, set according to the operational context. Some controllers stated that the upper bound for distance should be set, for example, at 10

[3] Where Letters of Agreement require aircraft separation at 10 NM.

NM only in sectors where the Letters of Agreement require transferring the traffic spaced at 10 NM; in general, **6 NM** seems to be one of the preferred choices. The chosen setting of TCT in RTS2 (8 min. and 6 NM) were considered a good trade-off between providing an automated support and keeping the human in the loop.

The context in which the alarm system is put in operation must be taken into account when calibrating the tool sensitivity.

Controllers confirmed that they had different preferences according to the sector they were working on. For example, the TCT filter at 6NM is useful when the separation minima is 5NM, it is not correct when, for example, the traffic needs to be passed to the adjacent sector spaced at 10NM.

In general, the parameter setting of TCT to filter out unwanted alerts must be defined according to the contextual factors such as ACC practices, radar accuracy, other alarming tools in the ATM system, human resources, airspace geometries, airspace complexity, traffic load, other sector characteristics and Letters of Agreement (LoA) – even if, according to the initial operational concept description, LoAs should not be something the TCT should take into account -.

In conclusion, the TCT scanning area defined by upper and lower parameter bounds is represented in Figure 1.

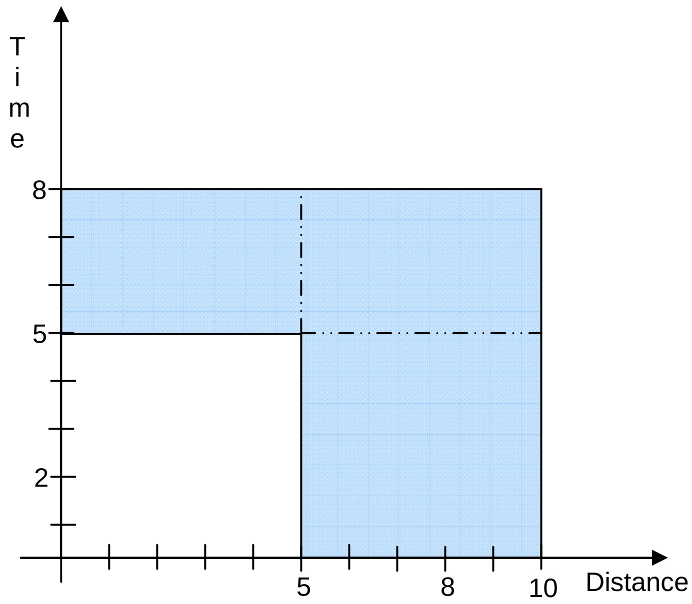


Figure 1: TCT Parameter Setting area

The parameters for miss-manoeuvres were set to 5 NM and 5 min, which is the upper level setting, since the aim was to get the major number warnings to evaluate it. However, the observation of the nuisance during the simulation revealed that the upper bound parameters should be set down to 3 NM and 3 min maximum, where these warnings are required. The rate and frequency of miss-manoeuvre warnings was too high. The tactical controller was often distracted to interact with the warning and understand the kind of risk signalled.

The rate and frequency of alarms should not exceed the users' information processing capabilities.

The rate and frequency of alarms was observed to be adequate to serve users 'information processing capabilities. During the Site Acceptance Tests several tunings of the system have been done. To validate the effectiveness of this tuning, the subjective assessment should be complemented by some data analysis. As the data available in our study were not sufficient to conclude about this topic, future tests should be set up to gather an adequate pool of data to conclude on the acceptability of the rate and frequency of alarms and get sufficient statistical relevance of the results. No workarounds such as suppressions and cancellations of TCT functionalities should be allowed when the rate and frequency is unacceptable when the system is in operation. Immediate interventions should be requested to solve issues.

Recommendation (follow-up): To test separation performances with a selection of different TCT parameter settings for different operational conditions (5-10-15 NM separation minima).

Recommendation (follow-up): To evaluate the usefulness and usability of the Miss-Manoeuvres functionality in further studies testing different parameter settings.

Recommendation (tech.): Controllers should not be able to suppress the TCT functionality.

Recommendation (tech.): Controllers should not be able to cancel the TCT alerting if a problem still exists.

Recommendation (tech.): The alerting time should allow controllers to pass through all the steps needed to detect the problem, make a decision and react in an effective way – while reducing the number of unnecessary alerts.

Recommendation (tech.): TCT must be tuned taking into account contextual factors such as human resources, ACC practices, radar accuracy and sector characteristics.

Recommendation (follow-up): To log an adequate quantity of data to get a percentage of nuisance or missed alerts with statistical relevance in future experiments.

5.2.1.2 Prioritization

As alarm principles state that ***concurrent alarms should be solved with their prioritisation***. In the TCT experiments, the simulated environment had concurrent alarms, such as STCA, TCT, MTCD and MONA. They were contemporarily somehow looking at the same sort of events. All these alarms' settings were set from 0 to the defined upper bounds. TCT, for example, was able to detect STCA occurrences and the MTCD was able to detect TCT and STCA occurrences. The concurrences have been solved by the prioritisation of the alarms' presentation according to their role/importance and time window. STCA, as being a safety net, had obviously the higher priority. The reason for making them all detect conflicts down to zero lies on the need to backup any possible failure of one of the alarming tools. Besides no gaps were left between an alarm system and another if the prioritisation is set only at the level of the visualisation instead of leaving it at the generation level. This sort of prioritisation avoids cases in which MTCD warnings could disappear and TCT alerts appear after a few seconds, because of different calculations of the algorithms. In these cases, the controller could be confused since he could think the risk is solved, while a more serious alert is going to appear.

The result of the implementation of their coexistence has been evaluating according to the following objective:

To assess the consistency between MTCD, TCT detected conflicts and their relationship with the safety net (STCA) information

End-of-simulation and post-run questionnaires, debriefings, interviews.

Apart from a few cases not statistically relevant, the alarm systems, i.e. TCT, STCA, MTCD and MONA, complemented each other without providing any major inconsistent information or showing any relevant unexpected behaviour.

TCT and MTCD

During the experiments, there was no evident inconsistency between TCT and MTCD because the same software module of the TCT was used to emulate the MTCD. Initially this set up was chosen because of technical constraints of the platform and it was criticised from a validation point of view, as explained before. However, by implementing a single module for both tactical and planning conflict detection activities, some benefits were observed in terms of coherency of information displayed on PC and TC positions. It is useful if the same tool provides the MTCD conflicts and the TCT conflicts. This is important because if two different tools are used then this is going to lead to conflicting information near the cross-over point between the two tools which will make the tools seem unreliable and cause confusion. If the Tactical Trajectory of the TCT can be used for short and medium term then this would probably be the best solution. The two different tools providing similar symbology for conflict information for the same aircraft in a ATC system is a poor solution, even if the same trajectories are used, and even worse if not. In some system deployments there may be instances where different implementations of TP are used for MTCD and TCT, such deployments require significant effort to integrate the results of both trajectory predictors and present a coherent picture to tools and controllers. Therefore, deployments which use the same TP to drive both MTCD and TCT are more likely to occur and succeed in implementation. So, what is fundamental is to have a single system trajectory that provides a sufficient level of performance to support both tools (whether they are combined or not).

Recommendation (tech.): It is recommended to make the planning trajectory as accurate as possible by using more frequent updates and a single system trajectory that provides a sufficient level of performance to support both conflict detection tools, TCT and MTCD (whether they are combined or not).

Recommendation (tech.): The implementation of a single tool to provide both MTCD and TCT conflict detection, using the same TP, would be the ideal solution to achieve an adequate MTCD/TCT integration.

<u>TCT and STCA</u>

No major inconsistencies were detected between TCT and STCA, despite some cases of STCA miss-detection (missed alerts) and STCA detection of non-operationally relevant occurrences (nuisance alerts). The missed alerts were detected by TCT and the nuisances were filtered out by TCT. The lack of coherency of information brought the controllers to rely on the most accurate system between the two. Further evaluations of alert systems behaviour in a realistic environment are necessary.

Every local implementation should have a well defined philosophy about how priorities are assigned to alarms.

In the TCT simulation environment different alarms in the same system have been properly prioritised. The highest priority has been given to the safety net, i.e. the STCA. Then, the TCT has got a priority with respect to the MTCD. MTCD and Missed-manoeuvres events are triggered for different hazards with different risks. The MTCD would have the priority as detecting a real warning instead of a risk of a possible missed manoeuvre. MONA has a higher priority with respect to the missed-manoeuvre functionality.

The prioritisation of alarms should be defined against the importance of the problem and the time available for a successful corrective action to be performed.

The STCA and TCT are intrinsically prioritised according to the importance of their tasks and their look-ahead horizon. STCA ensures the separation minima, while TCT detects probable losses of separation. In principle, the STCA should always trigger after a TCT alert if the tactical controller does not act, similarly TCT should detect a conflict where the planner does not or cannot act on an MTCD warning. The sequence of MTCD and TCT alarms was respected in accordance with these criteria also because the module used to detect conflicts was the same in practice. The PPD view helps controllers set priorities with both separation distance and proximity in time, mainly for the same group of occurrences detected by TCT and MTCD.

The sequence of TCT and STCA alarms was not always respected. During the tests, TCT filtered out some geometries that were not correctly being detected as conflicts, while STCA detected them as operationally relevant. On the contrary, during the simulations, TCT and STCA information were adequately prioritised and coherent most of the time, even if TCT was able to detect two conflicts that the STCA missed. TCT and STCA require appropriate and coherent tuning with a good separation of the area of applicability. It was observed, and confirmed by controllers, that when STCA activates without being anticipated by a TCT alert, it could mean there is no real conflict. The effectiveness and reliability of TCT could be detrimental to the reliability and efficacy of the STCA, if they are not tuned coherently. Controllers could start reacting to STCA only when preceded by TCT alerts.

However, not enough STCA alerts were generated during the simulation to adequately assess the consistency between MTCD and TCT detected conflicts and their relationship with the safety net (STCA) information. This was the first real time experiment for TCT in en-route with reduced resources, especially in terms of time and this objective could not be fully evaluated by the use of targeted scenarios. The next step would be to simulate specific scenarios were conflicts are injected in the exercises to observe TCT and STCA behaviour. Different conflict geometries should be tested to understand the behaviour of the conflict detection tool and the safety net and the human reaction to them.

Recommendation (follow-up): It is suggested testing different scenario of possible conflicts in vertical and horizontal geometries to study the performances of TCT and STCA and the human reaction to them.

Recommendation (tech. / implementation): TCT and STCA need to respect a coherent conceptual model to gain a logical behaviour. Thus, TCT and STCA settings need to be tuned together to guarantee coherent information, i.e. STCA parameters could be revised at the integration of the TCT in operations.

5.2.1.3 Presentation on Radar Plan View Display (RPVD)

The evaluation of the presentation of TCT and other alarm tools on the Radar Plan View

Display validates the objective below:

To assess the usage and technical usability of the detected conflict presentation on the Radar Plan View Display (RPVD)

The presentation of alarms on the RPVD has to satisfy the alarm design principles stated as follows:

The presentation of an alarm has to support the controller by going through the following steps:

1. ***Get controller attention by highlighting data or carrying new and distinguishable information to support and shorten controllers' recognition phase.***
2. ***Inform to support decision-making, i.e. facilitate diagnosis by identifying nature, location and severity of the problem correlated with information about causes and/or consequences of the detected event.***
3. ***Help react quickly by providing the user with the instruments required for an easy implementation of decisions made, i.e. support corrective action resulting from decision making.***
4. ***Support problem monitoring and resolution verification by showing information about the problem resolution until the situation is completely recovered, i.e. facilitate quick check of the resolution evolution and timely show whether the controller's action solved the problem - still leaving control in the hands of the controllers who are the experts.***

All alarms displayed on the RPVD are properly represented and draw controllers' attention respecting the right level of urgency. It is clear that the State Vector is more urgent than the Tactical Conflict as well as the STCA is more urgent than the TCT State Vector. In particular, the TCT information is represented in an adequate way to support the controller tasks of conflict detection. TCT conflicts are displayed by activation of the State Vector alert. The information associated with the State Vector, time and distance, supports a quick analysis of the conflict. Further information is easily accessible by interaction with the alert features, such as the flight leg display. The diagnosis phase, before taking a decision about the appropriate resolution, benefits from a clear identification of causes and consequences. Additional information about the room for action provided by the VAW and the flight leg displayed on the radar display horizontal view, which supports altitude changes or heading instructions respectively. The State Vector remains displayed until the conflict has been resolved, thus providing controllers with a means to verify actions and monitor the evolution of the situation.

Alarms must be legible and/or meaningful.

Information about an event generating an alarm should be essential (basic and fundamental) to allow a quick and clear interpretation of the event.

All information related to alerts is essential, legible and meaningful. Details will be provided later about possible cluttering of information.

Alarms should be easy and quick to locate as well as all information related to the highlighted problem.

The alarm information is displayed where the conflicts happen. In this way controllers' attention is drawn to relevant and meaningful locations on the display. The display of alarms in lists inside separate windows is considered useless.

5.2.2 HMI Elements Evaluation

The evaluation of the RPVD continued with the usability evaluation of each HMI element. The subtitles of each section below refer to HMI elements and are followed by a symbol that represents the rating of satisfaction (☹☹ = very low, ☹= low, ☺= neutral, ☺= high, ☺☺ = very high) given by the controllers during their evaluation.

5.2.2.1 Vertical Aid Window (VAW)

To assess the usage and technical usability of the TCT conflicts presentation in the Vertical Aid Window (VAW) - ☺☺

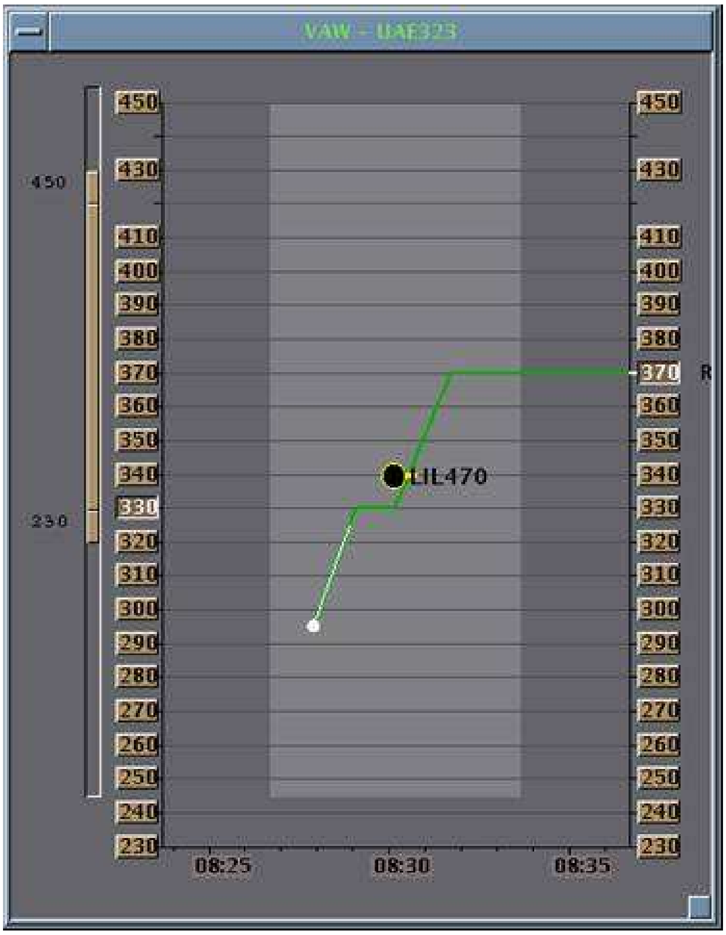


Figure 4: Vertical Aid Window (VAW)

The vertical presentation of TCT conflicts is available in the Vertical Aid Window (VAW). The VAW is used to check all vertical conflicts and also conflict-free flight levels before traffic enters a sector. The VAW gives an overview of the available flight levels to make decisions about conflict-free flight levels to be assigned to all climbing and descending flights. The VAW was used by the TC and the PC; however, it was the main means of analysis for the TC who could check the available Flight Levels for climbing and descending. Even if the trajectory was not accurate, the rate of vertical change was realistic. The profile of the speed vector in the VAW was very useful. The VAW helped to calculate the Top of Descent point taking into account possible conflicts. The VAW enabled efficient descent of a/c, thus optimising fuel consumption.

The PC used the VAW to understand the conflicts and solve those that require a change of Flight Level. The planner controller mainly used it to coordinate entry and exit flight levels (EFL and XFL). The tactical controller used the VAW to check the exit flight levels and when the controller planned any other level change within the sector due to traffic before deciding a Planned Flight Level (PFL). The more complex conflicts were acted on a little later and the PC frequently analysed whether resolutions could be effected by direct routes ort other tactical interventions. The Extended Label Window was used to ascertain the destination and other pertinent information (i.e. RFL) in the conflict resolution search by both the PC and TC.

Controllers had no problems with this vertical representation, even if not all of them were 100% clear at the beginning about the help they could get from the VAW. As the vertical view is not the way controllers are trained to think at the moment, this HMI element took some time to be understood and learned. With more practice they became more familiar with the HMI features and more confident (too confident?). They considered the VAW properly designed compared to existing vertical views in operations today since it had less clutter.

Controllers found the VAW useful to confirm their analysis and rapidly identify the first safe flight level in the case of conflicts. Then they come back to that aircraft later to issue another clearance to climb or descend further if on the vertical view the aircraft was free of conflicts. This HMI component prevents controllers from forgetting important actions, whenever possible, and helps verify actions. The VAW was very informative and user friendly. The blue line clearly shows possible occupied flight levels, the speed vector shows the rates of climb or descent of aircraft. All the information provided on the VAW was easy to interpret and helped quick decision-making.

The VAW provides only necessary information, i.e. it shows only contextual traffic. However, there were occasions when the VAW did not show opposite direction traffic in the on the vertical view. In these situations controllers did not feel comfortable because they realised only after the clearance that with a slow rate of evolution that traffic could have entered in conflict. The VAW could not show all traffic on the vertical overview because readability could be compromised. The VAW helped to build a better three dimensional traffic picture when the radar information was cluttered.

The VAW should not be used alone to help predict conflict situations. The VAW does not provide controllers with a complete picture about direction of flights (i.e. converging and opposing traffic and not all traffic was displayed because only contextual information was presented). So controllers should not rely on the VAW to clear an a/c through all the levels. The VAW works for probing information to find free levels where to clear a/c and needs to be combined with RPVD information.

5.2.2.2 Potential Problem Display (PPD)

To assess the usage and technical usability of the TCT conflict presentation in the Potential Problem Display (PPD) - ☺

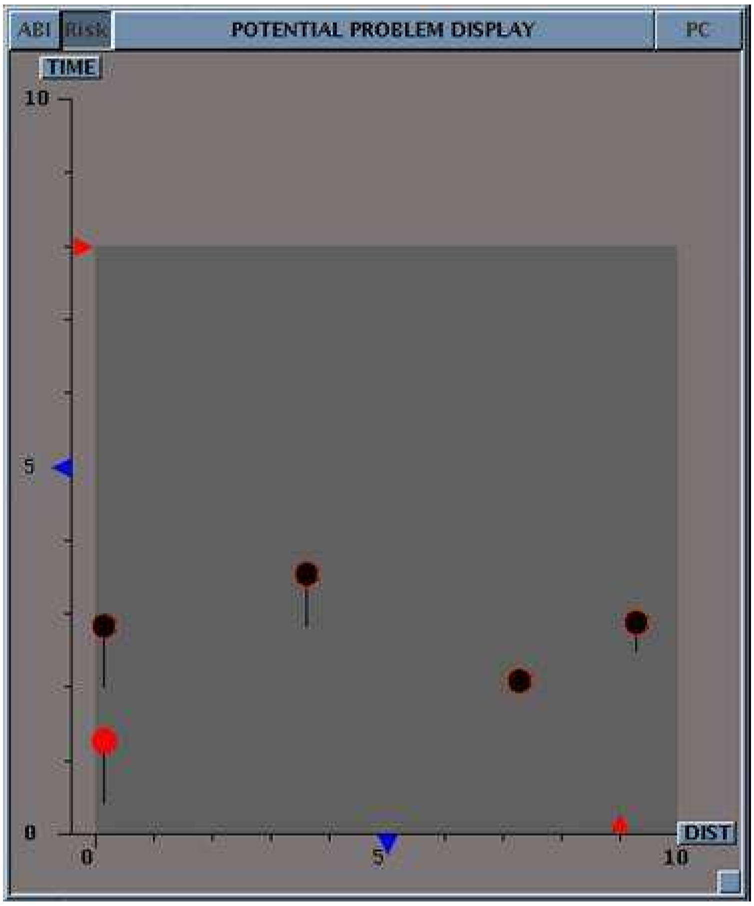


Figure 5: Potential Problem Display (PPD)

The controllers appreciated the simplicity of the PPD. The PPD information was accessible and easy to interpret, clear, timely and reliable. The information was not cluttered and no unnecessary or irrelevant elements were present (e.g. different shapes of the conflicts, arrows, numbers, etc). A number in the conflict HMI element on the PPD for prioritisation of display of the conflict was considered to be unnecessary.

The PPD facilitates monitoring and conflict detection, as well as the verification. By keeping an eye on the radar view analysis, some quick checks on the PPD help confirm the picture is coherent to reassure the controller he has not lost the situational awareness. In some cases the PPD detects conflicts earlier, especially when the a/c is outside the screen view. So controllers can anticipate the planning of actions for conflicts that will be shown by TCT. Then, when the a/c is closer to the sector the PC takes a decision about the best resolution.

The PPD gives information with meaningful aids to problem-solving and decision-taking for reaction. Its view helps controllers set priorities with both separation distance and the proximity in time mainly. It is, in fact, clear that the conflicts closer to the crossing of the axis are more serious. The PPD presents new information with meaningful aids to interpretation. The symbolism and the layout were easy to understand after an adequate training period.

5.2.2.3 State Vector (SV)

To assess the usage and technical usability of the State Vector (SV) information display ☺

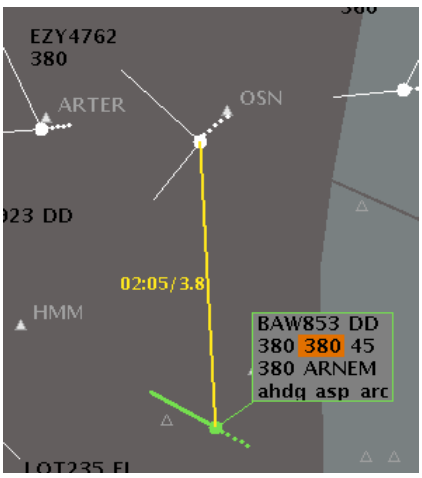


Figure 6: State Vector (SV)

Despite the working methods were negating with the use of TCT for monitoring, the TCT State Vector was used both for separation assurance and monitoring of conflicts during the simulation. This happened because of some sector geometries over the boundaries (converging point close to the boundary) and the defined parameter settings fixed for all tactical positions (i.e. 6 NM and 8 min). In fact, according to some controllers these parameters should be set close to valid separation, for example, 6NM, 5NM. Otherwise some state vectors would be perceived as nuisance in certain situations. However, the setting still depends on the accuracy of data.

The State Vector gets the right level of controller's attention. During the simulation it was soon clear to controllers that the SV communicates events more serious than the tactical trajectory conflict. The information is clear and intuitive, even though there are still some issues related to its representation. In some cases, users claimed that there were too many pixels as the line between the two aircraft is too thick and more than one SV could generate some cluttering, when controllers do not or cannot react immediately to solve them. The display of time and distance on the line was also debated. In conclusion, people agreed that it is important to know accurately the time, but particularly the separation to prioritise the sequence of resolutions when there is more than one SV, even if controllers' reaction still depends on their skills. The position of time/distance on the line helps also distinguish the SV from the elastic vector.

Recommendation (follow-up): To test different parameters within different scenarios to evaluate the controllers' usage of TCT features and associated airspace characteristics.

5.2.2.4 State Vector-oriented display

To assess the usage and technical usability of the State Vector-oriented display - 😐

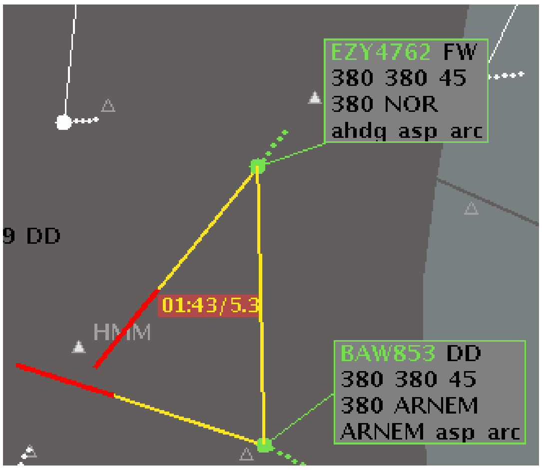


Figure 7: State Vector-oriented display

The State Vector-oriented display was used to check the distance of the conflicting traffic from the waypoint and evaluate which aircraft should be given a heading. The representation was easy to understand and provides clear conflict indication to aid decision-making. However, its usage was low. Some controllers have never used it during the simulation.

5.2.2.5 Tactical Trajectory Conflict (TT)

To assess the usage and technical usability of the Tactical Trajectory Conflict (TT) information display - ☺

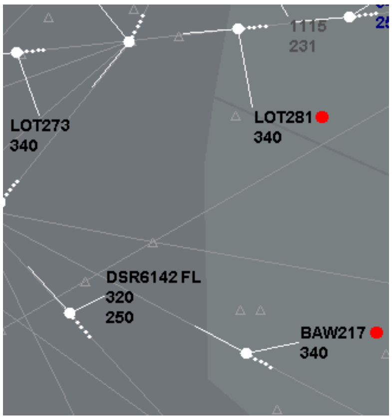


Figure 8: Tactical Trajectory Conflict (TT)

Controllers readily identified conflict pairs with the TT. Interaction with the red dots resulted in display of a good representation of the situation and reminded the controller “s/he has to do something”. The TT conflicts complemented the SV information; therefore any implementation of TCT would require the development of similar complementary detection/display functions.

5.2.2.6 Aircraft-oriented (MTCD) Flight leg

To assess the usage and technical usability of the Aircraft-oriented (MTCD) Flight leg information display - ☺☺

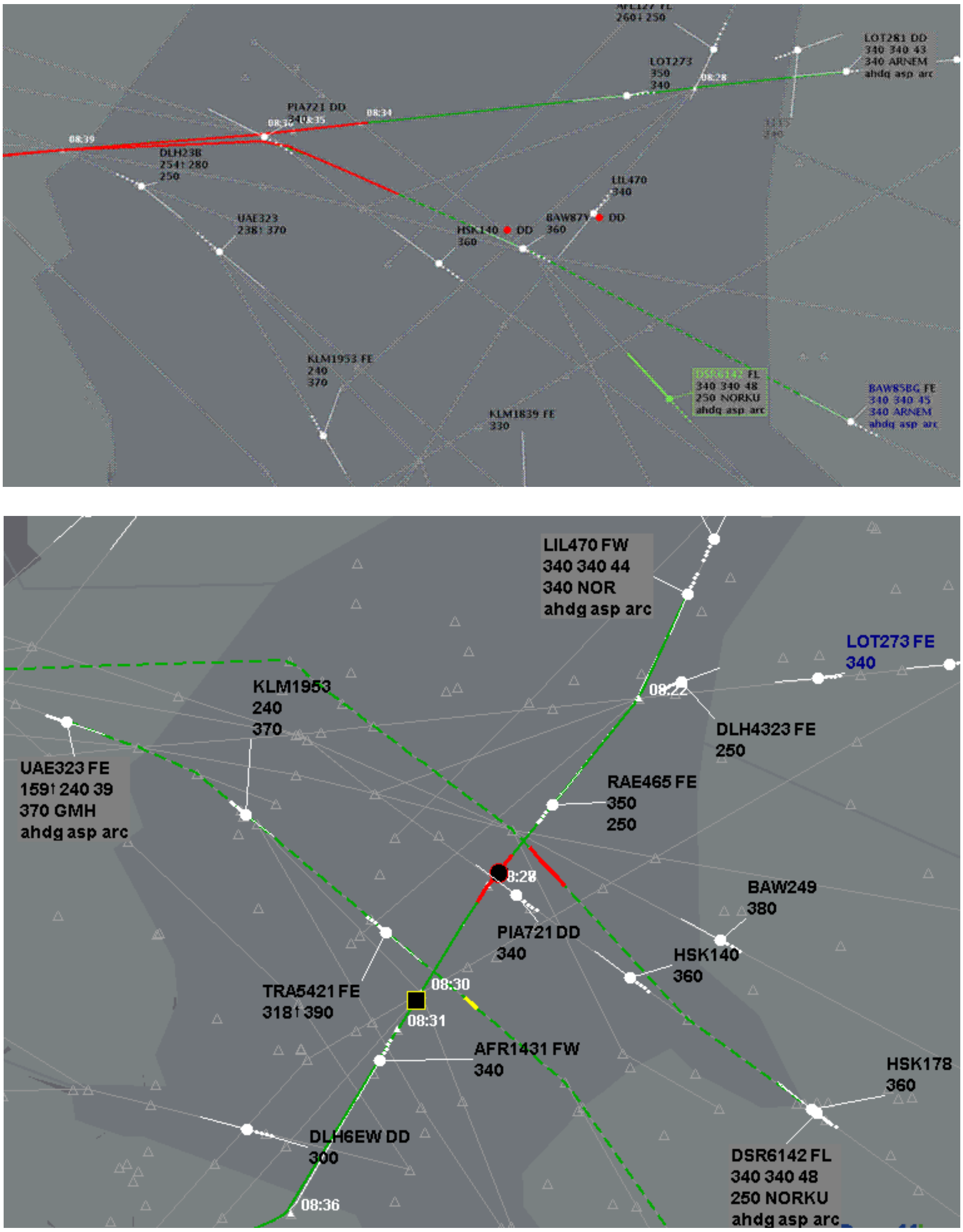


Figure 9: Aircraft-oriented (MTCD) Flight leg on

The aircraft-oriented flight leg facilitated the work of the controllers since it has provided them with accurate and detailed conflict information to understand the geometry, location in the sector and the severity or impact of the conflict. The aircraft-oriented flight leg was very useful when active upon assuming on aircraft. The flight leg displayed all conflicts the aircraft had inside the sector. The controller could ensure efficiency by selecting the best candidate aircraft to prioritise and resolve conflicts. The strategy employed was to modify the trajectory of the aircraft with the higher number of conflicts on its trajectory, in the attempt to resolve the other conflicts. The controllers agreed that this flight leg should be displayed for 3 seconds for each aircraft as it was ASSUMED on transfer in. However, controllers should be able to select their own preferences.

Recommendation (tech.): To give controllers the option select preferences as to highlight for 3 seconds the aircraft-oriented flight leg, the VAW, and the extended label on ASSUME of each aircraft. .

5.2.2.7 Miss-Manoeuvre (MM)

To assess the usage and technical usability of the Miss-Manoeuvre (MM) information display - 😐

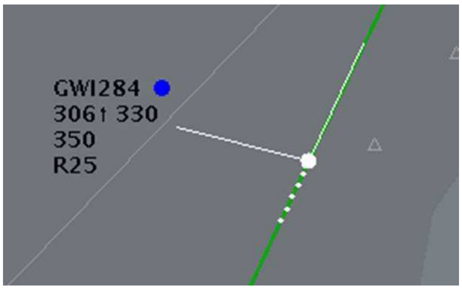


Figure 10: Miss-Manoeuvre (MM)

When a Potential Critical Manoeuvre-miss is detected by the TCT system, an indication of the detected risk is displayed attached to the normal aircraft radar label of the involved aircraft. The miss-manoeuvre function was not considered particularly useful by the controllers probably because the parameter was fixed to the maximum. Too many events with a very low probability of becoming real problems were detected. So, controllers filtered out the related alarms on the radar screen even if MM warnings were easy to see. This function was not fully implemented. Related flight legs would have helped understand quickly the signalled problems. The Miss-manoeuvre function requires further validation and experimentation after complete implementation of HMI functionalities and different parameter settings.

5.2.2.8 FlightLeg Mapping Window (FLM)

To assess the usage of the menu for HMI selection options, i.e. FlightLeg Mapping Window (FLM) - ☺

FLIGHTLEG MAPPING				
CALLSIGN	STANDARD	MTCD	VAW	ELW
CFL	STANDARD	NOT_DEFINED	VAW	ELW
EXIT_WAYPOINT	STANDARD	DFL	VAW	ELW
ASSUME	QUICKLOOK	NOT_DEFINED	VAW	ELW

Figure 11: FlightLeg Mapping Window (FLM)

During RTS1 controllers requested a window where they could set their own preferences for type of display layout. Controllers were able to enable the display of the conflict oriented flight leg when an aircraft was assumed. In general, the handover with login was suggested in order to set user parameters.

Recommendation (tech.): Handover with login to allow each user to set preferred parameter settings would be advisable.

5.3 Operability and Domain Suitability

5.3.1 Applicability

To evaluate the suitability of the Tactical Controller Tool in simple and complex route-structure environment in nominal and non-nominal situations

Interview, EoS questionnaires, Focus Groups

TCT and its related procedures were considered by controllers operable and suitable to support them in daily operations. The tool is usable in each route-structure environment and is greatly useful in complex route-structure environments in normal operation conditions, as observed in the simulation. TCT made the provision of air traffic service safer and more efficient in the Delta sector, which was less complex than the Munster sector. However, TCT seems to deliver more benefits in the Munster sector, which was comprised of very busy traffic in a more complex environment. The technology supported the controller in building the mental picture of the traffic; it enhanced the situational awareness especially when planner controllers could not provide sufficient support. TCT improves efficiency in high traffic, while maintaining safety levels of ATC services. TCT could improve safety levels adding an additional barrier in low traffic conditions, when controllers' attention has a tendency to decrease.

Controllers felt that no particular changes in the airspace or traffic characteristics would be required. Some basic problems were discussed in the focus groups in relation to route-structure. For example, it was observed that more straight routes would basically help reduce the number of conflicts, as controllers are used to giving directs and the TC would have more time to reduce conflicts. According to some controllers, more straight routes would implement point to point flights between airports with the support of TCT. In addition, crossing points close to the airspace boundaries create some nuisance alerts.

TCT is expected to be operable (usable and suitable) in non-nominal situations in most of the types of en-route and E-TMA environment. However, specific scenarios simulating non-nominal situations were not tested during this first experiment.

Recommendation (follow-up): In order to check the effect of trajectory predictions on TCT required accuracy, to simulate non-nominal scenarios pertaining conditions such as:

Weather avoidance (CB) and other unusual situations.

Different aircraft rates of climb.

5.3.2 Transition

To evaluate the impact of the introduction of the TCT tool in the transition period

Interview, EoS questionnaires, Focus Groups

The transition of TCT into the operational environment would not be complicated since what would be required is a TCT integration and setting in the local ATC system and adequate training on the new conflict detection tool and a transition ("digestion") period.

TCT integration and setting depend on three factors; 1) airspace characteristics. 2) local practices and 3) cultural aspects. The training should take account of the possible changes of the local practices and the cultural aspects to be organised.

Some of the simulation participants, one of them with a specific experience as a trainer, foresaw a period of theoretical lessons with an exhaustive description of the tool HMI elements and support functionalities. TCT was considered similar to MTCD in the role of conflict detection tool; controllers should not have difficulty in understanding it. Controllers suggested that classroom lessons should last no more than half a day. They should be combined with hands-on sessions in the simulator. The entire training should not last more than one week for each single controller. A possible continuation of the training should be evaluated for each individual controller at the end of the first mandatory week. Other opinions related to Shadow Mode (SHM) trials that would be required[4]. SHM trials could last only one or two days in the case of strip-less systems, while, as for units that use strips, it would be more difficult to get used to TCT and they would suffer a big disadvantage in the transition phase. TCT would require the controller to make duplicate updates both on the system and on the strips. Duplicate updates are time-consuming tasks and could introduce an increase of workload.

To have a stripless environment is not a requirement, but it is advisable. The PC work is facilitated by automatic updates and the SPO would be more easily introduced.

Recommendation (tech.): It is not recommended to introduce TCT in a paper strip environment.

5.3.2.1 Transition issues - Impediments for implementation

Possible problems related to TCT Implementation mentioned by participating controllers during the debriefings and in questionnaires are mainly related to:

- **Accuracy** of provided conflict information - difficulties to get accurate Trajectory

[4] According to one expert, the Shadow Modes Trials depend on the regulators, since the safety case often depends on the Regulator requirements. If not necessary, it might be possible to go directly into operations instead of having SHM trials first.

calculations compared to what would be required.

- **Cost** implications – Need for a Cost-Benefit assessment.
- **Safety Case** - Adequate safety studies in each context of implementation.
- Controllers **acceptance**:
    - Mistrust or over trust towards the tool - to gaining ATCOs trust in the system.
    - Controllers' resistance to change.
    - Resistance where there are other similar tools such as customised distance measuring devices.
- TCT **Integration** in each ATC System:
    - Crucial tuning in each specific environment in order to ensure reliability.
    - Difficulty and effort required to get the TCT compatible with user ANSP's facilities, i.e. redefinition of colour coding and symbols, and translation of messages.
- **Regulator Certification** - Responsibility in case of loss of separation when the TCT information is false or not displayed.

5.3.3 Working methods and Roles

To evaluate the suitability of the Tactical Controller Tool and their related working methods and roles in support of the controllers' tasks and their cognitive requirements

Interviews, Debriefings, EoS questionnaires

The operability of TCT depends on the balance of roles and responsibilities between the automated support and the PC/TC team. The introduction of a tool can affect the roles and responsibly between members of the team. To assess the operability and domain suitability of TCT, first the analysis of the role of TCT is presented, and then its impact on TC and PC roles and working methods are considered.

5.3.3.1 TCT Role

TCT is a complete supporting tool that serves controllers' needs. TCT is "filling in the gap between the MTCD and the STCA" and its introduction should yield major benefits however mitigation against the risks of misuse of STCA as a separation assurance tool is strongly advised. Controller agreed that TCT should be set in a manner to be a real safety barrier and detect the losses of separation. With the use of TCT, the STCA should trigger less frequently and its activation rate should be more coherent with the level of severity. The change of approach towards the use of STCA could eventually guarantee safer levels of operations (where it is currently abused). The rate and frequency of the STCA activations has important implications, since controllers would not underestimate the severity of the situation when the STCA triggers.

TCT was used in an unexpected manner during the simulation and its role of separation assurance tool was often confused with that of a monitoring/reminder tool. This unintended use of TCT was discovered in RTS1 and it affected the performance and the decisions about definition of working methods in RTS2.

5.3.3.2 RTS1 Working methods

In RTS1 the working methods and roles were not particularly prescriptive. The approach was quite exploratory because the goal was to observe and understand the implication of the TCT introduction and the controllers' resulting behaviour. The introduction of TCT did not dramatically change the current roles and responsibilities of the TC and PC. There was no deliberate distribution of activities and definition of different roles within the controller team. However, there was an implicit and spontaneous task distribution balance as a variable of traffic characteristics. There was a difference between high traffic and lower density traffic with steady-state flights or low unidirectional traffic flows. In general, in low/medium traffic conditions the TC was focused on managing in-sector conflicts using TCT, while the planner controller was more focused on entry/exit conditions, i.e. boundary conflicts detected by MTCD. In high traffic conditions, the PC was able to effectively support the TC managing internal conflicts by suggesting resolutions giving indications of available levels. The PC was able to predict solutions in advance and the TC sometimes had to rely on the PC. Controllers commented that this coordination could deliver a safer service with a higher quality.

However, it was observed that in case of high and complex traffic the PC was sometimes frustrated because he was not able to maintain the traffic picture and felt he could not fulfil his planning role as effectively as he would in reality. This effect was not due to TCT, but may be more related to the lack of familiarity with the simulation environment.

In certain occasions, the PC needed to be aware of the in–sector air situation (e.g. entry flight with a conflict on the exit and the PC would be able to change the XFL). The PC felt that needed to understand why a conflict was generated on the exit prior to coordination of a conflict-free exit condition. This was not always possible during the simulation due to absence of complete grasp of the simulation environment. The PC needed to maintain communication with the TC to understand the situation when needed and to make suggestions about possible resolutions. The PC cannot impose a resolution since this could conflict with the TC mental model. Both the ATCOs need to be aware of the implications of the impact of tactical interventions (i.e. conflict resolution strategies, direct routes, etc) on exit planning conditions. The TC was ultimately responsible for ensuring separation.

5.3.3.3 RTS2 Working methods

In RTS2 it was decided to completely separate the roles of the TC and PC to evaluate their behaviour and the suitability of TCT in certain staffing options. In RTS1 it was observed that the PC was relying a lot on the PPD, without completing some expected checks that are characteristic of controller behaviour. This may have been due to the lack of familiarity with the simulation environment. This reliance on the information in the PPD frequently resulted in the PC becoming engrossed with TC support to the extent that some planning tasks were overlooked. In RTS2 it was decided to separate the TC and PC to the extent that they could not talk to each other. This has impacted the results of the simulation. These working methods may be adequate where the PC may not be required to give too much help to the TC. The main tasks for the PC were planning entry conditions, such as EFL and direct routes. The PC was unable to plan XFLs since he would need to have a proper awareness of the TC strategy inside the sector, in particular in situations where there were many vertical movements. The efficiency seemed to be increased where the PC supported the TC in planning exit conditions. This was particularly evident with departing traffic that wished to continue climbing inside the sector. The PC could support the TC in finding free FLs. It is likely that safety levels would still be adequate without the PC but the efficiency would probably be decreased. The PC role and the teamwork would guarantee the efficiency.

5.3.3.4 Controllers' tasks

Working methods are the manner in which controllers perform their tasks. Each task is a composite of related activities (perceptions, decisions and responses) performed to de-conflict traffic. The working methods might not be dramatically changed by the introduction of TCT with respect to current operations, but the following ATM tasks (cognitive processes and ATC activities to support those processes such as coordination and communication) are affected by TCT use:

- **Monitoring/Searching** → As we know monitoring is a key task of the controllers' activity. Controllers actively scan the radar screen, even when they are involved in a very urgent task they continue monitoring. Monitoring is a continuous controllers' task that assures them to be aware of evolving risky situations before they become too serious. Because of the importance of this task, controllers feel they cannot "imprudently" rely on any assistance tool. A tool such as TCT should be fully reliable in detecting all significant occurrences in all the possible geometries well in advance to give the controllers enough time to find out a solution. The full reliability and consequent trust in the system were not easy to achieve at this stage of familiarisation with the tool, even if it was quite high. In RTS2 controllers kept checking that the traffic was proceeding fluently and expecting TCT to highlight what they detected before it most of the times. However, this continuous attention can be maintained in an experimental context, i.e. during one hour of exercise where controllers know they are observed. TCT could be useful when there are monitoring situations with less pressure such as with less busy traffic especially right after a peak. Human beings cannot sustain monitoring indefinitely and systematically such as a machine. They relax when, after a few consecutive checks, the situation looks stable after a peak of traffic where the scenario is less dense. Boredom, mind-wandering, inattention can influence monitoring and so affect safety and efficiency. Therefore, monitoring/searching is the task that mostly benefits from the introduction of TCT both in low and high density traffic situations.

According to some controllers' perception, the workload related to their monitoring task was considerably reduced. They claimed that TCT often detected conflicts before controllers did (this might depend on the knowledge of the environment and on the parameter settings). They understood that TCT was able to identify all potential future problems, so that the time and effort previously spent finding problems was available for controllers to concentrate on identifying appropriate solutions. In current operational systems, there are support tools based on MONA LAT_DEV (Thales RAM) that can partly achieve this effect, however, TCT is going to amplify it. The data from RTS2 are not adequate to validate the impact on controller's task workload due to monitoring release. An objective of monitoring work is to keep the traffic picture. Monitoring helps controllers enrich his mental model with elements useful to support decision making. Current measurement tools measure monitoring by counting the HMI interactions to retrieve information elements. It results that monitoring HMI information is increased by the introduction of TCT, because controllers tend to interact a lot with new HMI components, such as PPD, VAW and alert information. So, what controllers seem to monitor are elements of the HMI, which is in line with the natural conversion of current human monitoring to computer assisted monitoring. Controllers' increased understanding of the situation was enhanced because the TCT monitoring provides more information and they were able to elaborate alone. In particular, information related to available flight levels was an enabler to solve conflicts quickly, safely and more efficiently. Even if TCT results do not show a decrease in monitoring tasks, controllers confirmed that the tool was effectively useful to support these tasks, especially when the TC loses the PC second pair of eyes. This could happen when, for example, the PC is busy with the coordination of military traffic or airspace segregation. There was no evidence of this enhancement because specific scenarios were not simulated and observed.

Recommendation (follow-up): To simulate realistic traffic scenarios to observe performance of the tactical controller in monitoring tasks, where planner control capability is saturated by other tasks.

- **Understanding** → TCT eases the understanding of the traffic situation by displaying information in a brief and simple manner. New information is presented with meaningful aids to interpretation, then, recognition is facilitated rather than recall.
- **Remembering** → TCT reminds controllers about ongoing critical situations, where it is used as monitoring tool. This application of TCT was not desirable; however it was a feature of TCT use by participants. When there were several problems in the sector, the TCT alerts keep track of all the potential conflicts to be solved, complemented by information to prioritise them.
- **Predicting** → TCT enhanced prediction of conflicts by providing aids such as the flight leg information combined with the VAW display. This information was accessible when an aircraft was assumed to help controllers build an appropriate picture of the problems in the sector and solve them earlier. The flight leg and the VAW were also accessible via the TCT display. The flight leg highlighted all possible conflicting areas on the aircraft route in the subject sector. The VAW displayed all available free flight levels. TCT provided accurate predictions of future traffic scenarios throughout the sectors, thus highlighting the relationship of the incoming aircraft with the traffic in the sector. The predictions were reliable and evidently went beyond controllers abilities. Therefore, controllers could appreciate the tool support in building a complete picture of current and future evolutions of the traffic. During the experiment, these prediction aids particularly helped the simulation participants to deal with high traffic loads in an unknown environment, thus compensating with the incapability of controllers to apply their prediction abilities developed with job experience.
- **Problem-solving** → Being a conflict detection tool, TCT provided aids for problem-solving by indicating the existence of a problem. Tactical conflicts and state vectors indicate where the safety margins would be infringed if the controller did not intervene.
- **Decision-making** → Decision-making was eased by the completeness and quality of information provided to the controllers by TCT. When a conflict was detected by TCT, controllers' attention was drawn by a presentational change. This change consisted of a highlight of existing information and an introduction of additional data like symbols identifying the kind of detected problems, or data on the state vector related to the exact separation between two a/c (the closest distance) and the time to point of conflict displayed. This information helped controllers prioritise problems and subsequently intervene when and where it was appropriate e.g. flight leg information for a conflict pair could be analysed to permit identification of which flight should be manoeuvred and in addition the VAW provided information on available FLs for resolution of conflicts).

- **Verifying** → TCT was able to free cognitive resources for high-level tasks. It supported verification of mental calculations and estimation, thus reducing uncertainty and increasing predictability. It helped verification that conflicts were solved after controllers' actions. Controllers delegate the less risky tasks to the machine, i.e. to verify a conflict is resolved when they are focused on solving other more urgent situations. TCT alerts were displayed and disappeared as soon as a/c were separated and conflicts are solved when the TCT separation parameter was set to 6 NM.
- **Communication/Coordination between PC and TC** → TCT could affect communication and coordination tasks between PC and TC according to the setting of TCT parameters. Communication can be reduced because the PC does not need to inform the TC of possible conflicts in advance, the TCT directly alerts the TC. This was initially observed in RTS1, therefore working methods for RTS2 have been defined in a way to prevent most of the communication between the team members to observe the effects of this lack of communication. At the beginning, controllers had difficulties to work without any coordination with their colleagues. The lack of communication changes the distribution of tasks, in particular PC tasks, as s/he is no more able to support the TC to sort out conflicts in busy situations. The reduction of communication reduces PC workload and increases his/her frustration. The PC missed the PC support initially; however, with practice it became easier and more acceptable. Eventually the tactical controllers felt more job satisfaction as they were more aware of their specific tasks and the resultant task distribution as less flexibility in the task distribution is allowed depending on traffic loads.
- **Coordinating with other sectors** → The task of coordination with other sectors does not change, but the support of the TCT in monitoring/searching for conflicts released the PC from providing the 'second pair of eyes', especially when there was a need for more time for coordination with other sectors.

5.3.4 TCT in different staffing options

To evaluate the suitability of the Tactical Controller Tool with Conventional Planning and Tactical Control operations

Interview, questionnaires, Focus Groups

The combined use of TCT and MTCD was considered adequate to support the conventional TC and PC staffing configuration. Controllers stated there is no perceivable difference between working methods in RTS1 and in real operations. In RTS2 the tasks workload between TC and PC appeared to be unbalanced during the observations and this was confirmed during the focus groups and by the questionnaires. Planner controllers had fewer tasks to perform in RTS2 TCT organisation, since they could not support the TC work inside the sector in peak traffic or to change exit conditions.

TCT support in detecting conflicts was less intrusive rather than that of the PC. This was seen as positive in the HH sector where the PC interventions would have been a disruption, such as when PC was pointing out traffic on the TC screen.

To evaluate the suitability of the Tactical Controller Tool with Group-sector Planner operations (GSP) and with Single-person operations (SPO)

Interview, EoS questionnaires, Focus Groups

Most of the simulation participants stated that they had limited or no experience with concepts such as Group-sector Planner (GSP) and Single-person operations (SPO). However they expressed their opinions and their position was rather neutral regarding the suitability of TCT in GSP and SPO conditions. In general, some people felt that the introduction of these concepts could present some problems due to the fact that ATCOs are afraid of changes; they prefer to keep their comfort zone, e.g. same people, same equipment, same traffic and same procedures. However, during debriefing discussions, the participants concluded that TCT might make the SPO and GSP job smoother and safer. In particular, in the GSP operations the TC work should be easier because there is a planner supporting more than one TC. The training of a planner controller focuses on reacting to certain situations that would not drastically change if the sector was bigger and the traffic manageable. Structured tests should be carried out to validate these opinions. The simulation was not set up to validate this aspect adequately.

With SPO controllers should combine the tactical work with the planning tasks, which is more complicated and may bring fewer benefits with its implementation than with conventional TC/PC and GSP configurations. Both SPO and GSP implementations depend on traffic type and load and on sector size. In general, these staffing options could mainly work on upper sectors with limited vertical movements facilitated by the use of conflict detection tools. As it was observed in en-route, it is possible to handle more traffic than in the lower and more complex sectors. The traffic load of the sector should be calibrated taking account of human capabilities with the use of automated support. Controllers believed that there would be no problem handling all the information managed by both PC and TC, as long as the traffic is manageable for one person and the information provided by TCT and MTCD are fully reliable. If the traffic load is high, EFLs should be planned. Working as TC and sector coordinator it could be complicated, so it needs to be tested. SYSCO could mitigate possible difficulties to combine planning and tactical control. However, adjacent sectors should be as advanced as the sector in which these operations are in place.

Recommendation (follow-up): To investigate further with a specific experimental set-up to adequately test SPO and GSP operations.

Recommendation (tech.): Strep-less environments are a requirement for GSP and SPO with TCT.

Recommendation (tech.): SYSCO is a requirement for SPO, in order to easily manage co-ordination with adjacent sectors (SYSCO equipped).

Recommendation (follow-up): To conduct a proper safety assessment and audit before implementing any procedure such as GSP and SPO.

5.3.5 HF Impacts on Human Performances

When traffic increases, controllers' workload inevitably increases as well. Some automated support could reduce the workload where necessary and assist some cognitive processes that become more demanding in high and complex traffic conditions without impairing controllers' performances in lower traffic loads. TCT seems to have a beneficial impact on workload, in principle. It increased the situational awareness avoiding peaks of workload that could occur when the controller loses the traffic picture. If controllers trust their equipment and TCT, the benefits may be realised.

5.3.5.1 Workload

To evaluate the physical and cognitive workload of the user with the TCT introduction

Post-run Questionnaires, Interviews, Observation

The impact of TCT on workload is quite important as it is seen as an aid to "reduce workload per aircraft for the tactical controller by providing very accurate monitoring and conflict detection". Our analysis of tactical controllers' task changed as affected by this automated support tool confirms this. TCT supports monitoring workload, then the automation makes problem-solving and decision-making easier, simpler and faster, by providing means to support memory and interpretation, to predict future problems for an aircraft across the sector and to verify that clearances are followed until the resolution of the problem. TCT, as well as MTCD, reduces memory load since it facilitates the searching, the understanding of the situation and remembering issues to be addressed.

The controllers' subjective assessment seems to confirm that TCT reduces workload because in an unknown environment with complex route and an increase of traffic load (20%), they felt less stress and mental load as “Tasking does not emotionally drain you”. Then, they perceived less traffic load than that actually managed. The use of the VAW for monitoring (to analyse the vertical disposition of a/c) and problem solving (to detect the first safe level available) reduced the cognitive demand. Controllers were able to build a clear mental picture and predict future evolutions and possible conflicts. The VAW supported verification that the decisions taken did not generate further conflicts by looking at the vertical overview. Using the simulation’s MTCD functionalities, the PC attempted to solve problems the TC could encounter later inside the sector, thus the PC reduced complexity in the sector for the TC. The aim of the PC was to solve problems before sector entry to alleviate the ‘in-sector’ work of the TC. The PC used information available in the PPD to build the picture of all future conflicts. It was observed, that during the simulation the PC workload varied a lot. At the beginning of the exercise, the traffic arrived in blocks. Once the PC has solved potential conflicts he was then able to anticipate conflicts outside the area designated in the PPD window. The effort of the PC with the aid of the MTCD apparently decreased the workload of the TC. However, due to lack of experience in the airspace environment and the hesitation to rely on the new automation support tool, the TC concentration stayed the same. With a 100% confidence in the system the workload might evidently decrease.

Some people declared they do not need to monitor, so the monitoring time tends to decrease to leave spare time to solve problems in a strategic manner. This related to those ATCOs that showed a blind trust in the enhanced CDTs (TCT combined to an enhanced MTCD). The other participants declared that TCT checks if the situation degrades. The conflict detection tools do not replace human monitoring activities but they reduce the effort and associated stress of the monitoring task. The controller felt more comfortable with their decisions and TCT provided confirmation that the detection and decision-making was adequate to maintain a safe and efficient service.

Controller confidence grew to a level where even in high density traffic they seemed relaxed. The simulation effect and the reduction of monitoring and conflict search activities made controllers sometimes turn their active role into a more passive one. SME confirmed such behaviour stating that controllers did not focus on searching for future potential problems and verifying when they are solved. They concentrated more on strategic planning and solving problems.

The analysis of data has provided two kinds of information, the controllers’ perceived workload assessment in the baseline and in the TCT organisation and the Information Processing Load Bar Charts that modelled the task demand, and assume the workload and put it in direct relation with the capacity assessment.

The controllers' perceived workload, which was assessed at the end of each run showed an increase with the introduction of TCT. The Information Processing Load Bar Charts give indications about workload and their analysis shows that it might slightly increase. Workload redistribution with the planner controller is excluded because PC and TC complied with strict working methods that defined a sharp division of tasks. The PC workload appeared to increase with the introduction of TCT. In general, the increase may have been due to "Resolution Planning". The TC continuously searched for conflicts in an effort to anticipate TCT, so no decrease in monitoring was observed. The HMI interactions with the VAW, the PPD and the flight legs increased controllers' activity to find information to enrich the traffic picture and support the decision-making process. The number of interactions is probably elevated since; some controllers were often waiting until the last moment to issue a resolution clearance expecting to ensure the most appropriate instruction and consequently a more efficient service. In fact, the results show that the number of interventions was slightly less in the TCT organisation and more level change clearances (more efficient from the flight perspective) were issued rather than heading clearances. Controllers were monitoring the traffic evolution to solve conflicts, and frequently there were several interactions with the conflict information. TCT was used as a monitoring/reminder or productivity tool in critical situations. The complexity of traffic in the sectors was increasing, thus creating more stress to the TC and the PC. The PC had major difficulties to build a proper picture and help without direct communication with the TC.

These results contrast with common convictions that TCT brings benefits by decreasing the overall controllers' workload. If controllers had used TCT as expected, i.e. if they would have reacted promptly to alerts, the impact on the overall performances would probably have been different.

Recommendation (follow-up): To run a new experiment ensuring controllers apply the working methods in a prescribed and stricter manner.

5.3.5.2 Situational Awareness

To assess the impact of the Tactical Controller Tool on the situational awareness

Post-run Questionnaires, Interviews, Observation

The TCT aid positively affects the situational awareness since the display of conflicts and the correlated information can be used to build the mental picture of the evolution of the traffic and anticipate possible problems that could be more difficult to solve later. Controllers stated that there was rarely discrepancy between the controller situational awareness and the tool. When the controller needed to build the traffic picture quickly, the tool was always able to provide support for headings (the two state vectors were able to show which a/c was as first) and for level changes using the VAW, which shows the available levels.

Most of the automation supporting tools reduced the time spent by the controller to perform their tasks and increased the availability of time spent to build the traffic picture. We could observe that the process of information acquisition was eased by the accessibility of all data sets via HMI features.

Problems of losing the picture were observed only during high traffic conditions, when the PC was not able to manage the situation and to help for the TC. The problem does not depend on any TCT deficiency of information. It is rather caused by a lack of familiarity with the environment, the increased TC and HMI interaction and the working methods in RTS2 impeding the PC to talk with the TC. In RTS1, there was an observed decrease of this effect as soon as controllers achieved a good level of familiarity with the simulated environment and a good level of teamwork with the other participants. In a familiar environment, the lack of TCT and MTCD would not compromise the sense of situational awareness. As result of the observed learning effect, the PC was more of a help for the TC than in real operations.

To maintain the picture, the PPD and VAW are not sufficient to support TC decision-making. As stated earlier, the communication and teamwork is important to keep the situation awareness updated, especially with weather phenomena. The PC could lose the situation awareness working separately from the TC and this could also generate conflicting actions.

5.3.5.3 Trust

To evaluate the trust and reliability in the Tactical Controller Tool

Interviews, Observation, Debriefing, Q'naires

Trust was recognised as a key factor to guarantee safety and to get benefits such as flight efficiency and capacity. However, building trust can be challenging in real life and some workarounds with a tool that controllers do not trust can result in misuse or total disregard of the tool.

Controllers were selected that were unfamiliar with the simulated environment and this ensured some dependence on the system support for the conflict detection tasks in busy sectors. However, trust was easily built in the simulation since the TCT conflict detections were reliable and accurate.

Normally trust in new equipment is very difficult to build because controllers do not blindly trust in tools. Controllers are cautions about the validity of the system information and cross check it frequently. This difficulty of relying on automation is greater with more experienced controllers who may not readily accept change to their working practices. Controllers have the responsibility for providing a safe service and they tend to countercheck everything proposed by the system thus increasing workload instead of decreasing it. Even if controllers end up with trusting the tools with verifying that they are safe, they can easily setback at the first minimum contrary evidence. Controllers felt they would be able to trust in the TCT support if its information proves to be fully reliable and capable to meet their needs.

Once built the trust, we shall start worrying soon about the over-confidence, which consists in an excessive trust in the tool performances. This effect has been observed, but its implications need to be further investigated. The possibility of controllers' de-skilling could imply some safety concerns. Moreover, the supervisors would not be able to assess the professional knowledge and competence of the individual controllers by simple observation.

5.3.5.4 Experience and Skill change

To evaluate the resulting skill change with the TCT introduction into operations

Interviews, Observation

High traffic load and complexity would result in controllers having to trust and rely on the system. This enforced reliance on the automated support to detect potential conflicts could make controllers' searching skills redundant. It is possible that extra or different skills are required, but some of those skills that were important without TCT could become superfluous. In theory, experience, which directly affects controllers' skills, should turn current skills into those required to make TCT work properly. Their skills could turn into skills for monitoring tools. The evolution could take a short or long time depending on the reliability of the tool and the adaptability of the controllers. The controllers' resultant behaviour should make things work more efficiently and safely.

The choice of the participants facilitated their adaptation to the use of the new assistance tools, where consolidated experience in the environment could have confined its usage. It would be interesting to test TCT with controllers who are rated for the Delta and Munster sectors to evaluate their reaction to the tool and assess the transition effort required. The ability of the simulation controllers to adapt easily to the new operational environment with the use of the TCT was a question of necessity. The experience brings to the controller the skills to search conflicts, prioritise them and intervene quickly in all conditions. Their ability to quickly apply strategies in all possible conditions is derived from their experience since controllers interiorise characteristics of familiar airspace and the trends of the daily traffic, they recognise problems and conditions they have already encountered and apply resolutions which are optimised due to their experience. The simulation controllers did not have this knowledge, so they had to rely on the tool. During the simulation TCT reduced the controllers' level of anxiety or stress that was generated by the lack of experience in the new airspace. The involvement of the Maastricht controllers we could observe if the level of stress is further reduced where there would be enough relevant experience to reduce this anxiety. Observation and analysis has shown that TCT would facilitate the interchangeability of the operational staff. TCT can complement or may be a substitute for experience in detecting conflicts (.e. a controller using automated support tools while working in an unfamiliar airspace environment).

Recommendation (follow-up): To involve controllers experienced on the simulated environment and young students with no experience in a specific environment should be involved, i.e. controllers of different age and background in the future experiments.

Recommendation (follow-up): To involve controllers of the Delta and Munster sectors to make direct comparisons with the present study.

Recommendation (training): Controllers should be trained in a way to be motivated to make conflict detection in an autonomous way as much as they can, without the computer support boring them or to react in a lazy way to the automation.

5.3.5.5 Stress/anxiety

The TCT allows ATCOs to dedicate more time to solve the problems. In normal operations, the level of stress is influenced by the traffic load and complexity. The level of stress should be higher where the traffic load increases; however, during the RTS it was not as high as it would have been without the CDTs. Stress has not proved to be linked to safety hazards, however stress can transcend into anxiety in certain conditions. The anxiety could impair safety because of panic attacks that could occur in critical situations.

In RTS2 controllers did not show signs of stress, although in normal operations the stress with the same density of traffic is often rather high. It was evident that during the TCT exercises the level of stress was low from the controllers' attitude in dealing with the timing of conflict resolutions. In baseline exercises the controllers reacted as soon as they detected a conflict. The participants commented that if they did not react it could be a cause for regret later. In the organisation with TCT, the reaction was taking place later. Controllers were waiting for the best moment to act to provide an effective service to the air users, who normally prefer altitude changes to heading instructions and not to descend too early. TCT provided controllers with flexibility to plan and apply any strategy in a timely and stress free manner because of the automated support.

5.3.5.6 Motivation and Job Satisfaction

To evaluate the resulting job satisfaction and motivation after the TCT introduction

Interviews, Observation

Controllers' job satisfaction was derived from providing a safe and effective service particularly in high density and complex traffic conditions. Job Satisfaction and motivation benefit of high workload as controllers derive satisfaction by the challenges of their work. This attitude originates from their training and their culture. Studies have discovered that low workload after peaks or low workload for controllers that have never worked under low pressure can have safety implications. The absence of boredom seems to be a factor to be essentially guaranteed in air traffic management.

The introduction of new automation support tools with cognitive implications can affect job satisfaction. Controllers' skills and responsibilities can be affected thus impacting on capable and ambitious controllers. Automation, trainers and supervisors must try to preserve controllers' motivation and job satisfaction. Controllers need to be trained to use their equipment and the new tools in a flexible way to adapt their task demand according to the workload. For example, in the TCT simulations controllers balanced a reactive approach towards the TCT alerts during peak periods with a more proactive approach in lower traffic, thus maintaining the search and problem-solving in advance and in a more autonomous way. Controllers thus were able to manage their workload so that fewer peaks were present in the output from the used metrics.

TCT ensured controllers' job satisfaction during the simulation. The experiment participants realised that with the TCT assistance they were able to work in an unknown airspace with a high density and complex traffic, while providing an efficient and safe service to their customers with less stress. So, the TCT tool does not take away their ability to show the excellent air traffic service they can provide by applying their skills and professionalism. It should be considered that the simulation effect could have positively influenced their level of stress and the performances of the tool were not fully realistic (e.g. they were not affected by different aircraft behaviour).

Motivation is more a personal issue. Lack of motivation and indolence could probably generate a misuse of the TCT tool. Controllers might end up with blindly relying on tools to detect conflicts without making any effort to double-check. To be able to monitor TCT and ensure that it is working properly and safely, controllers need to be motivated to make conflict detection in an autonomous way as much as they can thus avoiding boredom or laziness due to over dependence on the automated support. Trainers and supervisors need to supervise possible indolence and keep their staff motivated.

Recommendation (training): Trainers and supervisors need to supervise possible indolence and keep their staff motivated.

5.3.5.7 Perceived Benefits and Barriers

To assess the perceived improvement of system performances with the introduction of the Tactical Controller Tool

E-o-S Questionnaire, Interviews

The job satisfaction derives from a mixture of reasonably high workload and perceived high service performances generated from the perceived benefits of the TCT introduction.

- The simulation team and participants were impressed by the ability of participants to control a high traffic volume in a new environment using a different HMI and a new set of automated supporting tools. The TCT evidently allows controllers to work in alien environments with a variety of partners of varying skills and ability. This TC adaptability could give more flexibility to rosters.
- TCT provides controllers with flexibility to plan and apply any strategy in a timely manner because of the automated support.
- The TCT would resolve the human role incompatibilities that controllers' training forces them to counteract everyday. Controllers are expected to concentrate on building strategies and solving problems while continuously monitoring the airspace to check if other problems develop. However, by somehow resolving this incompatibility, other role incompatibilities may emerge (e.g. the expectations that controllers maintain all skills and knowledge for rare emergency situations). The controller might be expected to retain the responsibility for tasks that cannot be performed with adequate skills and sufficient level of knowledge.
- When the TCT detects conflicts before the controller does, the controller activity moves from tactical intervention to strategic planning. Proper planning provides benefits to service efficiency.
- In some current operational strip-less environments there has been a beneficial impact on the teamwork and on the increase of time devoted to planning. With the use of TCT the tactical controller focuses even more on the planning phase and becomes proactive in the anticipation and optimisation of manoeuvres.
- Assuming that the TCT works well in real operations, the MTCD & TCT are beneficial (in terms of workload reduction, potential capacity, flight efficiency, etc).
- The reduction in monitoring tasks and the support provided in problem-solving will affect the traffic load controllers can manage. This means the sector capacity might increase. The effect is that the controller will be able to more easily manage traffic

than today.

- Flight efficiency. The Planning increases flight efficiency, some example are provided as follows:
    - o The quality of the provided service was higher due to aircraft maintaining or achieving their RFL and descent profiles were closer to those required than current operations.
    - o The conflicts displayed on the flight legs have an impact on flight efficiency as the number of the instructions issued were reduced.
- Controller comments - For sure safety, because you have a better conflict detection tools, more time to react for the conflict and you can find the better solution, because you have a better situational awareness. You do not lose the picture with the PPD and VAW. The TCT is a good backup! If the PPD works well you do not see TCT conflicts. Because the controller manages conflicts outside the TCT window. So when they are not solved and the SV and TT appear you did not have enough time or you forget to solve a conflict. This mainly happens when you prioritise conflicts; the last one is the most dangerous!! The TCT steps forward when the situational awareness is lost, so it helps the controller to back up! If everything works properly you do not see the STCA and this is important because you do not get desensitised to STCA alerts.
- If we want to keep the same level of safety we can increase capacity of a sector. The tool and the working methods to use the tools efficiently are important.

5.4 Safety

To assess the impact on safety of the TCT introduction

Safety is cornerstone in air traffic management. Whatever design decision is taken, the evaluation of its impact shall not detriment the entire system and affect the safety of the provided service. The safety of the system depends on the way the system is used and the behaviour controllers develop according to this use. Some of these behaviours have been closely observed and analysed in relation to analysed safety performances. The safety performance assessment has been combined with the application of HAZOP, which is a structured technique identifying hazards resulting from potential malfunctions of the equipment. The hazards were then analysed to identify possible human errors, technical failures and mitigations to their consequences. Problems are resolved in the form of design or procedure modification or training requirements.

5.4.1 Safety Analysis

To evaluate the mitigation of safety-related potential errors occurring the current system and the introduction of any possible safety issues in the future system

Debriefings, Focus Groups. HAZOP analysis

Discussions during debriefings and focus groups about the impact of the TCT on the safety of the current and future ATC system produced some interesting observations.

During the human factors impact analysis some issues have already been identified as a result of the introduction of TCT. Controllers' deskilling in monitoring/searching activities has been elaborated. Residual control should probably be ensured in the short term to avoid bringing the controller into a position of automation monitoring. Different strategies could be used to maintain the skills such as training and adequate TCT parameter settings that would leave room for autonomous conflict detection. It is possible that this approach would only be applicable in the short term, since in the future heavier traffic loads could induce radical changes in the requested ATC services. In other contexts than the one foreseen in the near future, certain controllers' skills such as those for conflict detection might not be necessary or might even limit effective operations.

Another possible effect observed by controllers could be the possible lost of contact with reality such as with video games, but major insight in this problem would be required in future experiments.

As commented while talking about trust, another issue that might have safety implications is the over-reliance on the TCT. In particular, some controllers were observed while focusing on the PPD only, without checking the RPVD. They were relying on TCT detections and did not have the opportunity to detect issues by independent controller analysis. The over-reliance can have safety implications. Therefore, it could possibly be mitigated by constant refresher trainings.

If the TCT detections were less accurate than the STCA ones, the precision of the TCT could also affect the level of controllers' reliability on the STCA. Controllers could come to the conclusion that STCA alerts not preceded by a TCT alerts might not be operationally relevant. So the safety net alerts might be perceived to have less importance. Coherence between STCA and TCT information must be guaranteed by proper system tunings.

In principle, TCT should prevent improper use of the STCA as conflict detection or monitoring tool instead of a safety net. TCT should fill in a gap between MTCD and STCA. It needs to be always cleared up TCT is not a safety net, but a conflict detection that identifies problems before they become critical. This further barrier helps increase current safety levels, if a "compensation effect" does not take place, where capacity increases compensate safety benefits. The controller should see less STCA occurrences.

The TCT supports controllers in detecting conflicts also in adverse conditions such as non-nominal situations or bad weather conditions when the traffic is dense and complex. Under these conditions, the TCT would prevent the risk of loss of situational awareness which would impact negatively on the detection of potential conflicts. Another risky situation where TCT could guarantee adequate safety levels is in low density traffic, especially after peaks. TCT supports the TC providing "a second pair of eyes" especially when in busy situations where the PC may be occupied with other planning tasks and co-ordination actions. The TCT would also back up the TC when the system is degraded and some barriers (e.g. MONA) could fail to prevent problems in case of a/c missed manoeuvre.

After issuing an instruction to solve a conflict, the TCT supports the controller remembering and verifying the traffic evolution until complete resolution is ensured. This automated activity reduces the controllers' mental load and waste of scanning time. In addition, the TCT detects any possible conflict that could be generated by an error. The TCT aids provide sufficient information and warn controllers where pilots misinterpret an ATC clearance or where the incorrect aircraft follows and ATC clearance.

To complete the safety analysis, further scenarios should be tested. Starting from the HAZOP analysis, the outcome could be used as a starting point to define the scenarios and enrich the picture provided by the participants in this first experiment. Some detailed scenarios could be envisaged, such as the case of state vector conflict activation where aircraft are out of conformance.

Recommendation (follow-up): To test scenarios envisaged in the HAZOP analysis and other specific scenarios such as the case of state vector conflict activation in case of aircraft out of conformance.

5.4.2 Separation performances

To assess overall separation performances of the new system with the introduction of TCT

INTEGRA (Separation performance tool output - according to alarms available on the display and reaction time)

The findings of the separation performances were not as expected. In principle, controllers should have detected the conflicts in advance and consequently acted in advance, however controllers were mainly working over the edges of separation by looking at the predicted separation. Controllers monitored the predicted separation and did not intervene in some situations thereby using the tool as a monitoring aid. In the TCT organisation, interventions to solve potential conflicts were made later than in the Baseline organisation, whilst after intervention aircraft were predicted to be further apart.

Figure 12 shows the number of interventions that were done to solve potential occurrences of loss of separation. The number of interventions both in baseline (lilac bars) and in TCT organisation (purple bars) are shown per each conflict with a time of potential loss of separation within one of the selected timeframes. From the results of intervention separations shown in the graph in Figure 12, it is evident that a major number of interventions in TCT organisation tool place between 3 and 5 minutes before the potential loss of separation with respect to the baseline.

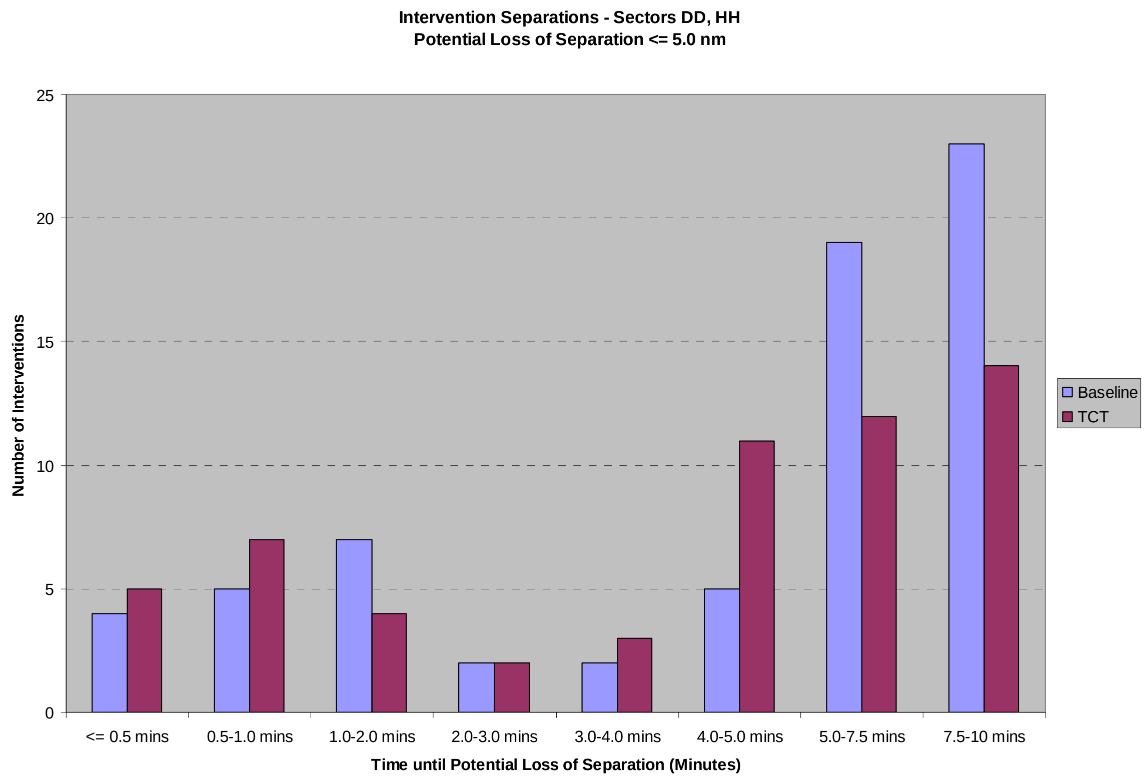
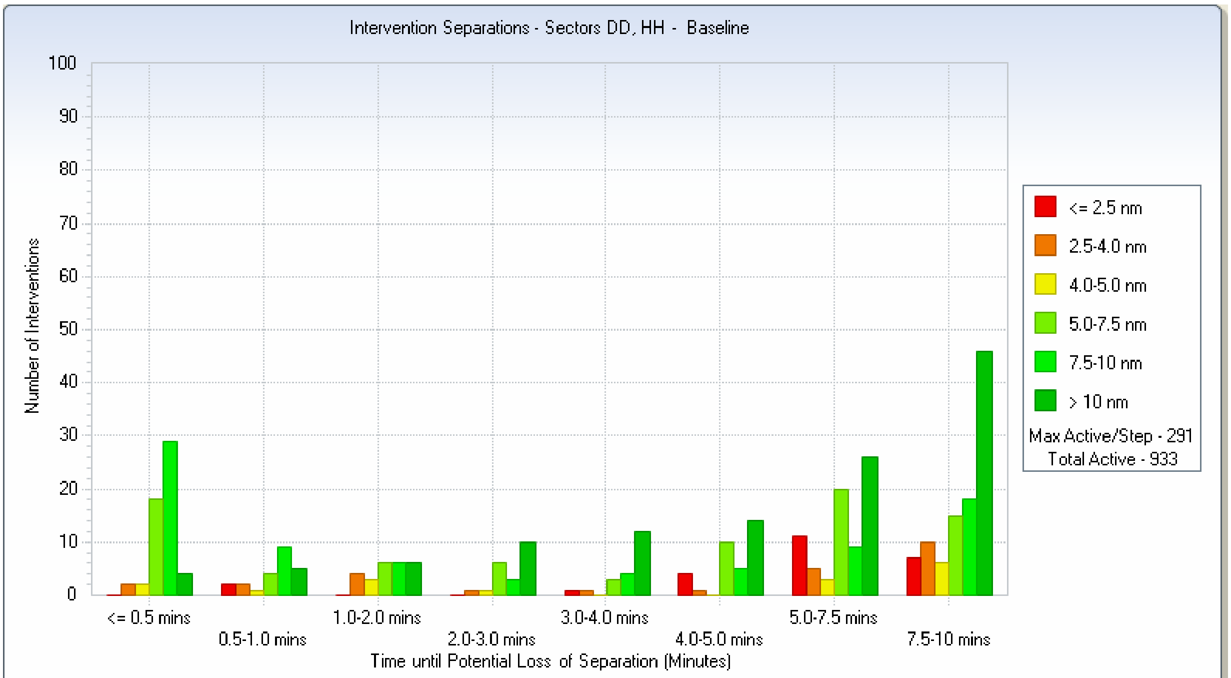


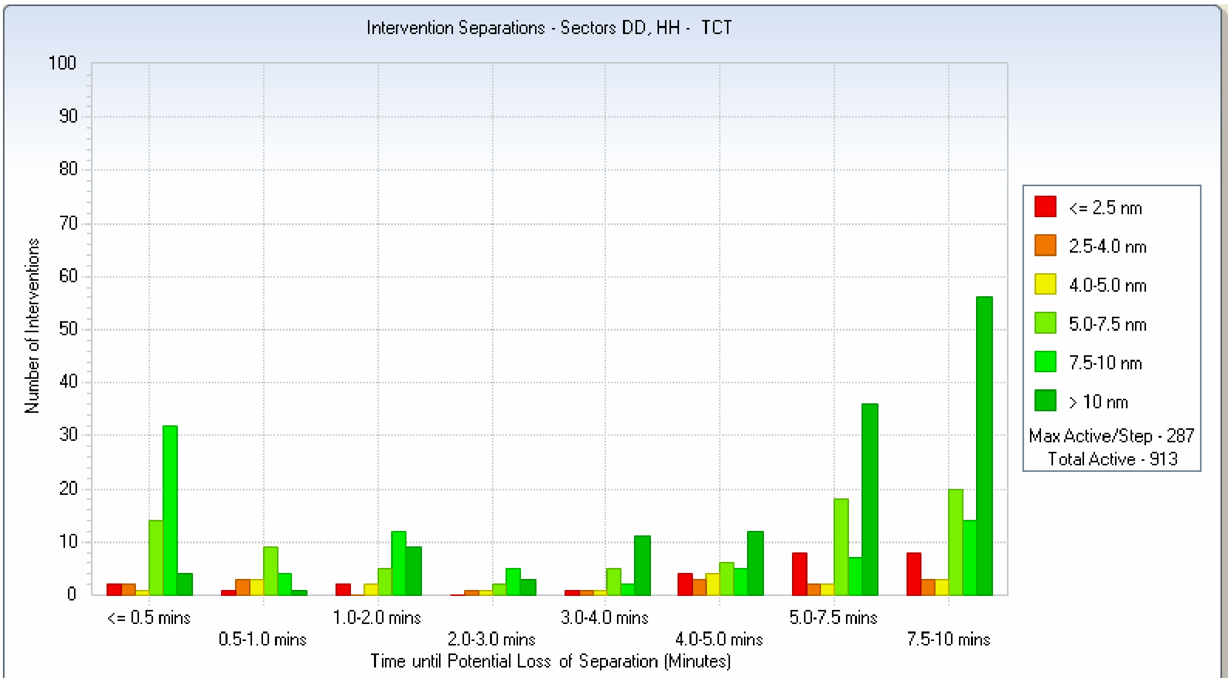
Figure 12: Intervention Separations

From further analysis of Figure 13 and Figure 14, it could be seen that in the second organisation with TCT the number of interventions between 5 and 10 minutes increased, especially to solve severity of predicted loss of separation between 5 and 10 NM. While the number of interventions for serious conflicts were increased between 0 and 2 minutes.



	<= 0.5 mins	0.5-1.0 mins	1.0-2.0 mins	2.0-3.0 mins	3.0-4.0 mins	4.0-5.0 mins	5.0-7.5 mins	7.5-10 mins
<= 2.5 nm	0	2	0	0	1	4	11	7
2.5-4.0 nm	2	2	4	1	1	1	5	10
4.0-5.0 nm	2	1	3	1	0	0	3	6
5.0-7.5 nm	18	4	6	6	3	10	20	15
7.5-10 nm	29	9	6	3	4	5	9	18
> 10 nm	4	5	6	10	12	14	26	46

Figure 13: Intervention Separations in Baseline



	<= 0.5 mins	0.5-1.0 mins	1.0-2.0 mins	2.0-3.0 mins	3.0-4.0 mins	4.0-5.0 mins	5.0-7.5 mins	7.5-10 mins
<= 2.5 nm	2	1	2	0	1	4	8	8
2.5-4.0 nm	2	3	0	1	1	3	2	3
4.0-5.0 nm	1	3	2	1	1	4	2	3
5.0-7.5 nm	14	9	5	2	5	6	18	20
7.5-10 nm	32	4	12	5	2	5	7	14
> 10 nm	4	1	9	3	11	12	36	56

Figure 14: Intervention Separations in TCT organisation

The following graph in Figure 15 shows the differences between the two organisations in terms of the amount of aircraft flight time spent in the separation categories within the sectors across all runs. Separation categories used for this simulation as well as the time windows for the "time until potential loss of separation" in the figures above, were essentially defined by default settings. It is recommended to plan in advance all the parameter settings needed for the INTEGRA graphs before launching the experiments and start data recordings (**recommendation**).

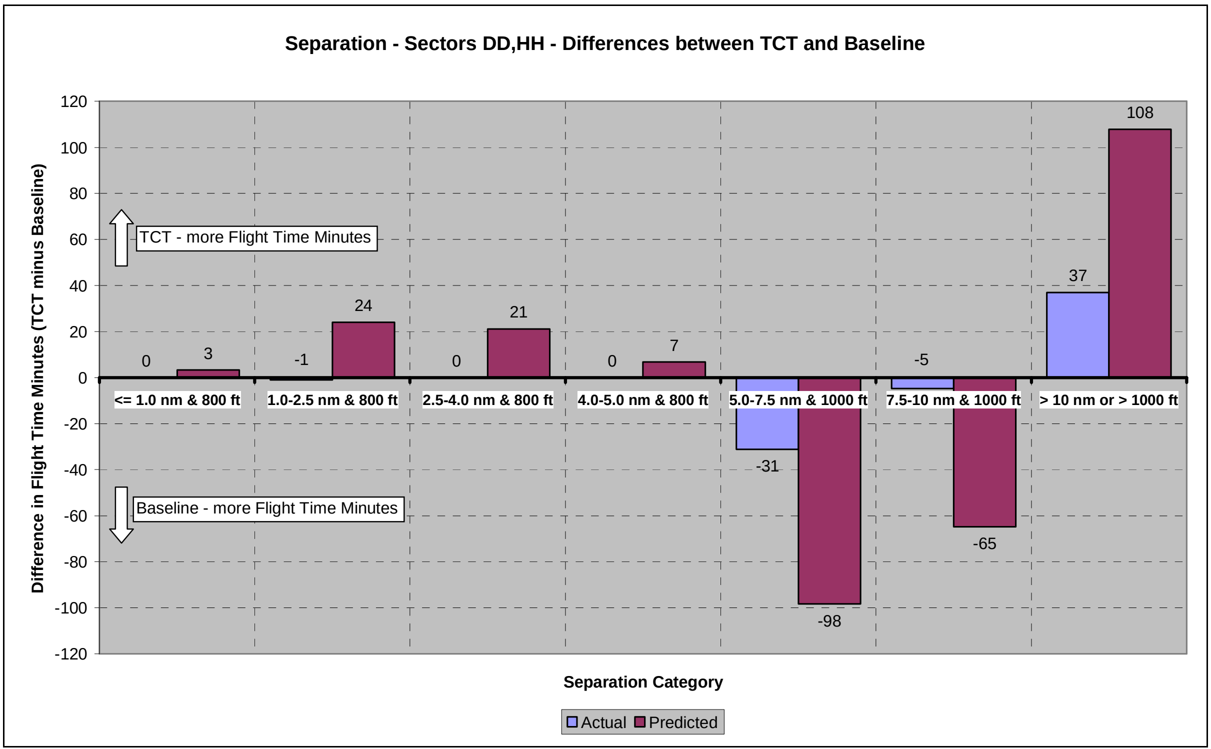


Figure 15: Separation: difference between TCT and Baseline

In the above graph, the comparison between the variations of Actual and Predicted Separation indicates that in the TCT organisation, aircraft with potential conflicts (predicted below the minimum separation criteria) were resolved later than in the Baseline. However, in the TCT organisation after tactical interventions, aircraft were kept further apart than the Baseline. The details are as follows:

- Actual separation: This is a measure of what actually occurred to aircraft in the simulation run showing the amount of time aircraft spent in the separation categories. As would be expected, there is almost no variation between the two organisations in the separation categories under the minimum separation criteria (5 NM and 800 ft). However, there is a variation of 36 aircraft flight minutes just above the minimum separation criteria (5 to 10 NM and 1000 ft) – where the Baseline organisation has more aircraft flight minutes than the TCT organisation. So although aircraft have maintained minimum separations in both organisations, the TCT organisation has resulted in lower occurrences of actual separation in the 5 to 10 NM and 1000 ft range when compared to the Baseline – indicating aircraft were kept further apart.

- Predicted Separation: This is a measure of what would have happened without tactical interventions during the simulation runs. Below the minimum separation criteria (5 NM and 800 ft) there is a difference of 55 more aircraft flight minutes when the aircraft were predicted to cause a conflict under the TCT organisation compared to the Baseline. However, just above the minimum separation criteria (5 to 10 NM and 1000 ft) there is a difference of 163 less aircraft minutes in the TCT organisation compared to the Baseline. The balance of 108 minutes in the TCT organisation is in the above 10 NM and/or 1000 ft category. The variation between organisations indicates that under the TCT organisation there was more aircraft flight time when flights were predicted to be below the minimum separation criteria, but less aircraft flight time when flights were predicted just above the minimum separation criteria. This would indicate that in the TCT organisation, interventions to solve potential conflicts were made later than in the Baseline organisation, whilst after intervention aircraft were predicted to be further apart.

In conclusion, these trends probably confirm that once again controllers used TCT as monitoring tool instead of promptly reacting to possible conflicts. They were relying on the fact that TCT would have reminded them about a conflict even if their attention would have been diverted by other actions. As result, controllers' interventions were happening later than without TCT monitoring. However, in the end controllers were able to maintain better separation performances in the TCT organisation than in the baseline.

5.5 Capacity and Efficiency

5.5.1 Efficiency

To assess the impact on flight efficiency of the TCT introduction in relation to airspace complexity

Integra, Q'naires, Focus Groups

TCT was used as a means to increase the effectiveness of the service provision. Controllers have used TCT information to build more effective strategies to guarantee an increase of flight efficiency. When an aircraft was assumed, the TCT HMI information showed the flight leg and the VAW. The VAW informed controllers of the available flight levels and controllers are able to clear aircraft to climb to higher flight levels, or to climb to intermediate flight levels before being cleared to climb to the requested flight level. Similarly, controllers used the VAW information so as not to descend aircraft too early. The flight leg provided further information to guarantee the effectiveness of manoeuvres. The controller used the conflict trajectory flight leg to detect which aircraft to manoeuvre depending on the number of conflicts that could be resolved with a single instruction. The state vector flight leg supported the issuing of suitable heading instructions.

The TCT provided more flexibility to the ATC system for strategy planning and thus on efficiency. The total number of instructions decreased. In particular, heading instructions decreased, while flight level change instructions increased. More altitude instructions (preferred by air users) can be issued compared to heading instructions with the use of the VAW. Speed instructions remain the same, as the sector size is too small to allow controllers to use them.

From the analysed data, it could be noticed controllers used the TCT aids to delay their interventions to solve conflicts in order to have the time to observe the evolution of the situation and issue the most efficient instruction at the right moment. To guarantee flight efficiency controllers issued more direct route clearances. This behaviour created more complex and unpredictable traffic configurations. When the complexity is combined with a high density of the traffic, the risk of missed conflict detections could increase. TCT provided valuable support however the level of workload increased.

Recommendation (follow-up): Flight efficiency shall be measured in terms of time and distance flown over a sector to validate the improvements induced by TCT introduction.

5.5.2 Sector Capacity

To assess the impact on sector capacity of the TCT introduction in relation to airspace complexity

Integra, Q'naires, Focus Groups

Capacity has been investigated over several years of research. Measuring it and/or predicting the potential increase in capacity with the introduction of automated capabilities is not an easy task. The measurement of capacity is a variable that depends on controller's workload and sector complexity. In the analysed data, there is an evaluation of capacity metrics based on Information Processing Load tasks, such as interaction detection, resolution planning, resolution implementation, monitoring and co-ordination. In general, the increase of information processing load is also due to "Resolution Planning", which could be an indication of the required increase of HMI interactions mainly with the VAW, the PPD and the flight legs. The number of interactions increased due to delay of action on conflicts and increased monitoring of the evolving situation. The resulting complexity generated by the delay, among other reasons, was increased. Thus, the PC had major difficulties to build a proper picture and be of help without talking with the TC. The resulting capacity could be affected in such conditions.

The complexity, increased to have more flight efficiency, should be reduced to increase the sector capacity, since it affected controllers' workload. However, the capacity of the airspace was already increased in the traffic samples (e.g. by 20%) and the complexity of the sector was increased with respect to the real configuration in order to generate more conflicts. Therefore, indications of possible capacity enhancements are encouraging considering that the participant controllers were not familiar with the airspace and that they worked easily with the increased traffic load and more complex route structure.

5.6 User Acceptance

To assess the impact of the TCT introduction on the user acceptance

Debriefing, Questionnaire, Interviews

The user acceptance was assessed against the TCT capability to serve beneficial ATM purposes targeted at users' needs. The controllers participating in the experiments judged their acceptance on the basis of their subjective cost-benefit estimations.

The TCT was easily and immediately accepted. No particular resistance was observed that would go beyond understandable initial reservation towards new concepts and tools. ATCOs were extremely satisfied due to TCT usefulness as the tool was considered to increase safety and reduce workload thus improving work effectiveness. The TCT prototype was judged as user friendly, intuitive and reliable. During the simulation it provided controllers with accurate information that helped them confirm that their calculations were correct. The tool displayed only relevant information that was directly related to controllers concerns or what was pertinent to accomplish their tasks.

There are several other factors to be analysed independently and objectively to complement controllers' subjective feedback in order to understand if the tool is used for the purpose for which it was designed for and to the consequences resulting from alternative use. Controllers' acceptance must be guaranteed to obtain a positive climate at the introduction of the tool, which helps people work together in the development and integration phase of the automation in operations. Users' participation yields superior performances. In the TCT experiment user acceptance seemed to be validated against the specific application and context in which the controllers worked and thus conceived their opinions.

5.6.1 Human in System

To summarise the assessment of the HMI technical usability

E-o-S Questionnaire, Interviews, Observation

The TCT HMI was considered user friendly, while the algorithm calculations were very intuitive. The HMI elements and the information provided by the tool were considered:

- Accurate
- Timely - according to preferred parameter setting!
- Easy to understand and learn
- Easy to access
- Easy to interpret

- Easy to use

The integration of the TCT and MTCD tools was ideal because the same software module was used both as separation assurance and as a monitoring tool by setting different parameters for the TC and PC. The only problem foreseen in real operations is the need for very accurate trajectory information, essential in particular for traffic in vertical evolution.

The coherency of information between the STCA and the TCT was not complete; however, their relationship must be further evaluated.

5.6.2 Domain Suitability/Operability

To summarise the assessment of the procedures, roles and responsibilities + Organisation & Staffing + Working Environment

E-o-S Q'naire, Interviews, Observation

The TCT would probably suit the roles and working methods in each operational environment, as observed in RTS1. Its use would not require any route-structure modifications or radical changes in current controllers' working practices.

The use of the TCT as support to improve safety in staffing options such as Single Person Operations or Group Sector Planning is considered advisable. However, its introduction should not bring to a greater change of current limitations to traffic characteristics suitable for the implementation of these staffing options.

5.6.3 Teams & Communication

To assess the change in teamwork and communication

Interviews, Observation

The introduction of TCT together with MTCD can strengthen the teamwork where no barriers are imposed as in RTS2. The communication and teamwork is important to maintain situation awareness, especially with weather phenomena where the TC would require some additional support. The PC could lose the situation awareness working separately from the TC and he could also generate conflicting actions.

The coordination with the PC increased by interaction aids helps the TC manage the traffic more efficiently. When available from communication with other actors, the PC can support the TC in his decision making by submitting proposals. In RTS1, the TCT seemed to require controllers' co-operation, team dynamics and relations in the case of conflict resolution, even if the responsibility remains with the TC. With the RTS2 working methods segregating the PC and TC, it was possible to evaluate the benefits of less team interaction. It was observed that this approach was useful to define how much the PC is allowed to intervene in the TC work and understand how to define the skills controllers should have to respect these interaction dynamics. However, during the simulation PC support was well appreciated. The PC is more than a second pair of eyes, he is able to support TC decision making concretely and effectively. On the other hand, the quality of the PC coordination with other actors increased as a result of more PC availability in performing this task.

5.6.4 Training & Development

To evaluate the extent of the required training and its compatibility with the current one

Training Questionnaire, Interviews, Observation

The transition of TCT into real operations would, most likely, not imply a huge jump in controllers' cognition in specific operational environments. Some controllers estimated the required learning time to be about two simulation days.

It should be judged whether conflict detection skills of the TC should be kept as well as the decision-making tasks. To learn how to detect conflicts, the preliminary training should be without any support tool. Support tools should be introduced after the basic training. Refresher training on the basics for contingency situations should be coupled to the rehearsal of conflict detection skills that could be used for emergencies. The refresher training should maintain the skills and the level of alert higher.

On the other hand, it could be observed that conflict detection skills would not be sufficient if the TCT fails. Controllers would not be able to handle the traffic; the traffic congestion would be so high – as increased by TCT introduction - that controllers would not be able to react effectively. If the traffic load increases, there is no way for controllers to catch up with the traffic management.

Reliable systems are fundamental; however, operations could be backed up by neighbour centres. Redundancy of ACC would be a key factor to maintain safe operations.

6 Conclusions and Recommendations

Conclusions and recommendations are summarised. The recommendations concern issues identified in this initial study that should be investigated and validated in future activities.

6.1 Conclusions

In general, the support provided by the Conflict Detection Tools (CDT), TCT and MTCD, was greatly appreciated by the controllers. It was evident from the traffic complexity and throughput of the sectors that CDT combined with the other FASTI tools empowers the controller team and facilitates both an increase in efficiency and capacity while maintaining safety.

- TCT efficiently supports controllers due to its systematic conflict detection thus releasing controllers' mental resources;
- TCT provides all information necessary to support problem solving, decision making and resolution verification by
    - Monitoring all the a/c pairs to detect potential problems by looking at both the trajectory and the flight plan, and
    - Detecting conflicts in configurations that would otherwise be difficult to detect by scanning all vertical and horizontal geometries in the same way;
- TCT adequately supports controllers where human limitations may be surpassed or close to saturation level. The controller scanning activity is not usually facilitated by the unstructured and complex information presentation on the radar display;
- The tool helps controllers prevent errors such as forgetting planned instructions or monitoring more complex aircraft evolutions;
- Controllers considered and used the TCT as a tool with the capability to increase the efficiency of the air traffic control service;
- There was no inconsistency between TCT and MTCD because the same software module of the TCT has been used to emulate the MTCD. It was observed that the implementation of the same tool to provide both MTCD and TCT conflict detection, in addition to the same TP, would be the best solution to achieve an adequate MTCD/TCT integration.
- No major inconsistencies were detected between TCT and STCA.

6.2 Recommendations for Follow-up Activities

Bearing in mind the limitations of this project activity and the maturity of the concept validation (i.e. V1 and V2 of the E-OCVM concept maturity scale), the results of the TCT/MTCD evaluation has provided very encouraging feedback. A complete validation activity should be planned and carried out to move to a further stage and bring the concept to more mature validation levels. In addition, issues related to TP performances and impacting on CDT (i.e. TCT and MTCD) should be investigated within the FASTI Programme. Some of the initial recommendations for future work are listed as follows:

- Different working methods should be prescribed and assessed for a variety of environments;
- Simulate realistic traffic scenarios to observe performance of the monitoring tasks of the tactical controller, where the planner control capability is saturated by other tasks;
- Involve controllers of a variety of age profiles and experience in a number of simulations to assess impact of tools on skill and training;
- Assess the viability of CDT with Single Person Operation and Group Sector Planner staffing configurations;
- Investigate the usefulness and usability of the Miss Manoeuvre functionality of TCT with different parameter settings;
- Investigate the implications of non-nominal scenarios where CDT and FASTI tools are deployed:
  - Weather avoidance scenarios;
  - Variable rates of vertical change for a range of aircraft types;
  - Open-loop trajectories (e.g. pilot intention unknown or unpredictable)
- Investigate issues identified in the HAZOP analysis:
  - Out of conformance aircraft;
  - STCA and TCT performance issues and human behaviour related to activations;
- Test separation performance with a selection of parameter settings (i.e. 5-10-15nm) for different operational conditions;

- Assess change to flight efficiency with the introduction of CDT;
- Extend the validation process to include further RTS studies as well as Shadow Mode Trials and Live Trials of CDT.

Further recommendations related to technical and implementation aspects are available in the document. They need to be read in relation to the described findings, therefore these recommendations are not reported in this final section.

7 Appendix A: Simulation Plans

7.1 RTS1 Plan

TCT Trials - Simulation 1 Plan

	Monday 13/10/2008	Tuesday 14/10/2008	Wednesday 15/10/2008	Thursday 16/10/2008		Friday 17/10/2008
09:00	Welcome Presentation (FASTI Programme, Simulation, Training)	Run 1: TCTM80 Rotation: R1 + Observation	Run 5: TCTM100 Rotation: R2 lost	Run 8: TCT M120 Rotation: R3 + 2 Questionnaire	09:00	Run 11: TCT A120 Rotation: R3* + Observation
09:15					09:15	
09:20					09:20	
09:30					09:30	
09:45			Run 5: TCTM100 Rotation: R2 + 2 Individual Interviews		09:45	
10:00					10:00	
10:15		Coffee break			10:15	
10:20	Coffee break	Run 2: TCTA80 Rotation: R2 + Observation		Coffee break	10:20	Coffee break
10:30	Training Classroom & run 1 (TCTM80)			Run 9: TCTA120 Rotation: R1* + 2 Questionnaire	10:30	Final Debriefing
10:45			Coffee break		10:45	
11:00			Run 6: TCTA100 Rotation: R3 + 2 Individual Interviews		11:00	
11:15					11:15	
11:20		Run 3: TCTA100 Rotation: R3 + Observation			11:20	
11:30					11:30	Final & overall q'naire
11:45	*Trainer support*				11:45	Lunch
12:00	Lunch		Lunch	Lunch	12:00	
12:15		Lunch			12:15	Bus to: Cite' Universitaire Place d' Italie
12:30					12:30	
12:45					12:45	
13:00				Run 10: TCTM120 Rotation: R2* + 2 Questionnaire	13:00	
13:30	Training run 2 (TCTA80)		Run 7: TCTM120 Rotation: R1 + 2 Individual Interviews		13:30	Thank you & ciao See you in December
13:45		Run 4: TCTM100 Rotation: R1 + Observation			13:45	
14:00					14:00	
14:20					14:20	
14:30	*Trainer support*			Coffee break	14:30	
14:45		Coffee break	Coffee break	Debriefing	14:45	
14:50	Coffee break	Post-it Exercise	Post-it Exercise		14:50	
15:00	Training run 3 (TCT M80)				15:00	
15:15					15:15	
15:20		Debriefing	Debriefing		15:20	
15:30					15:30	
15:45	Presentation on Evaluation				15:45	
16:00					16:00	
16:15					16:15	
16:20					16:20	
16:30	Training q'naire				16:30	

Coulour code

Presentation	Training run	Questionnaire	Debriefing	RUN

Run name de-code

TCT = Tactical Controller Tool project;
M = Morning traffic sample;
A = Afternoon traffic sample 1;
80, 100 and 120 = percentage of traffic load

7.2 RTS2 Plan

TCT RTS2 - Simulation Plan

	Monday		Tuesday		Wednesday		Thursday		Friday
09:00	Briefing		Briefing (TCT W-M & HMI)		Briefing for Interviews		Briefing for E-o-S Questionnaire		
09:15	Run 1: TCTM1 Rotation: R1 Baseline	Observation	Run 4: TCTA1 Rotation: R4 TCT	Observation	Run 7: TCTA2 Rotation: R2 TCT	Interview (AN01)	Run 10: TCTA1 Rotation: R4 Baseline	Interview (AN01)	End-of-Simulation Q' naire (CC27)
10:30	Questionnaire	Debriefing with SMEs	Questionnaire	Debriefing with SMEs	Questionnaire		Questionnaire		
10:45	Coffee break		Coffee break		Coffee break		Coffee break		Coffee break
11:00	Run 2: TCTA2 Rotation: R2 Baseline	Observation	Run 5: TCTM2 Rotation: R5 TCT	Observation	Run 8: TCTM2 Rotation: R5 Baseline	Observation	Run 11: TCTA3 Rotation: R6 Baseline	Interview (AN01)	End-of-Simulation Debriefing Acceptability (CC27)
12:15	Questionnaire	Debriefing with SMEs	Questionnaire	Debriefing with SMEs	Questionnaire	Debriefing with SMEs	Questionnaire		
12:30	Lunch		Lunch		Lunch		Lunch		Lunch
13:30	Run 3: TCTM3 Rotation: R3 Baseline	Observation	Run 6: TCTM3 Rotation: R3 TCT	Interview (CE10)	Run 9: TCTA3 Rotation: R6 TCT	Observation	Run 12: TCTM1 Rotation: R1 TCT	Interview (AN01)	Bus to: Cite`Universitaire Place d`Italie
14:45	Questionnaire	Debriefing with SMEs	Questionnaire		Questionnaire	Debriefing with SMEs	Questionnaire		
15:00	Coffee break		Coffee break		Coffee break		Coffee break		
15:15	Debriefing and Briefing on RTS 2 Working Methods (CE10)		Debriefing and Focus Group on Usability (CE10)		Debriefing and Focus Group on Operability (CE10)		Debriefing and Focus Group on Suitability (CE10)		-
17:00									

Colour code							
	RUN	Debriefing	Observation	Interview	Q'naire	Break	E-o-S Q'naire