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Safety Argument for Precision RNAV in Terminal Airspace

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Abstract

This document presents a structured argument for why P-RNAV has been safely specified. It is based heavily on the recently updated P-RNAV safety assessment (FHA/ PSSA). It is expected that local safety cases will make use of this document and expand it to cover the implementation, transition and operational lifecycle phases.

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Contact Person(s)	Tel	Unit
M Lissone	+32 2729 3261	DAP/APN

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EATMP Infocentre
EUROCONTROL Headquarters
96 Rue de la Fusée
B-1130 BRUSSELS

Tel: +32 (0)2 729 51 51
Fax: +32 (0)2 729 99 84
E-mail: eatmp.infocentre@eurocontrol.int

Open on 08:00 - 15:00 UTC from Monday to Thursday, incl.

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The following table identifies all management authorities who have successively approved the present issue of this document.

AUTHORITY	NAME AND SIGNATURE	DATE
P-RNAV project manager	M. Lissone	16/05/2008
Navigation Domain Manager	R. Rawlings	16/05/2008
Head of Airspace, Network Planning and Navigation Business Division	J. Sultana	16/05/2008

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EXECUTIVE SUMMARY

Background

A large number of ECAC States are in the process of implementing Precision Area Navigation (P-RNAV) procedures in Terminal Airspace (TA). Over the last 5-10 years, EUROCONTROL has conducted P-RNAV safety studies in co-operation with ECAC stakeholders. The last EUROCONTROL P-RNAV safety assessment and safety argument (version 2.0) received considerable peer review and as a result EUROCONTROL has updated both documents. This report presents the revised safety argument which is supported by the updated safety assessment [**4**].

Method and Main Findings

A high level safety argument is presented using Goal Structured Notation (GSN). This technique links a top level claim about the safety of P-RNAV operations to a structured set of arguments and supporting evidence. The main arguments follow the P-RNAV concept lifecycle:

1. Specification
2. Implementation
3. Transition
4. Operational Service

The focus of this document is Argument 1 concerning the specification of safe P-RNAV operations. The specification sub-arguments reflect the need to consider not just the risk associated with explicit system failures, but also the risk under fault free conditions. The main findings with respect to specification are as follows:

Intrinsic safety	Given better defined lateral navigation under the P-RNAV concept, and the available guidance concerning procedure design and route spacing, it can be argued that obstacle collision and aircraft-aircraft loss of separation risk should be no greater, and potentially will be less, than under conventional navigation in the absence of failure.
Design completeness and correctness	The safety assessment developed functional and physical models of the P-RNAV system to ensure that comprehensive safety requirements have been specified. Extensive operational experience with RNAV operations in TA, together with simulations, provide further evidence as to the completeness and correctness of the specification. Local Concepts of Operations to support local safety assessments/ cases may be needed in addition to the generic EUROCONTROL/ JAA/ ICAO documentation that goes together to define the generic P-RNAV concept considered in this document.
Design robustness	The series of P-RNAV safety assessments have considered the impact of external failures and abnormal conditions and concluded that the specified concept is robust. As above, the extensive operational experience with RNAV operations in TA provides further evidence as to concept robustness.

Safety under failure conditions	With respect to failures internal to P-RNAV, the generic safety assessment [**4**] has indicated that safety criteria should be met by the proposed P-RNAV concept, i.e. risks will not increase from current levels and they have been reduced as far as reasonably practicable. The quantitative Safety Requirements have been linked to practical risk mitigation measures to allow stakeholders to concentrate on these mitigation factors and demonstrate that accepted standards, guidance and good practice have been followed with respect to these mitigations. That can then be used to show that the safety criteria will be met at a local level as well.
Requirements practicability/ realism	The most recent work commissioned by EUROCONTROL has concentrated on re-verifying and re-validating the processes and outputs from previous P-RNAV safety studies. These activities have indicated that the revised safety requirements are practicable and realistic. Fulfilment of the requirements and/or the mitigations that support the safety requirements, are all capable of direct verification by stakeholders.

Limitations and Stakeholder Usage

The following caveats apply to this document:

- Many of the stakeholder comments on the previous version of the safety assessment/ argument concerned the potential problems if VOR/ DMEs are used for P-RNAV procedures. EUROCONTROL's procedure design guidance [**2**] is based on use of GNSS and/ or DME-DME. The forthcoming update of TGL10 (to AMC 20-16) is likely to remove VOR/ DME from the list of sensors. Hence this safety argument does not address use of VOR/ DME as an input to P-RNAV operations. A local safety assessment would be required if a P-RNAV procedure is based on use of a VOR/DME.
- If local P-RNAV Concepts of Operation differ from the functional model summarised in the safety assessment [**4**], or from the standards/ guidance documents listed in section 4.3 of this document, or if the assumptions in section 8 below are not applicable, a specific safety assessment should be conducted. Otherwise local safety assessments/ safety cases should be able to make considerable use of the generic material contained in the safety assessment [**4**] and this safety argument.

In order for stakeholders to produce comprehensive local Safety Cases the following stages would be anticipated:

1. Review the arguments in this document concerning "Specification" and the supporting safety assessment [**4**] to determine applicability to the local Concept of Operations. Adapt as necessary to include in local Safety Assessment/ Case.
2. To address "Implementation", document how the requirements in Ref. [**4**] (plus any locally derived requirements) have been met in the local implementation. Where relevant make use of EUROCONTROL's P-RNAV "Implementation Methodology" [**27**] for this argument and for Transition.
3. To address "Transition", conduct a System Safety Assessment (SSA) of the transition plan and derive safety requirements/ mitigations specific to the transition phase. Document the SSA and how the transition requirements have been met.

4. To demonstrate safety throughout "Operational Service" requires the local stakeholders to link the safety assessment outputs to the Safety Management System (SMS) that will ensure ongoing safety. Of particular importance will be monitoring systems to record and investigate incidents involving P-RNAV procedures. In addition, the SMS element covering risk assessment when a change is made will also be critical, e.g. when a proposal to decommission a Terminal VOR/ DME is made.

Conclusions

This document presents a structured analysis of the safety of P-RNAV operations, considering both fault free operations and failure conditions. The focus has been on the specification stage of the P-RNAV concept and the supporting evidence provided by existing standards and guidance documents and the P-RNAV safety assessment [**4**].

In summary, and subject to the assumptions and limitations stated herein, safety requirements and mitigations have been determined which if implemented are predicted to ensure that risk will not increase from current TA levels and that risk has been reduced as far as reasonably practicable.

Guidance has been provided for how this material can be used in local Safety Assessments/ Cases.

1. INTRODUCTION

1.1 Historical Background to P-RNAV

Since 1998, **Basic** RNAV (B-RNAV) has been implemented throughout ECAC En-route airspace. The B-RNAV system specification was set out to meet en-route RNAV requirements and as a result these systems do not provide either the accuracy or the functionality demanded of complex terminal RNAV procedures. Consequently, except under some very restrictive conditions (e.g. design of procedures in accordance with en-route design criteria with operations maintained above MSA/MRA), B-RNAV is not appropriate for Terminal Airspace operation.

In assessing requirements for a minimum performance RNAV capability suitable for Terminal Operations, the JAA produced Temporary Guidance Leaflet No 10 – Airworthiness and Operational approval for **Precision** RNAV (P-RNAV) Operations in Designated European Airspace [**1**]. , ICAO Doc 8168 (PAN-OPS) contains obstacle clearance criteria for sensor-based RNAV procedures (Basic-GNSS and DME/DME) and guidance material has been developed by EUROCONTROL to provide additional support to procedure designers in the development of RNAV procedure designs [**2**]. ICAO Doc 7030 (Regional Supplementary Procedures) has also been updated to take account of P-RNAV, identifying ATC operational requirements including contingency procedures and ATC phraseology.

However, in the intervening period, States have found it necessary to implement RNAV procedures and, since there are insufficient RNAV systems approved to TGL 10, have adopted a number of solutions including the use of B-RNAV systems in Terminal Airspace. Moreover, flight crews have been making more and more use of the RNAV functionality available on many aircraft to fly the existing conventional instrument procedures. The result has been that:

(i) Conventional Terminal Airspace procedures (including SIDS and STARS) have been flown using the RNAV functionality available on most modern aircraft, since the 1980s.

(ii) RNAV procedures, that need a P-RNAV capability for them to be flown accurately, have been developed and operated at a number of European airports for some time without actually requiring P-RNAV capability from the aircraft involved.

(iii) ATC have not always been aware that some RNAV systems have not met P-RNAV capability and have therefore not necessarily been prepared for results of system deficiencies and their consequences.

(iv) The equipage requirements for TMA RNAV procedures specified in Aeronautical Information Publications (AIPs) differ between States and are not identified in a common manner thus making it difficult for operators to identify and understand the requirements/limitations

(v) Whilst aircrew may be aware of differences, the previous lack of certification standards to address the individual States requirements makes it difficult for them to know whether their equipment enables them to operate safely on the procedures.

These factors together led to there being a difficulty in providing assurance that there remained a safe system operation and therefore an urgent need existed for a solution to this mixed, uncoordinated application of RNAV standards.

This resulted in an integrated initiative being agreed by ECAC States in which a coordinated approach to P-RNAV was developed by EUROCONTROL. As part of this initiative, EUROCONTROL developed a Safety Argument (Ref. [**3**] v2.0) to help States produce adequate and coherent Safety Cases for the introduction of P-RNAV in Terminal Airspace, in their respective areas of responsibility. That version of the Safety Argument and the safety assessment that underpinned it, received considerable peer review. As a result EUROCONTROL has updated the P-RNAV Safety Argument and safety assessment [**4**] to address all the stakeholder comments and to bring the Argument into the updated EATM Safety Argument format.

1.2 Aims and Objectives

The main aim of this Safety Argument is to provide a coherent structure and sufficient evidence to support the claim that P-RNAV in Terminal Airspace will be acceptably safe.

The objectives of this report are to:

- Document the main results of the Safety Assessment [**4**], conducted in accordance with the EUROCONTROL Safety Assessment Methodology.
- Conclude whether the P-RNAV operations, as proposed, are acceptably safe or state the requirements necessary to ensure acceptable safety.
- Provide a basis for ANSPs to produce their own local safety cases, where applicable.

1.3 Scope of the Safety Argument

This document addresses the specification stage of the P-RNAV concept only. However the Safety Argument, developed using Goal Structured Notation (GSN), does provide a framework for the development of assurance related to the implementation, transition and in-service stages of the concept lifecycle.

It sets Safety Targets and develops Safety Functions, Safety Objectives and ultimately Safety Requirements which, <u>if</u> satisfied in the implementation of P-RNAV by the individual States, would result in an acceptably safe operation of P-RNAV in Terminal Airspace.

The analysis and conclusions presented herein cover all phases of Terminal Airspace operations <u>except</u> Final and Missed approaches which are not addressed within JAA TGL 10. B-RNAV applications in TA are not covered.

The Safety Argument covers operational environments with radar surveillance, both below and above MRA, and without radar surveillance.

1.4 Document Layout

Section 2 presents the high-level safety argument encompassing the safety lifecycle, thus providing a basis for the development of a complete Safety

Case by local ANSPs. This document focuses on specifying P-RNAV operations so that they are safe (**Arg 1**). **Arg 1** is then sub-divided into lower level arguments which are addressed in **Sections 3-10** of this document.

Section 11 states the limitations of this Safety Argument.

Section 12 presents guidance as to what local stakeholders should address in Arguments 2, 3 and 4 concerning the remaining lifecycle of the concept if they are required to produce a local safety case.

Section 13 has the document's main conclusions.

Appendix A lists all the safety issues raised in previous versions of this document and summarises their status.

2. SAFETY ARGUMENT

2.1 Overall GSN

The high level safety argument is presented in Figure 2.1 below using Goal Structured Notation (GSN):

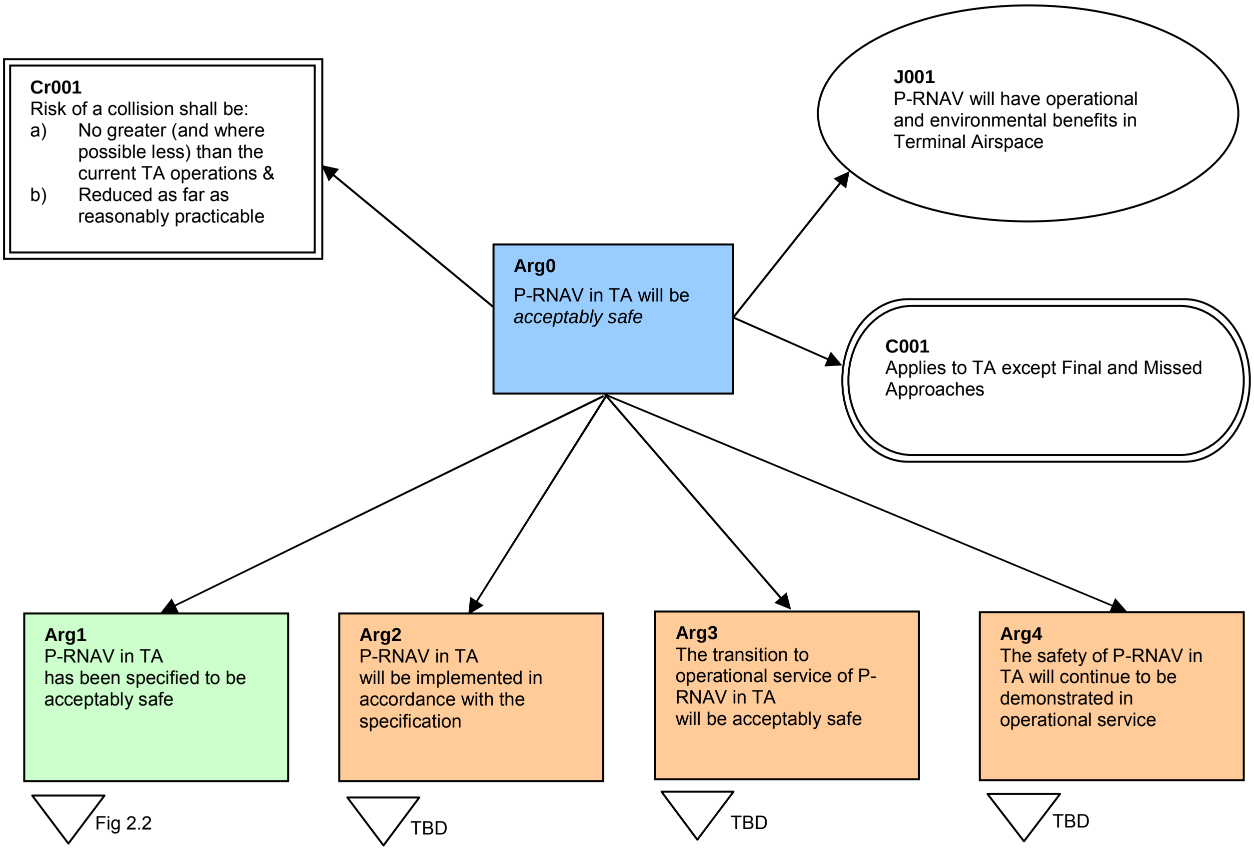

Figure 2.1: Overall Safety Argument

2.2 Top Level Claim

The ***top-level claim*** (**Arg0**), which forms the basis of this safety case, is that P-RNAV operations in Terminal Airspace (TA) will be acceptably safe.

2.3 Justification

The justification for introducing P-RNAV operations in Terminal Airspace is that they provide the following main benefits:

(i) Enhanced airspace utilisation.

(ii) Increased opportunity to fly more fuel-efficient profiles.

(iii) Reduced environmental impact.

(iv) Reduced ATC workload (including reduced RTF) with the consequent potential for increase in ATC capacity[1] .

In addition, the introduction of RNAV operations en-route with the consequent need to provide links to and from the existing runways together with the placing into service of new runways/airports where it has not been possible to implement conventional procedures, have both necessitated the introduction of RNAV procedure introduction in Terminal Airspace.

2.4 Context

The context within which the argument (**Arg0**) set out herein applies to all phases of flight in Terminal Airspace, except for Final and Missed Approaches.

The common P-RNAV application proposed by EUROCONTROL and ECAC partners (http://www.ecacnav.com/content.asp?CatID=22) requires a coherent approach including:

- where RNAV is used in TA it will require P-RNAV equipage;
- procedures will be designed to take due account of P-RNAV system capability;
- data will be of the required integrity; and
- both pilot and ATCO training will be sufficient to ensure mutual awareness of system requirements, capability and limitations.

2.5 Safety Criteria

The following safety criteria have been used consistent with other EATM projects:

1. The risk of collision (CFIT and Mid-Air Collision, MAC) under P-RNAV shall be no higher than (and where possible less than) that presented by current arrivals, initial and intermediate approaches and departures.
2. The risk of collision under P-RNAV shall be reduced as far as reasonably practicable.

A quantitative Target Level of Safety (TLS) has been determined that is consistent with the first criterion (see Appendix A.1 of the Safety Assessment [**4**]). It has been based on historical accident frequencies relevant to ECAC Terminal Airspace and apportioned to match the scope of the P-RNAV relevant hazards. This has been used within the quantitative risk assessment that has been conducted. In addition, qualitative safety assessment within Ref. [**4**] has been used based on the criteria above.

2.6 GSN Strategy

The top level claim (**Arg0**) is decomposed into four principal Safety Arguments, using the GSN convention that an argument can only be considered to be true if each of the sub-arguments is shown to be true.

[1] Controller workload is only one of the factors affecting airspace capacity and therefore the realisation of capacity gain is dependent upon a number of changes occurring, inter alia, correct airspace design and support to the controller to enable them to effectively manage the flow of traffic.

The four principal arguments form the basis for a full safety case, as would be required before introducing the concept into service. However, for the purposes of this Safety Argument only Arg1 is covered in detail.

2.6.1 Specification

Arg1 asserts that P-RNAV operations in Terminal Airspace have been specified to be acceptably safe. The satisfaction of this argument is achieved primarily through a comprehensive safety assessment carried out in accordance with ESARR 4 and the EUROCONTROL Safety Assessment Methodology. Arg1 is the basis of this current Safety Argument document.

2.6.2 Implementation

Arg2 asserts that P-RNAV operations in Terminal Airspace have been implemented in accordance with the specification derived in Arg1. This argument would be supported by the results of a full System Safety Assessment (SSA), to be carried out by the responsible ANSP.

2.6.3 Transition

Arg3 asserts that the transition to operational service of P-RNAV operations in Terminal Airspace will be acceptably safe. This argument requires evidence that all preparations for operational service have been completed. As with Arg2 the ANSP is responsible for satisfying this argument. However, EUROCONTROL has produced some guidance regarding implementation and transition via the "Implementation Methodology" [**27**].

2.6.4 Operational Service

Arg4 asserts that P-RNAV operations in Terminal Airspace will continue to be acceptably safe in operational service. Monitoring of operational safety by the ANSP is important to validate the conclusions of the initial safety assessment required for Arg1, and to ensure that any issues which arise during service are duly investigated and appropriate corrective action taken. Only by monitoring the performance of the concept in service can it be determined whether the safety criteria described above have been met.

2.7 Specification (Arg1)

As stated above, the focus of this document is Arg1 concerning the specification of safe P-RNAV operations. The decomposition of Arg1 is shown in Figure 2.2 below. It comprises the following eight sub-arguments which reflect the need to consider not just the risk associated with explicit system failures, but also the risk under fault free conditions.

2.7.1 Intrinsic Safety of the Concept (Arg1.1)

Arg1.1 asserts that P-RNAV operations in Terminal Airspace are intrinsically safe, i.e. it establishes whether the concept is capable of satisfying the safety criteria, assuming that a suitable system design could be produced and implemented. The key parameters which make the concept intrinsically safe are to be identified.

2.7.2 Design Completeness (Arg1.2)

Arg1.2 asserts that the design of the system which enables the concept is complete. The objective is to show that Safety Requirements have been derived to cover everything necessary in terms of system design to fulfil the concept. Traceability between the basic concept, safety criteria and safety requirements will form part of the evidence here.

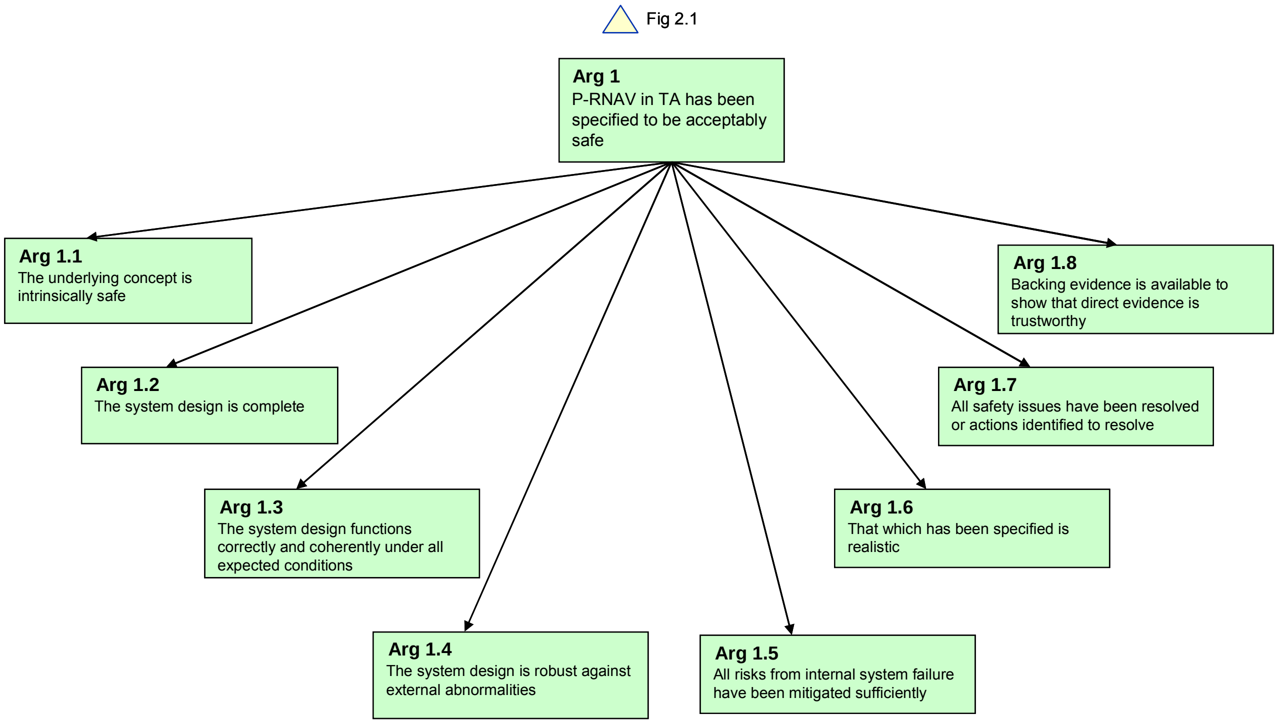

Figure 2.2: Decomposition of Argument 1

2.7.3 Design Correctness (Arg1.3)

Arg1.3 asserts that the system design functions correctly and coherently under all normal operating conditions. The main issue here is the internal coherency and dynamic behaviour of the system over the full range of conditions to which the system is expected to be subjected in its operational environment.

2.7.4 Design Robustness (Arg1.4)

Arg1.4 asserts that the system design is robust against external abnormalities in the operational environment. Evidence is required to show that the system can continue to operate effectively and that such abnormalities do not cause the system to behave in a way which could induce risks that would otherwise not have been present.

2.7.5 Mitigation of Internal Failures (Arg1.5)

Arg1.5 asserts that all risks from internal system failure have been mitigated sufficiently. Here, the internal behaviour of the system is addressed from two perspectives; how loss of functionality could reduce the effectiveness of the system and how anomalous behaviour of the system could induce a risk that would otherwise not have arisen.

2.7.6 Requirements are Realistic (Arg1.6)

Arg1.6 asserts that the requirements which have been derived to ensure the safety of the concept are achievable and practicable in a typical implementation. Unrealistic requirements will limit the application of the concept and / or place a financial burden on the ANSP / operator which may prevent implementation and negate the perceived benefits of the concept.

2.7.7 All Safety Issues Addressed (Arg1.7)

Safety Issues identified in the series of P-RNAV safety assessments have either been resolved or actions identified to resolve them.

2.7.8 Backing Evidence Provided (Arg1.8)

Backing evidence is provided to indicate that the direct evidence provided in sub-Arguments 1.1 to 1.6 is trustworthy.

Further decomposition of the arguments is presented in the following sections of this document together with supporting evidence.

3. INTRINSIC SAFETY (ARG 1.1)

The objectives of this section are to show:

- That the Concept is capable of satisfying the safety criteria, assuming that a suitable system design could be produced and implemented;
- The key parameters that make the concept safe in principle.

3.1 Strategy

The strategy for satisfying Arg1.1 is to provide evidence that the following lower-level arguments are true:

a) **Arg 1.1.1**. The operational context and scope of the Concept has been clearly described.

b) **Arg 1.1.2**. Differences from existing operations have been described, understood and reconciled with the Safety Criteria.

c) **Arg 1.1.3**. The impact of the concept on the operational environment has been assessed and shown to be consistent with the main safety criteria.

d) **Arg 1.1.4**. The functionality and performance parameters have been defined and shown to be adequate to satisfy the main safety criteria.

3.2 Operational Context and Scope (Arg1.1.1)

The specification of Safety Functions and Safety Objectives is based on the application of P-RNAV to all phases of flight in Terminal Airspace, except for Final and Missed Approaches – i.e. to:

(i) Arrivals.

(ii) Initial Approaches.

(iii) Intermediate Approaches, up to and including the Final Approach Fix.

(iv) Departures.

The analysis discussed below covers both a radar-controlled/monitored environment and a non-radar environment. Other operational contextual issues are covered above in section 2.4.

3.3 Differences from Current Operations (Arg1.1.2)

3.3.1 Current Operations

In TGL10 (Rev 1) Annex C there is a description of a number of steps envisaged in the transition from today's conventional terminal airspace procedures to future RNP-RNAV procedures. Steps (a) to (d) represent the mix of operations currently found in ECAC TAs.

(a) Conventional Procedure

A conventional procedure design (VOR radials, NDB bearings and DME fixes/arcs, ILS, MLS). Flown with conventional means (VOR, DME, ADF, ILS and MLS).

(b) Conventional Procedure flown by an RNAV system coded to ARINC 424

A conventional procedure design but stored in a navigation database using the full set of ARINC 424 Path Terminators (currently 23 different leg types).

(c) Conventional Procedure meeting RNAV criteria

A conventional procedure designed specifically to meet RNAV criteria using sensors such as VOR/DME, DME/DME and GNSS. This procedure is published as a conventional procedure and may reference VOR radials, NDB bearings and DME fixes. However, it will have associated waypoints to define the RNAV path. This removes the ambiguity/approximations found in conventional procedures of paragraph (b), when flown using RNAV systems and ensures repeatability of the intended path over the ground.

(d) RNAV Procedure (Not RNP)

A procedure designed specifically for RNAV using sensors such as DME/DME and GNSS. Use is made of waypoints located according to minimum distance requirements as laid down in PANS-OPS. This procedure is identified as an RNAV procedure and the sensor used for the design must be published. The procedure is intended for Precision RNAV or RNP-RNAV certified system.

In addition to steps (a) to (d), current TA operations also include aircraft being radar vectored by ATC.

The conventional procedure of paragraph (a) was originally designed for hand-flown operations and does not always lend itself to the use of RNAV systems. Navigation database providers have had to interpret the procedure specification using the leg types available in the full ARINC 424 tool kit. This has resulted in the need for additional fixes (Computer Navigation Fixes (CNF)) to be defined in order to construct a best fit to the procedure path. In general, these aspects are transparent to ATC, but can result in path deviations under given conditions of aircraft type, configuration (weight, CG), FMS manufacturer, and wind. The RNAV system, whilst commanding path steering, may be restricted by built-in bank-angle or performance limits. The consequence of such limits may be a path deviation which may be recovered automatically or may require pilot intervention.

At all times, the conventional procedure, be it coded according to ARINC 424 or not, may be monitored by the flight crew against raw radio aid data, and the integrity of the navigation database is not really an issue. From the aircraft perspective, the safety of flight envelope is maintained, although separation from obstacles or other traffic may be eroded.

3.3.2 Comparison with Proposed Operations

If comparing to the Conventional Procedure in (a) above, the P-RNAV concept (step (d) above) is different in the following major respects:

i. Use of an aircraft navigation Database (DB) together with FMS/RNAV equipment onboard to fly the route

ii. More accurate and repeatable flying in the lateral dimension

iii. Use of non-ground-based Navaids, i.e. GNSS, possible

iv. Different procedure design criteria – RNAV criteria are considered more conservative as they take more account of the RNAV capabilities – bank angles are limited below 3000ft agl, actual path terminator performance is accounted for and the relationship between speed and turn performance is addressed more specifically. However procedure design is based broadly on similar principles of providing separation from obstacles based on fault-free performance distributions (3σ) of aircraft position plus use of appropriate buffers.

While i) and iii) are major differences, under fault free conditions, providing the procedure design criteria take account of RNAV and GNSS specific issues, the risk should not be increased. Indeed points ii) and iv) above suggest that fault-free risks could even be lower than current operations in the absence of failure.

If the P-RNAV concept is compared to the “Conventional Procedures” defined in steps (b) and (c) above, there is clearly less difference; the aircraft navigation DB and FMS/RNAV equipment onboard are already being used to fly the route. However, the introduction of P-RNAV in step (d) will introduce a number of potential risk benefits relative to (b) and (c) namely:

- A minimum standard for aircraft navigation functionality and integrity[2] [**1**].
- Defined and improved standards for navigation data integrity [**11**].
- Operational standards for P-RNAV approval [**1**].
- Detailed guidance to achieve consistency in the design and charting of TA procedures [**2**].

It should be noted that a VNAV capability is optional for P-RNAV. According to TGL10 Annex D it should be possible to fly a published profile manually given adequate flight deck information and with appropriate crew training. Procedure design takes this into account. Thus under fault free conditions, it is not considered that vertical profiles of aircraft will lead to an increased risk of obstacle collision relative to current operations.

3.4 Impact on the Operational Environment (Arg1.1.3)

The following points about the operational environment for P-RNAV are relevant:

- Aircraft separation minimum (MRS) are not changed from current TA operations.
- Route spacing minima are assumed not to change unless a comprehensive, appropriate[3] safety assessment of this change has been conducted.

[2] Also relevant for Arg1.5 in section 7

- Obstacle clearance is based on the same principles as conventional procedures.
- The introduction of RNAV needs to be accompanied by a review of the airspace structure to ensure that the sectorisation remains appropriate once the new RNAV procedures are adopted [**30**].
- Mixed mode issues – there is a perception from some controllers that the introduction of P-RNAV routes alongside conventional procedures could lead to increased workload. However, experience to date appears to show that this can be managed (see Arg. 1.3.2 below).

In addition, any potential impact on the main aviation safety nets should be considered:

- There should be no significant impact on the effectiveness of TAWS/ GPWS as obstacle clearance criteria have not changed and hence the relative position of aircraft to terrain will not be made more critical. There might be a possibility for new false alerts if P-RNAV routes are significantly different from established routes but this is true of introducing all new routes and is not specific to P-RNAV.
- There should be no significant impact on ACAS or STCA effectiveness as aircraft separation minima are not affected. Any potential for extra false alerts or reduced effectiveness due to any proposed changes in route spacing must be part of a local safety assessment on route spacing.

3.5 Key Functionality and Performance Criteria (Arg1.1.4)

A functional safety model and the functional operations of P-RNAV are described in full in section 2.1 and 2.2 of the P-RNAV safety assessment [**4**]. For each of the functions detailed performance parameters are defined in section 2.3 of the P-RNAV safety assessment.

Based on fault-free navigation performance, PANS-OPS and EUROCONTROL's Guidance Material for Design of Terminal Procedures [**2**] design procedures to ensure adequate clearance from obstacles and limit obstacle collision risk in fault-free operations. Route spacing criteria/ guidance in ICAO Annex 11 and EUROCONTROL documents [**5**] also take account of fault-free navigation performance although these studies are concerned primarily with the tails of the navigation position distribution which are typically dominated by the failure conditions covered in Arg1.5.

3.6 Conclusions (Arg1.1)

Given better defined lateral navigation under the P-RNAV concept, and the available documentary guidance concerning procedure design [**2** & **6**] and route spacing [**5**], it can be argued that obstacle collision and aircraft-aircraft loss of separation risk should be no greater, and potentially will be less, than under conventional navigation in the absence of failure.

[3] i.e. using Collision Risk Modelling

4. DESIGN COMPLETENESS (ARG1.2)

The objective of this section is to show that Safety requirements have been specified to cover everything, in terms of system design, that is necessary to fulfil the concept.

4.1 Strategy

The strategy for satisfying Arg1.2 is to provide evidence that the following lower-level arguments are true:

a) **Arg1.2.1** The boundaries of the system are clearly defined

b) **Arg1.2.2** The Concept of Operations fully describes how the system is intended to operate

c) **Arg1.2.3** Everything necessary to achieve safe fulfilment of the concept - related to equipment, people, procedures and airspace design - has been specified as safety requirements for each element of the system

d) **Arg1.2.4** All safety requirements on, and assumptions about, external elements of the end-to-end system have been captured.

4.2 System Boundaries (Arg1.2.1)

As well as defining the P-RNAV system at the functional level, the P-RNAV safety assessment also developed a physical (architectural) model of P-RNAV allocating equipment, procedural and people related aspects to each of the functions (see Appendix H of Ref. [**4**]). This clearly defines the boundaries of what has been considered in the P-RNAV concept.

4.3 Concept of Operations (Arg1.2.2)

There is no single generic Concept of Operations for P-RNAV. Rather a set of documents define the Concept.

The application of P-RNAV to Terminal Airspace will require that procedures are designed in accordance with the relevant requirements of PANS-OPS [**6**] and will take due account of the EUROCONTROL Guidance Material [**2**]. Procedures will be validated in accordance to Ref. [**9**] and flight tested following Ref. [**10**]. Aircraft operating on these procedures will be equipped and will operate on RNAV procedures in accordance with the JAA TGL 10 [**1**] or equivalent. Regional Supplementary procedures as set out in ICAO Doc 7030 [**7**] will be followed. The necessary training will be provided to aircrew [TGL10 section 10.5] and ATC [**8**] on the capabilities, requirements and limitations associated with RNAV operations. The navigation database will be from a supplier complying with ED76 [**11**]. Data origination will be covered by appropriate survey standards [**12**] and data handling up to AIP publication will follow best practices [**13**].

Given the wide variety of Terminal Airspace designs, it is likely that ANSPs will want to develop local Concepts of Operations to support their local safety assessments/ cases.

4.4 Concept Safety Requirements (Arg1.2.3)

Based on the functional and physical models noted in Args. 1.1.4 and 1.2.1, Functional Safety Requirements were developed for each sub-system as described in Ref. [**4**]. This involved a systematic and exhaustive process of allocating the safety functions among the groupings from the physical model below. This ensured that everything necessary to achieve safe fulfilment of the Concept was covered. The resulting Functional Safety Requirements (FSRs) are presented in Appendix F of the safety assessment (together with the corresponding Safety Integrity Requirements – see Arg. 1.5 below).

The FSRs are presented in the following groups.

The ***Aircraft Equipment*** group comprises the Airborne Navigation Receivers/Sensors, RNAV computer, VNAV computer option, Navigation Database and Flight Deck Displays.

The ***Air Operations Centre*** (AOC) includes the Flight Planning Facility and AOC Database.

The ***Aeronautical Information*** group comprises the AIS Data Provider, the Data House and Data Packer organisations and facilities.

The ***Air Traffic Control Equipment*** group comprises a selection of ATC equipments that typically contribute to the P-RNAV operation: Flight Data Processing System, Flight Progress System, Operational Display System, Arr/Dep Sequence Planning System, Conformance Monitor and Communication systems.

The ***Navigation Infrastructure*** group completes the physical elements of the configuration while the human resource and procedural elements are represented by the ***Flight Crew, ATC Controllers, and PANS-OPS Procedures*** groups.

Elements such as Autopilot, Radar Data Processing System, CFMU, air data sensor, transponder and radar heads have not been included as their functionality does not change as a result of P-RNAV and/ or they have no safety impact on P-RNAV operations.

4.5 External Elements (Arg1.2.4)

Those external parts of the ATM system that can act as mitigations have been accounted for in the safety assessment (see [**4**], Appendix A) in the determination of appropriate conditional probabilities for hazards becoming accidents. Other external elements are captured in the assumptions considered below under Arg 1.6.4.

4.6 Conclusions (Arg1.2)

This section has provided adequate Argument and supporting Evidence that the Concept system boundaries are clearly defined, its operation is clear at a generic high level, Functional Safety Requirements have been specified and external elements appropriately treated.

Local Concepts of Operations developed by ANSPs to support local safety assessments/ cases may be needed in addition to the generic material reviewed above.

5. DESIGN CORRECTNESS (ARG1.3)

The objective of this section is to show that the concept system design functions correctly and coherently under all reasonably foreseeable normal environmental conditions

5.1 Strategy

The main issues in this argument are the internal coherency and dynamic behaviour of the system over the full range of conditions expected in the operational environment.

The strategy for satisfying Arg1.3 is to provide enough evidence that the following lower-level arguments are true:

a) **Arg1.3.1** The design is internally coherent

b) **Arg1.3.2** The design functions correctly, in a dynamic sense, under all reasonably foreseeable normal operating conditions / range of inputs

5.2 Internal Coherency of the System Design (Arg1.3.1)

Interactions between functions and between sub-systems of the physical model have been considered in the safety assessment [**4,** section 2]. Initiation of each function with respect to the others was considered and the data flows between functions was comprehensively mapped to ensure data compatibility, compatibility of timings etc. No significant problems concerning internal coherency which could not be addressed through the derived safety requirements were identified in the safety assessment. The simulations and field data noted below provide additional evidence that the system design is internally coherent.

5.3 Dynamic behaviour of the Design (Arg1.3.2)

As noted in section 1.1 above, conventional Terminal Airspace procedures (including SIDS and STARS) have been flown using the RNAV functionality available on most modern aircraft, since the early 1980s. Thus there is considerable field operational data indicating that the proposed system can work dynamically. As noted in sections 1.1 and 3.3 use of overlays and "ad hoc" TA RNAV operations have caused some problems historically in terms of dynamic usage. However, use of procedures following PANS-OPS and EUROCONTROL's [**2**] design guidance have been shown to remove these problems. This has been evidenced in the successful implementation over the last seven years of RNAV STARs at Helsinki Vantaa and RNAV SIDs and STARs at Montpellier, Stockholm Arlanda, Lulea-Kallax Cargo Airport and Amsterdam Schiphol.

Additionally simulations, including, in particular, the 3 States real time simulation at the EEC in 2000 [**30**] have identified a significant workload reduction in an RNAV environment subject to the proviso that there is an adequate level of RNAV equipage and hence a limited need for mixed mode operations.

Flight inspection and validation ([**9**] and [**10**]) provide further assurance that the dynamic behaviour of the system will be safe.

5.4 Conclusions (Arg1.3)

This section has provided adequate Argument and supporting Evidence that the Concept system design functions correctly and coherently under all normal environmental conditions.

6. DESIGN ROBUSTNESS (ARG1.4)

The objectives of this section are to show that the Concept system design is robust against external abnormalities in the operational environment.

6.1 Strategy

The reaction of the system to abnormal events in its operational environment was considered from the following perspective:

- Can the system continue to operate?
- Could such conditions cause the system to behave in a way that introduces additional risks?

The strategy for satisfying Arg1.4 is to provide evidence that both of the following lower level arguments are true:

a) **Arg1.4.1** The system can react safely to all reasonably foreseeable external failures, i.e. failures in its environment / adjacent systems

b) **Arg1.4.2** The system can react safely to all other reasonably foreseeable abnormal conditions in its environment / adjacent systems

6.2 Reaction to External Failures (Arg1.4.1)

The safety assessments ([**4**] and [**14**]) considered:

- Lost comms
- Surveillance loss
- Aircraft failures not related to navigation
- Aircraft on-board emergencies

Consideration was given to whether P-RNAV operations had a negative impact on the effects of such external failures. No impacts were identified with one exception as described below.

The main extra issue related to these external failures is the impact of lost comms on the choice of open or closed procedures turning onto Final Approach. There are risk advantages and disadvantages associated with these two types of procedure and lost comms is a relevant failure that should be considered in local safety assessments.

6.3 Reaction to Other Abnormal Conditions (Arg1.4.2)

As noted in section 5.3 above, there is over 20 years of operational experience with RNAV operations; inevitably these operations will have experienced a range of conditions including abnormal conditions and probably external failures such as the ones analysed above.

In addition to this operational experience, the safety assessment [**4**] explicitly considered:

- Adverse weather
- False ACAS (& TAWS) alerts

In neither case were effects considered more severe due to P-RNAV operations. Aircraft operators and ANSPs will have standard operating procedures to cope with these conditions as appropriate.

6.4 Conclusions (Arg1.4)

This section has provided adequate Argument and references to supporting Evidence that the Concept system design is robust against external failures and other abnormalities in the operational environment.

7. MITIGATION OF INTERNAL FAILURES (ARG1.5)

The objective of this section is to show that all risks from internal failure have been assessed and mitigated sufficiently.

7.1 Strategy

Internal failure of the system is assessed from two perspectives:

- How loss of functionality would reduce the effectiveness of the system;
- How anomalous behaviour of the system could induce risks that might otherwise not occur.

The strategy for satisfying Arg1.5 is to provide evidence that the following lower-level arguments are true:

a) **Arg1.5.1** All reasonably foreseeable hazards have been identified.

b) **Arg1.5.2** The severity of the effects of each hazard has been correctly assessed, taking into account any mitigations that might be available.

c) **Arg1.5.3** Safety objectives have been set such that the corresponding aggregate risk is within the specified safety criteria

d) **Arg1.5.4** All reasonably foreseeable causes of each hazard have been identified

e) **Arg1.5.5** All external and internal mitigations have been captured as either safety requirements or assumptions as appropriate.

f) **Arg1.5.6** A risk assessment for each hazard has been carried out, showing that the aggregate risk is within the specified safety criteria.

7.2 Hazard Identification (Arg1.5.1)

A series of hazard identification workshops and post workshop analyses have been conducted for the P-RNAV safety assessment. A consolidated set of hazards is presented in Ref. [**4**] Appendix B and summarised below.

The previous FHA/ PSSA [**15**] conducted a systematic hazard identification exercise applying a set of 5 guide phrases to each of the 19 functions. The 5 guide phrases are shown in Table 7.1 along the top row. The previous hazard identification was reviewed as one of the tasks in the June 2007 P-RNAV safety workshop (see [**4**], Appendix B).

- The unshaded boxes in Table 7.1 represent hazards that were identified as relevant in the previous study which have been retained in the present study
- The grey shaded boxes represent hazards that were not carried forward in the previous study from hazard identification into the subsequent risk analysis either because they were unchanged by the introduction of P-RNAV or had no significant safety impacts or were not credible/ meaningful. These grey boxes have also not been carried forward in the present study.

- The yellow shaded boxes represent hazards that were not carried forward into the subsequent risk analysis last time, but which have been investigated this time with fault tree modelling. Loss of these 3 airborne functions are now considered valid hazards (A1.1, A3.1 and A4.1) that should be modelled in the risk assessment.
- The two blue shaded boxes represent hazards (B7.1 and B7.3) that were considered in the previous study, but which are actually not affected by P-RNAV and hence have not been analysed further.

Table 7.1 – Applicability of Potential Hazards

SF Ref	Function	Loss	Credible Corruption	Detectable Corruption[4]	Early	Late
01	Flight Path Definition	A1.1	A1.2	A1.3	A1.4	A1.5
02	Position Determination	A2.1	A2.2	A2.3	A2.4	A2.5
03	Navigation Data	A3.1	A3.2	A.3.3	A3.4	A3.5
04	Navigation Processing	A4.1	A4.2	A4.3	A4.4	A4.4
05	Flight Management Function	A5.1	A5.2	A5.3	A5.4	A5.5
06	Flight Control	A6	A6	A6	A6	A6
07	Vertical navigation	A7	A7	A7	A7	A7
08	Aircraft	A8	A8	A8	A8	A8
09	Sys Flight Plan Generation	B1	B1	B1	B1	B1
10	Sequence & Separation Planning	B2.1	B2.2	B2.3	B2.4	B2.5
11	Surveillance	B3	B3	B3	B3	B3
12	Tactical Separation Maintenance	B4	B4	B4	B4	B4
13	Flight Progress Monitoring	B5	B5	B5	B5	B5
14	Flight Interaction	B6.1	B6.2	B6.3	B6.4	B6.5
15	Co-ordination and Transfer	B7.1	B7.2	B7.3	B7.4	B7.5
16	Flight Plan Source	C1	C1	C1	C1	C1
17	P-RNAV Status	C2.1	C2.2	C2.3	C2.4	C2.5
18	Aeronautical Information	C3.1	C3.2	C3.3	C3.4	C3.5
19	Depart & Arrival Procedures	C4.1	C4.2	C4.3	C4.4	C4.5

7.3 Hazard Severity (Arg1.5.2)

To preserve consistency with the previous FHA/ PSSA [**15**] severity was judged relative to “Hazardously Misleading Information” (HMI) and “Loss of Nav information” which are covered by certification objectives in TGL 10. The rules followed were:

- If one aircraft is subject to credible corruption of critical nav/ position information/ HMI or an equivalent failure such that a deviation from intended path is likely it is denoted as H.

[4] In the risk analysis below detectable corruption is grouped together with “Loss”

- If multiple aircraft are subject to credible corruption of critical nav/ position information/ HMI or an equivalent failure such that simultaneous deviations from intended path are likely it is denoted as H+.
- If a single aircraft is subject to a lesser severity event or to a precursor to credible corruption of critical nav/ position information/ HMI it is denoted as H-.
- If one aircraft is subject to loss of critical nav/ position information it is denoted as L.
- If multiple aircraft are subject to loss of critical nav/ position information it is denoted as L+.

Applying these rules to the relevant hazards in Table 7.1, the severities in Table 7.2 were derived.

Table 7.2: Severity Classification

Hazard ID	Fault Tree ID	Effect Severity	Rationale/ Comment
A1.1	R01A – Loss of Path definition	L	Equivalent to Loss of Nav information from TGL10
A1.2	R01 – CC of Path Definition	H	Equivalent to HMI from TGL10
A2.1s	R05 – Loss of Position Determination – single aircraft	L	Equivalent to Loss of Nav information from TGL10
A2.1m	R02 – Loss of Position Determination – multiple aircraft	L+	Loss but potentially affecting several aircraft simultaneously
A2.2s	R03 – Credible Corr PD single ac	H	Equivalent to HMI from TGL10
A2.2m	R04 – Credible Corr PD multiple ac	H+	HMI but potentially affecting several aircraft simultaneously
A3.1	R06A – Loss of Nav Data Function	L	Equivalent to Loss of Nav information from TGL10
A3.2s	R06 – Credible Corruption of Nav Data function – single ac	H	Equivalent to HMI from TGL10
A3.2m	R07 – Credible Corruption of Nav Data function – multiple ac	H+	HMI but potentially affecting several aircraft simultaneously
A4.1	R08A – Loss of Nav processing	L	Equivalent to Loss of Nav information from TGL10
A4.2	R08 – Credible corruption of Nav Processing and Display	H	Equivalent to HMI from TGL10
A5.2	R09 – Credible corruption of Flt Management	H	Equivalent to HMI from TGL10 as could lead to deviation from ATC expectation
A5.5	R10 – Late operation of FLt Mgt	H-	Generally less severe than A5.2 as it is a delay rather than an immediate deviation
B2.2	RO11 – Credible corruption of Seq and Sepn	H	Equivalent to HMI from TGL10 as could lead to deviation from ATC expectation
B6.2	RO12 – Credible corruption of Flt Interaction	H	Equivalent to HMI from TGL10 as could lead to deviation from ATC

Hazard ID	Fault Tree ID	Effect Severity	Rationale/ Comment
			expectation
B7.2	RO14 – Credible corruption of Coordination and Transfer	H	Equivalent to HMI from TGL10 as could lead to deviation from ATC expectation
C2.2	RO15 - Credible corruption of PRNAV status	H	Equivalent to HMI from TGL10 as could lead to deviation from ATC expectation
C3.2	RO16 - Credible corruption of Aeronautical Information	H+	Equivalent to HMI but potentially affecting several aircraft simultaneously. Pessimistic as unlikely that multiple aircraft will deviate simultaneously.
C4.2	RO17 - Credible corruption of PRNAV procedures	H+	Equivalent to HMI but potentially affecting several aircraft simultaneously. Pessimistic as above.

For each of the severity classifications in Table 7.2 a conditional probability was estimated of the hazard becoming an accident. This process was based on historical data ([**4**], Appendix A).

7.4 Safety Objectives (Arg1.5.3)

In order to meet the overall TLS:

$\sum SOi \times CPi < TLS$

where SOi is the safety objective (maximum tolerable frequency) for Hazard i and CPi is the relevant conditional probability for Hazard i. This sum over the 19 hazards in Table 7.2 effectively forms a collective safety objective for the hazards. As the TLS is based on current TA risk levels, this collective safety objective ensures that P-RNAV risk will not be greater than current levels, thereby satisfying the first criterion in section 2.5 . In addition the frequencies of the hazards should be reduced as far as reasonably practicable to meet the second safety criterion in section 2.5.

7.5 Hazard Cause Identification (Arg1.5.4)

Comprehensive sets of causes were identified for each hazard based on safety workshops and post-workshop analysis. These causes were represented in fault trees for each hazard ([**4**], Appendix E). The base events of the fault trees were populated quantitatively using several data sources including:

- TGL10 – for onboard equipment failure rates. TGL10 provides certification objectives covering accuracy, integrity (credible undetected corruption or loss) and continuity of function (detected loss or corruption). Based on contacts with one manufacturer, it is likely that the in-service failure rates are significantly lower than the certification objectives set out in TGL10. However, in order to avoid making this generic safety assessment equipment type specific, and to ensure an element of conservatism in the risk results, the TGL10 values have been used.
- IRP/ CATS - EUROCONTROL's Integrated Risk Picture, IRP [**16**] and the Dutch Ministry of Transport's Causal Air Traffic Safety, CATS [**17**]

project have conducted considerable analysis of precursors to CFIT and Mid Air Collisions. Much of this analysis is based on accident and incident data. These data have been used in the safety assessment [**4**] primarily to populate pilot error related boxes and ATC related boxes on the Fault Trees. Typically there is a lack of alternative data for such causal factors.

- EUROCONTROL Database Studies - EUROCONTROL has commissioned a number of studies looking at the consistency of Nav data bases with each other and with AIP information (e.g. [**18**]). Experts who have been closely involved with these studies have been asked for estimates of errors arising at various points in the data chain.
- ANSP/ EATM data - ANSPs have been approached to obtain in-service failure rate data (detected loss and credible corruption) for ground Navaids. They have also been asked for similar information for GNSS. Their responses have been averaged before use in the fault trees. EATM were asked for data on the proportion of flights in ECAC which were unlikely to have runway updates and appropriate data were forthcoming.

These sources provide strong evidence for the credibility of the risk assessment and reduced the need for expert judgement unsupported by data to a very small number of base events. Procedure design, EUROCONTROL, ANSP and pilot expertise was used to obtain those remaining judgements.

7.6 Mitigation and Safety Requirements (Arg1.5.5)

The fault tree analysis allowed the estimated risks to be compared to the TLS. This showed that the estimated risk was within the TLS and hence the quantitative values in the fault tree could be considered compliant Safety Integrity Requirements (SIRs). These SIRs are presented in Appendix F of Ref. [4]. In addition, for each SIR practical mitigation measures have been summarised. This allows stakeholders to concentrate on these mitigation factors and demonstrate that accepted standards, guidance and good practice have been followed with respect to these mitigations.

Table 7.3: Summary of Mitigations to Support the SIRs

Elements	Hazards[5]	Main Mitigations
Flightcrew (FC) errors	**A5.2** **B6.2** **A1.2** A5.5	• Procedures and training contained in TGL10 plus state guidance (e.g. [**19**]) • Cockpit Resource Management (CRM) • Airborne certification including Human Machine Interface • Clear and unambiguous route and Waypoint (WP) naming conventions • Control of duplicate WPs • Use of standard RT phraseology • Risk assessing and controlling use of Direct Tos and tactical WPs • Harmonisation between WP names and procedure IDs used by pilots and ATC and between charts and Nav DBs • ATC technique (e.g. giving turn direction to help pilot Situational Awareness) • Minimisation of route complexity
ATCO Errors and FC interaction errors	**B2.2** **B6.2** **B7.2**	• ATC procedures and training • Use of standard RT phraseology • Risk assessing use of open v closed procedures onto final approach • Risk assessing and controlling use of Direct Tos and tactical WPs • Minimisation of route complexity
Data Quality	**A3.2s** **C3.2** **C4.2**	• Standards and guidance on data quality, including suppliers ED76 [**11**], origination [**12**], AIM [**13**], operators (JAR-OPS 1/3.035) • Procedure and flight validation [**9** and **19**] • Feedback loop from data house to originator. • Timely notification to users when errors are detected (NOTAM etc.) • Training and awareness for all data chain personnel. • Extra processes to compare raw data with output from data houses. e.g. NADIA [**18**] • ANSP or regulator to co-ordinate a review of the datahouse output after every major change • Operator spot checks concentrating on higher risk elements and changes [**19**] • Company policy on use of out of date NAV DBs (see draft TGL26).
Flight planning – P-RNAV status	C2.2	• Aircraft Operator (AO) flight plan procedures • AO pre-flight procedures, e.g. concerning late change of aircraft, checks by flight crew • FC procedures concerning RNAV failures and training • ATC procedures for transfer of information between sectors/ centres
Nav infrastructure failures	A2.1m A2.2m	• Design standards of navaids • In-service management including maintenance management of nav infrastructure (covering scheduling to protect critical navaids and including responses to failures). • Timely and accurate NOTAMs

[5] Hazards in bold show the main risk contributors – see Table 7.2 for hazard descriptors

Elements	Hazards[5]	Main Mitigations
Aircraft equipment failures	A1 – A4	• Airborne certification • Flightdeck contingency procedures • Flightcrew training

7.7 Risk Assessment (Arg1.5.6)

The safety assessment [**4**] shows that estimated risk under P-RNAV is below the TLS. In addition, a qualitative assessment was carried out based partly on a review of accident/ incident data in TA operations. Both quantitative and qualitative assessments indicate that there is no reason why P-RNAV operations would be expected to be higher risk than current TA operations. Safety requirements and mitigations identified in [**4**] will help ensure that this is the case and that risks have also been reduced as far as reasonably practicable.

7.8 Conclusions (Arg1.5)

With respect to internal failures, the generic safety assessment [**4**] has indicated that safety criteria should be met by the proposed P-RNAV concept, i.e. risks will not increase from current levels and they have been reduced as far as reasonably practicable. The linkage of the SIRs to practical risk mitigation measures allows stakeholders to concentrate on these mitigation factors and demonstrate that accepted standards, guidance and good practice have been followed with respect to these mitigations. That can then be used to demonstrate both to the stakeholders and the regulators that the safety criteria will be met at a local level as well.

8. SAFETY CASE PRACTICABILITY (ARG1.6)

The objective of this section is to show that the Safety Requirements which have been derived in the safety assessment [**4**] are practicable and achievable, and that all assumptions are valid.

8.1 Strategy

The strategy for satisfying Arg1.6 is to provide evidence to show that the following lower-level arguments are true:

a) **Arg1.6.1** All safety relevant aspects of the system have been captured as Safety Requirements or (where applicable) as Assumptions

b) **Arg1.6.2** All Safety Requirements are verifiable – i.e. satisfaction can be demonstrated by direct means (e.g. testing) or (where applicable) indirectly

c) **Arg1.6.3** All Safety Requirements are capable of being satisfied in a typical implementation in hardware, software, people and procedures.

d) **Arg1.6.4** All Assumptions have been shown to be necessary and valid

8.2 System Design (Arg1.6.1)

A comprehensive functional model was developed in the safety assessment [**4**]. The safety functions were then allocated in a systematic, traceable manner to the physical model. These models ensured that there are no gaps and that all the safety relevant aspects have been captured as FSRs or SIRs or Assumptions.

8.3 Verification and Satisfaction of Safety Requirements (Args 1.6.2 &1.6.3)

A number of issues were raised by stakeholders concerning the requirements in the previous version of the safety assessment [**15**] and safety argument [**3**]. As a result of these comments EUROCONTROL commissioned a re-verification/ re-validation project that has involved:

- Verifying the process by which the requirements were generated (see [**4**], section 3)
- Validating the FSRs via consultation with appropriate experts and through comparison to existing standards and guidance documents (see [**4**], Appendix F)
- Validating the SIRs by comparison against historic data sources and track keeping studies which provide frequencies of significant track deviations (see [**4**], section 3.8.6, Appendices C and F)

These activities have indicated that the revised requirements presented in Ref. 4 are practicable and achievable. Fulfilment of the requirements and/or the mitigations that support the SIRs, are all capable of direct verification by stakeholders.

8.4 Validity of Assumptions (Arg1.6.4)

A number of assumptions were made in the safety assessment [4] and these are addressed in Table 8.1 below. In addition, Table 8.2 addresses the assumptions made in TGL10.

Table 8.1: Safety Assessment Assumptions

Ref.	Description	Source/ Validation
A1	It is assumed that the current level of risk presented by conventional approaches and departures is tolerable.	Has formed basis for TLS (see [**4**] Appendix A). P-RNAV is not intended to lead to significant safety improvements – that is not the justification for its introduction. Rather it should tidy up the ad-hoc TA RNAV initiatives so far.
A2	It is assumed that the current separation minima between aircraft, in the horizontal and vertical dimensions, will apply under P-RNAV operations and that route spacing will not change.	None of Concept documents indicate a change [section 3.4 above]
A3	It is assumed that the requirements for obstacle and terrain clearance under P-RNAV will be as specified currently in ICAO Doc 8168 (PANS-OPS).	PANS-OPS
A4	It is assumed that airborne equipment fit is capable of P-RNAV performance in accordance with the defined standard for the area(s) in which operations are intended. This includes achieving lateral track keeping accuracy of better than +/-1NM for 95% of the flight time.	Eurocontrol Standard 003-93, TGL10 supported by historical studies which have shown this accuracy is achieved e.g. [**20**]
A5	It is assumed that the navigation infrastructure, both ground and space elements, meets with defined standards.	Annex 10 requirement
A6	Controllers will exercise similar levels of deviation detection performance as for that achieved using current techniques.	No requirement for enhancements relative to today
A7	P-RNAV procedures will be flown using GNSS or DME-DME.	If VOR/DME is used this will require a local safety assessment
A8	Where adequate GNSS or DME coverage is available it is assumed that the effect of any VOR source has a negligible adverse impact on position determination.	Based on equipment manufacturer information
A9	Before any VOR/ DMEs are removed from Terminal areas there will be a safety assessment of the impact on RNAV procedures (i.e. contingency arrangements in case of loss of RNAV capability, cross checking capabilities etc.)	Consistent with ECAC Navigation strategy [**28**]

The following assumptions are declared in TGL10, section 4.

Table 8.2: TGL10 Assumptions

Ref.	Description	Source/ Validation
A9	All terminal P-RNAV procedures: i. are consistent with the relevant parts of ICAO Doc 8168 PANS OPS ; ii. are designed following the guidelines of EUROCONTROL document NAV.ET1.ST10 ' Guidance Material for the Design of Procedures for DME/DME and GNSS Area Navigation' , as amended, or equivalent material; iii. take account of the functional and performance capabilities of RNAV systems and their safety levels as detailed in TGL10; *Note: Particular attention should be given to the constraints implied by the certification objectives of TGL10 paragraph 6.* iv. take account of the lack of a mandate for vertical navigation by ensuring that traditional means of vertical navigation can continue to be used; v. support integrity checking by the flight crew by including, on the charts, fix data (e.g. range and bearing to navigational aids) from selected waypoints.	i) Covered in the EUROCONTROL guidance on the design of P-RNAV Procedures [**2**] paragraph 1.1.5 ii) Covered in ref [**2**] section 4 (design factors), section 6 (development of procedures), section 8 (departure procedures), section 10 (arrival procedures) and section 11 (procedure descriptions). iii) Coverage in ref [**2**] of functional and operational requirements is **implied** by inclusion in its list of references EUROCONTROL Std 003-93 [**21**] and by para 1.3.2 references to DO236A [**22**]. Safety levels are covered in para 2.2.3. iv) Coverage in ref [**2**], is **limited** to use of VNAV in Final Approach v) Covered in ref [**2**], para 11.2.2 (m) and 11.3.7 (**l**)
A10	All routes/procedures are based upon WGS 84 coordinates and its realisation in ETRS 89 or equivalent.	Covered in the EUROCONTROL guidance on the design of P-RNAV Procedures [**2**], paragraphs 4.3.2.1.(e) and 4.4.2
A11	The design of a procedure and the supporting navigation infrastructure (including consideration for the need of redundant aids) have been assessed and validated to the satisfaction of the responsible airspace authority demonstrating aircraft compatibility and adequate performance for the entire procedure. This assessment includes flight checking where appropriate.	Covered in the P-RNAV Procedures safety requirements – see [**4**] reqt FSR-ADF04
A12	If the procedure allows a choice of navigation infrastructure, e.g. DME/DME, VOR/DME or GNSS, the obstacle clearance assessment has been based upon the infrastructure giving the poorest precision.	Covered in the EUROCONTROL guidance on the design of P-RNAV Procedures [**2**] para 2.7.1

Ref.	Description	Source/ Validation
A13	The required navigation aids critical to the operation of a specific procedure, if any, i.e. those which must be available for the required performance, are identified in the AIP and on the relevant charts. Navigation aids that must be excluded from the operation of a specific procedure, if any, are identified in the AIP and on the relevant charts.	Covered in the P-RNAV Procedures safety requirements – see [**4**] reqts FSR-ADF06 and FSR-ADF07
A14	Barometric altitude compensation for temperature effects is accounted for in accordance with current approved operating practices. (Temperature compensation is not addressed as a special P-RNAV consideration in this leaflet).	This reflects current practice
A15	The supporting navigation infrastructure, including the GNSS space segment, is monitored and maintained and timely warnings (NOTAM) are issued for non-availability of a P-RNAV procedure, if navigational aids, identified in the AIP as critical for a specific P-RNAV procedure, are not available.	Covered in the Navigation Infrastructure safety requirements– see [**4**] reqt FSR-NSS05 although this has modified the TGL10 assumption to NOTAM with respect to the navaid and not the procedure.
A16	For procedures which allow aircraft to rely only on GNSS, (see paragraph 5.1), the acceptability of the risk of loss of P-RNAV capability for multiple aircraft due to satellite failure or RAIM holes, has been considered by the responsible airspace authority. Similarly, the risk is considered where a single DME supports multiple P-RNAV procedures.	Covered in the P-RNAV Procedures safety requirements – see [**4**] reqt FSR-ADF08 & ADF09
A17	The particular hazards of a terminal area and the feasibility of contingency procedures following loss of P-RNAV capability are assessed and, where considered necessary, a requirement for the carriage of dual P-RNAV systems is addressed in the operational approval for the aircraft and, if appropriate, identified in the AIP for specific terminal P-RNAV procedures, e.g. procedures effective below the applicable minimum obstacle clearance altitude where RNAV is required for the safe recovery of the aircraft or where radar cannot be used for the purposes of providing guidance to an aircraft with a failed RNAV system.	Covered in the P-RNAV Procedures safety requirements – see [**4**] reqt FSR-ADF10
A18	Where reliance is placed on the use of radar to assist contingency procedures, its performance has been shown to be adequate for that purpose, and the requirement for a radar service is identified in the AIP.	Covered in the ATC Equipment safety requirements - see [**4**] reqt FSR-ADF11
A19	RT phraseology appropriate to P-RNAV operations has been promulgated.	Covered in the AGA safety requirements – see [**4**] reqt FSR-AGA01
A20	Navigation aids, including TACAN, not compliant with ICAO Annex 10, are excluded from the AIP.	This is a requirement of ICAO Annex 15

8.5 Conclusions (Arg1.6)

This section has provided adequate Argument and supporting Evidence that all relevant safety aspects have been captured as requirements or assumptions and that these have been verified/ validated as far as possible at this stage. The requirements have been shown to be realistic and assumptions have been shown to be valid.

9. RESOLUTION OF SAFETY ISSUES (ARG1.7)

The objective of this section is:

(i) To provide a consolidated list of the **issues** that have arisen both in the previous Safety Arguments and in this present document.

(ii) To show the current **status** of those issues.

9.1 Issues and Status

For historical interest, Appendix A of this document presents all the safety issues raised in previous versions of the Safety Argument together with their status. All issues have either been closed out or have been referred to existing standards/ guidance material. They are considered to be adequately covered if procedures are implemented in accordance with the existing standards and guidance.

In terms of new safety issues raised during the course of the current safety assessment update they are summarised below:

1. The update of TGL10 (AMC 20-16) should remove reference to VOR/ DME (current treatment of VOR/DME in TGL10 has caused considerable confusion).
2. The next revision of TGL-10 should also reword Section 4 assumption (g) to NOTAM out the navaid not the procedure. The pilot is responsible for knowing what the effect is of this critical navaid outage on planned procedure.
3. It is recommended that EUROCONTROL pursue the development of appropriate training material for dispatchers. In particular this training needs to ensure that navigation infrastructure, aircraft equipment and crew are appropriate and available for the intended P-RNAV operation.
4. It is recommended that EUROCONTROL updates the presentation made to the P-RNAV Implementation Issues Group (PRIIG) on September 27th 2007 concerning closed and open procedures to provide clear guidance as to the preferred method and further promulgates this through updating the procedure design guidance [**2**].
5. The FHA/ PSSA gave special consideration to stand-alone GNSS operators. It was concluded that ATC techniques currently being used when GA and heavier, faster traffic are mixed in Terminal Airspace would generally be sufficient to manage potential hazards. Potential extra mitigations, over these ATC techniques were identified as:
    a. Providing special routes for GA aircraft (e.g. special SIDs, STARs or transit routes); however, the practicability of this may be constrained by airspace considerations.
    b. States to provide guidance/ briefing material for GA pilots covering P-RNAV issues with special reference to use of GNSS.

10. BACKING EVIDENCE AVAILABLE (ARG1.8)

The objective of this section is to show that the evidence presented in the previous sections is likely to be trustworthy.

10.1 Safety Process

The safety assessment process is consistent with ESARR4 [**23**] and EUROCONTROL's Safety Assessment Methodology [**24**]. Appendix D of the safety assessment [**4**] maps the requirements of ESARR4 and shows how the P-RNAV work has complied with these requirements.

The process of preparing this safety argument has followed EUROCONTROL's Safety Case Guidance Material [**25**] and the latest guidance from EUROCONTROL's DAP SSH section of structuring a Preliminary Safety Case [**26**].

10.2 Personnel

The previous version of the Safety Argument [**3**] showed how competent experienced personnel had been responsible for developing the safety model, conducting the hazard analysis and reviewing the safety outputs. In the most recent review and update of the safety assessment [**4**] and argument, a safety workshop and review meetings with stakeholders have been held to obtain expert input. These meetings involved procedure designers, P-RNAV experts, pilots, former controllers and safety assessment practitioners (see Appendix B of [**4**]). The safety assessment practitioners have been involved in numerous previous safety assessments/ cases for EUROCONTROL and ANSPs.

11. LIMITATIONS

The following caveats apply to this Safety Argument and need to be considered in the context of the overall conclusions presented in Section 13 below.

- Many of the stakeholder comments on the previous version of the safety assessment/ argument concerned the potential problems if VOR/ DMEs are used for P-RNAV procedures. EUROCONTROL's procedure design guidance [**2**] is based on use of GNSS and/ or DME-DME. The forthcoming update of TGL10 (to AMC 20-16) is likely to remove VOR/ DME from the list of sensors. Hence this safety argument does not address use of VOR/ DME as an input to P-RNAV operations. A local safety assessment would be required if a P-RNAV procedure is based on use of a VOR/DME.
- If local P-RNAV Concepts of Operation differ from the functional model summarised in Ref. [**4**], section 2 or from the standards/ guidance documents listed in section 4.3 of this document, or if the assumptions in section 8 above are not applicable, a specific safety assessment should be conducted. Otherwise local safety assessments/ safety cases should be able to make considerable use of the generic material contained in the safety assessment [**4**] and this safety argument.
- A specific example of a variation from the assumption list would be a proposed change in route spacing. This should be subject to a local safety assessment and any impact on safety net effectiveness should be included in such an assessment.

12. IMPLEMENTATION, TRANSITION AND OPERATIONAL ISSUES (ARGS 2-4)

Sections 3 to 10 above have concentrated on Arg1, the specification of safe P-RNAV operations. In order for stakeholders to produce comprehensive local Safety Cases the following stages would be anticipated:

1. Review Arg1 above and the supporting safety assessment [**4**] to determine applicability to the local Concept of Operations. Adapt as necessary to include in local Safety Assessment/ Case.
2. To address Arg2, document how the requirements in Ref. [**4**] (plus any locally derived requirements) have been met in the local implementation within the local Safety Assessment/ Case. Where relevant make use of EUROCONTROL's P-RNAV "Implementation Methodology" [**27**] for this argument and for Transition.
3. To address Arg3, conduct a safety assessment (SSA) of the transition plan and derive safety requirements/ mitigations specific to the transition phase. Document the SSA and how the transition requirements have been met.
4. To demonstrate safety throughout the operational life requires the local stakeholders to link the safety assessments covering Arg1-3 to the Safety Management System (SMS) that will ensure ongoing safety. Of particular

importance will be monitoring systems to record and investigate incidents involving P-RNAV procedures. In addition, the SMS element covering risk assessment when a change is made will also be critical, e.g. when a proposal to decommission a Terminal VOR/ DME is made.

13. CONCLUSIONS

This document presents a structured analysis of the safety of P-RNAV operations, considering both fault free operations and failure conditions. The focus has been on the specification stage of the P-RNAV concept and the supporting evidence provided by existing standards and guidance documents and the P-RNAV safety assessment [**4**]. Safety requirements and mitigations have been determined which, if implemented, are predicted to ensure that risk will not increase from current TA levels and that risk has been reduced as far as reasonably practicable.

Guidance has been provided for how this material can be used in local Safety Assessments/ Cases.

14. REFERENCES

1. JAA Temporary Guidance Leaflet, TGL 10 - Airworthiness and Operational Approval for Precision RNAV Operations in Designated European Airspace, Rev. 1
2. EUROCONTROL NAV.ET1.ST10, Guidance Material for the Design of Procedures for Area Navigation (DME/DME, B-GNSS, Baro-VNAV and RNP-RNAV), Edition 3.0, March 2003.
3. EUROCONTROL (2005): "Safety Argument for Precision RNAV (P-RNAV) in Terminal Airspace", 9 March 2005, Version 2.0
4. EUROCONTROL (2007): "P-RNAV Safety Assessment, FHA and PSSA", July 2007, Version 1.1
5. DNV (2005): "Review of P-RNAV Route Spacing Safety Assessment", October 2005 version 0.1 for EUROCONTROL
6. ICAO Doc. 8168 "Aircraft Operations, PANS-OPS", Vol. II, March 2007, Edition 5
7. ICAO Regional Supplementary Procedures, EUR Region (Doc 7030/4).
8. EUROCONTROL Training Support Material – htttp://elearning.eurocontrol.int/IANS/NAV/prnav/prnav_free_access/index.htm
9. EUROCONTROL (2005): "Guidance Material for the Validation of RNAV Procedures", Edition 1, May 2005
10. EUROCONTROL (2005): "Guidance Material for the Flight Inspection of RNAV Procedures", Edition 3, May 2005
11. EUROCAE/ RTCA ED76/ DO200A "Standards for Processing Aeronautical Information"
12. EUROCONTROL (2007): "Integrity of Aeronautical Information – Aeronautical Data Origination", May 2007, version 3.1, ANT 43
13. EUROCONTROL (2003): "Integrity of Aeronautical Information – Principle and Guidance" v0.7, November 2003 and associated AIM series
14. DNV/ STASYS (2002): "System Safety Assessment and Development of the Safety Argument for the Use of P-RNAV in Terminal Airspace" Issue 2, May 2002
15. EUROCONTROL (2004): "EUROCONTROL P-RNAV Safety Argument, Functional Hazard Assessment & Preliminary Safety Assessment Review", 26th May 2004, Issue 1.0 by PRAXIS for EUROCONTROL
16. EUROCONTROL (2006): "Methodology Report for the 2005/2012 Integrated Risk Picture for Air Traffic Management in Europe", for EUROCONTROL, DNV Project No. C24209819/2, Revision 2 – 16 March 2006, (see Appendix III for MAC and Appendix V for CFIT)
17. DNV (2002): "Causal Modelling of Air Safety" final report for Ministerie van Verkeer en Waterstaat, Rev. 1, November 2002
18. Davidson (2006): "NADIA", Final Report for EUROCONTROL, Version 2.0, February 2006

19. UK CAA (2007): “Area Navigation (RNAV) – CAA Guidance Material”, FODCOM, 20/2007
20. EUROCONTROL (1988): “Navigational Accuracy of Aircraft Equipped with Advanced Navigation Systems”, EEC Report No. 216, June 1988
21. EUROCONTROL Standard 003-93 – Operational Requirements and Functional Requirements for Area Navigation Equipment
22. EUROCAE/ RTCA ED-75A/ DO-236A “Minimum Aviation System Performance Standards: Required Navigation Performance for Area Navigation”
23. EUROCONTROL (2001): “ESARR4 Risk Assessment and Mitigation in ATM”, Edition 1.0
24. EUROCONTROL (2006): “Safety Assessment Methodology SAM Electronic” v2.0
25. EUROCONTROL (2005): “Safety Case Development Manual”, Edition 2.0, September 2005Latest PSC guidance
26. EUROCONTROL (2007): “Generic Safety Argument for ATM Safety Assessment”, v1.0, May 2007
27. EUROCONTROL P-RNAV “Implementation Methodology” http://www.ecacnav.com/content.asp?PageID=85
28. EUROCONTROL Navigation Strategy for ECAC, NAV.ET1.ST16-001 Edition 2.0 dated 21 December 1998
29. DFS/ NLR (2002): “Identification of Requirements Associated with the Development of a System Safety Case for the Use of RNAV in the Execution of SIDS, STARS and Approach Procedures up to the Final Approach Fix”, Final Report, TRS/ 060/ 01
30. EUROCONTROL (2000): “3 States Real-Time Simulation”, EEC Report No. 347 Project SIM-S-E3 Issued: May 2000

15. GLOSSARY OF TERMS & ABBREVIATIONS

ACAS	Airborne Collision Avoidance System
ADF	Automatic Direction Finding Equipment
AIP	Aeronautical Information Publication
AIRAC	Aeronautical Information Regulation and Control (cycle)
AIS	Aeronautical Information Service
ANSP	Air Navigation Service Provider
AO	Aircraft Operator
AOC	Air Operations Centre
Arg.	Argument
ARINC	Aeronautical Radio Inc.
ATC	Air Traffic Control
ATCO	Air Traffic Controller
ATM	Air Traffic Management
ATS	Air Traffic Service
B-RNAV	Basic RNAV
CATS	Causal Air Traffic Safety
CG	Centre of Gravity
CNF	Computer Navigation Fixes
DB	Database
DME	Distance Measuring Equipment
EATM(P)	European Air Traffic Management (Programme)
ECAC	European Civil Aviation Conference
E/R	EUROCONTROL Response
ESARR	EUROCONTROL Safety Regulatory Requirement
EUROCAE	European Organisation for Civil Aviation Equipment
EUROCONTROL	European Organisation for the Safety of Air Navigation
FC	Flightcrew
FDPS	Flight Data Processing System
FHA	Functional Hazard Assessment
FL	Flight Level
FMS	Flight Management System
FPL	Flight Plan
FSR	Functional Safety Requirement

GA	General Aviation
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GPWS	Ground Proximity Warning System
GSN	Goal Structured Notation
HMI	Hazardously Misleading Information
ICAO	International Civil Aviation Organisation
ICARD	ICAO Codes and Route Designator System
ILS	Instrument Landing System
INS	Inertial Navigation System
IRP	Integrated Risk Picture
IRS	Inertial Reference System
JAA	Joint Aviation Authorities
JAR OPS-1	Joint Aviation Requirements OPS-1 Commercial Air
LNAV	Lateral Navigation
MASPS	Minimum Aviation System Performance Standard
MLS	Microwave Landing System
MOPS	Minimum Operational Performance Standards
MRA	Minimum Radar Altitude
MRS	Minimum Radar Separation
MSA	Minimum Safe Altitude
NAA	National Aviation Authority
NDB	Non-Directional Beacon
NOTAM	Notice to Airmen
OEM	Original Equipment Manufacturer
PANS-OPS	Procedures for Air Navigation Services Aircraft Operations
PANS-ATM	Procedures for Air Navigation Services – Air Traffic Management,
P-RNAV	Precision RNAV
PSSA	Preliminary System Safety Assessment
QA	Quality Assurance
RAIM	Receiver Autonomous Integrity Monitoring

RDPS	Radar Data Processing System
RNAV	Area Navigation
RNP	Required Navigational Performance
RTF	Radio Telephony
SARPS	(ICAO) Standards and Recommended Practices
SID	Standard Instrument Departure
SIR	Safety Integrity Requirement
SMS	Safety Management System
SOP	Standard Operating Procedure
SSA	System Safety Assessment
STAR	Standard Terminal Arrival Route
STCA	Short Term Collision Alert
TA	Terminal Airspace
TACAN	Tactical Air Navigation Aid
TAWS	Terrain Awareness and Warning System
TGL	Temporary Guidance Leaflet
TLS	Target Level of Safety
TMA	Terminal Control Area
TPINS	Transition Plan for the Implementation of the Navigation Strategy
TSO	(FAA) Technical Standard Order
VOR	Very High Frequency Omnidirectional Radio Range
WGS84	World Geodetic Reference System 1984
WP	Waypoint

APPENDIX A – STATUS OF ISSUES FROM PREVIOUS VERSIONS OF THE P-RNAV SAFETY ARGUMENT

TABLE A.1 – Issues From First Safety Argument

	Safety Issues	Explanation and Cross Reference	International/European Standards and Guidance Material	Current Status
1.	**Overall Standards/Guidance Issues and General Safety Management Issues**			
1.1	Need for update of standards and guidance material (specific issues are described in the rows below)	The need for updates has been identified in the safety studies, e.g. [Reference 14, paragraph 8.4] [Reference 29, paragraph R1, R8, B3 and D6]	EUROCONTROL does not anticipate any changes to TSOs, ACs, MOPSs or MASPSs. JAA has reviewed TGL 10 and in 2003 produced, with EUROCONTROL Assistance, additional supplementary interpretative material for regulators. Interpretative material addressed use of VOR/DME or INS/IRS, accuracy, integrity and continuity aspects, the requirement to manually deselect navaids and the relationship between the TGL and TSO 115, AC 9045A and AC 20-130.	Complete
1.2	Inconsistency between TGLs 2 and 10	The issues of training and RAIM are treated inconsistently in the two TGLs. [Reference 14, paragraph 8.3.1]	Consideration should be given to the review and harmonisation of TGLs 2 and 10 particularly in respect of: a) training for Flight Crew and airline operations ground staff (and contractors where applicable); and b) RAIM. The harmonisation of TGL 2 (ACJ20X4) and TGL 10 will not require changes to TGL 10. Any changes to TGL 2 will not impact the P-RNAV safety argument.	**Closed**, as far as P-RNAV is concerned, by incorporation of the training and RAIM requirements into the FSRs
1.3	System monitoring/ Incident reporting	TGL 10, section 10.4, describes incident reporting requirements. TGL 10 and JAR-OPS 1 emphasise the requirement to report incidents arising from equipment issues. However, deviations arising from human factors/ procedural issues should be treated equally seriously as these could highlight weaknesses in the overall system. [Reference 14, paragraphs 8.3.1 and	Consideration should be given to amending TGL 10/JAR-OPS 1 to encourage the reporting of occurrences caused by human factors and procedural issues. This would be consistent with ESARR 4. Incident reporting issues are not P-RNAV specific and there is a requirement for these in all ECAC States. There is a requirement for P-RNAV related incidents to be identified and analysed as part of a post-implementation monitoring process.	**Closed** by local stakeholders under Arg 4 – see section 12 of main report

	Safety Issues	Explanation and Cross Reference	International/European Standards and Guidance Material	Current Status
		8.3.8]		
1.4	Stepwise introduction of P-RNAV	P-RNAV has significant implications for regulators and service providers alike and should be introduced progressively. [Reference 14, paragraphs 8.2.3]	RNAV should be introduced in a Step-wise manner, as illustrated in the EUROCONTROL ATC Perspective document, throughout the industry as experience and confidence in procedures is built up.	Whilst a single date by which the work should be completed has been given, there is no attempt to require a single implementation date. Therefore this requirement is being met
1.5	Training (See also 1.2 above)	Training is an essential pre-requisite to P-RNAV implementation. It applies to all disciplines (Airspace/ Procedure Design; ATC; Commercial and General Aviation Pilots; Airline Ground Operations/Flight Planning/Flight Dispatchers and contractors; Database Providers). [Reference 14, paragraphs 8.2.6, 8.3.6, 8.3.7 and 8.3.8] [Reference 29, paragraphs C1 to C9, H3]	Regulatory requirements and guidance material recommendations regarding training need to be extended and strengthened for all disciplines as well as being harmonised across the disciplines. All authorities need to ensure appropriate training requirements are in place while all stakeholders need to demonstrate compliance with those requirements	**Closed** - by incorporation of the training requirements into FSRs
2.	**The Integrity and Accuracy of Data and Databases**			
2.1	Database contain errors	This issue is, at first sight, sufficiently covered by the relevant standards. There are, however, inconsistencies between these Standards, nor are they universally applied. Hence, this item cannot be deemed to be solved in practice and poses a major safety concern. [Reference 14, paragraphs 8.2.1 and 8.3.2] [Reference 29, paragraph A3]	a) Harmonisation of the Standards for database accuracy and integrity contained in ICAO Annex 15, ED 76 and TGL 10 and assured universal application of those Standards. *Note: Standards are in place but the extent to which database errors affect P-RNAV procedures has still to be established.* *The integrity and accuracy standards that are currently published in TGL 10 and Annex 15 should be sufficient for P-RNAV although may not be acceptable for RNAV approaches.*	**Closed** - by incorporation of the AI requirements into FSRs and SIRs Considered closed as data integrity issues addressed as far as practicable and further evaluation should be provided as part of the post implementation safety

	Safety Issues	Explanation and Cross Reference	International/European Standards and Guidance Material	Current Status
			However, EUROCONTROL and JAA should review existing integrity and accuracy standards. b) States to consider regulating to ensure that database standards are met. [Note: JAR 21, Production Organisation Approval procedures, when implemented, will have a significant influence in this area.] c) Wider aeronautical data comparison activity to be considered. *This is a possible means of improving the overall database integrity and is needed for validation AIP data whilst awaiting completion of the regulatory process on the origination, management and publication of AIP data* d) ICAO Annex 15 should be amended to require States/AIS AIPs to provide the ARINC 424 coding and so remove opportunity for ambiguity. (N.B. DFS disagree with this measure). e) Ensure data accuracy and integrity. *The advent of the EAD may support this requirement to some degree. The AIS AGORA website is also of assistance but will probably remain a need for data validation process to continue, prior to completion of the regulatory process.*	analysis
2.2	Published information for	Published information for RNAV	a) A review should be conducted to assess whether there is adequate charting guidance, e.g. identification	**Closed** - by incorporation of the procedure design

	Safety Issues	Explanation and Cross Reference	International/European Standards and Guidance Material	Current Status
	RNAV procedure unclear	procedure, including charting, is incomplete, insufficient or unclear. [Reference 14, paragraphs 8.3.4 and 8.4] [Reference 29, paragraph A5]	of RNAV procedure critical navaids, providing the co-ordinates for use of runway intersections and Quick Align points. *EUROCONTROL has produced Charting Guidance Material which addresses this problem. However, Annex 15 and Annex 4 are in the process of being updated and will cover these issues. . EUROCONTROL has drafted appropriate amendments.* b) Consideration should be given to ensuring the harmonisation of charting for RNAV procedures so that controllers and pilots use the same waypoint names.	requirements into FSRs
2.3**	Misinterpretation and errors during the database coding process	Concerns related to the provision of pre-described coding schemes in the AIP and errors by database coders. [Reference 29, paragraph A1]	a) Adequate training for the procedure designer is required to ensure proper navigation and FMS-system knowledge, their constraints and the ARINC 424 rules. *Requirement is already stated in Guidance Material. Commercial training courses exist.* b) Additionally, close co-operation between ANSP and the database provider on one hand and the database provider and the database packer on the other hand is urgently required.	**Closed** – by incorporation of the AI requirements into FSRs and the recommended mitigations in the safety assessment

	Safety Issues	Explanation and Cross Reference	International/European Standards and Guidance Material	Current Status
2.4**	VOR/DME require a different database coding	VOR/DME sensors require a *different* database / FMS coding than GNSS- and/or DME/DME based systems [Reference 29, paragraph [R5]]	*E/R - for final approach only; not applicable to P-RNAV.*	**No further action** required
2.5	Training for procedure designers	See 1.5 above. Training for Procedure Designers must also take into account the operational requirements of ATC. [Reference 14, paragraph 8.2.6]	Stakeholders should ensure that their procedure designers are properly trained. .	**Closed** - by incorporation of the training requirements into FSRs
2.6**	Wrong database is used	In particular, procedure changes via NOTAMs after their publication in the AIP may result in database problems. [Reference 29, paragraph A4]	The interaction between AIRAC and ARINC cycle needs to be improved. Stakeholders should avoid changes to RNAV procedures between AIRAC cycles unless absolutely essential.	**Closed** - by incorporation of the requirements into FSRs
3.	**RNAV Procedure Design**			
3.1**	Procedures have to be designed for the worst case scenario of the stated navigation sensors.	Software tool needed to validate navaid coverage and to support flight checks [Reference 29, paragraph R6]	a) A software tool is required to determine these worst case stations (I) for VOR in general (ii) for DME. *The current DEMETER tool now supports assessments in the terminal area.* *There is no commercially available flight check facility to check RNAV procedures The problem is that checking that coverage of all possible ground aids is time consuming using existing flight checking equipment* *EUROCONTROL is undertaking development of Flight Check guidance material and validating through the development of a prototype system leading to a MASPS for RNAV Flight Check systems.* *However, there is no reason why existing flight checking capabilities are not employed in the interim*	**Closed** - by development of Guidance Material by EUROCONTROL on Validation of RNAV Procedures and Flight Inspection of RNAV Procedures [Refs. 9 and 10]

	Safety Issues	Explanation and Cross Reference	International/European Standards and Guidance Material	Current Status
			although it is accepted that the overall checking task could be greater than if the flight check facilities were fully deployed. The safety requirements can therefore be met. *There may be advantages in improving DEMETER functionality. The flight check MASPS needs to be finalised and implemented.* Need to address training for procedure designers on this issue	
3.2	ICAO PANS-OPS requires pre-promulgation flight check for IFR procedures.	P-RNAV procedures and aircraft navigation systems flying them use a multiplicity of navaids to define the route. [Reference 29, paragraph R7]	The checking of the procedure could be lengthy if special facilities are not available	See 3.1 above.
3.3	AIP published procedure publication/calculati on errors	Procedures are being published with errors. [Reference 29, paragraph A-2] .	Note: ICAO Annex 15 requires AIS providers to have a QA system (ISO 9000 series compliant) which should avoid such problems. The availability of the required tools and appropriate training for procedure designers and pilots is required to ensure and demonstrate compliance with the standards..	**Closed** - by incorporation of the AI requirements into FSRs and the recommended mitigations in the safety assessment
3.4	Procedure complexity	Complex RNAV procedures with a large number of waypoints, are difficult for flight crew to interpret and increase the opportunity for errors. [Reference 14, paragraph 8.2.5]	Design RNAV instrument procedures with a minimum number of waypoints consistent with operational requirements and in accordance with guidance material. *Requirement that RNAV procedures are kept simple is already stated in Guidance Material*	**Closed** - by *Guidance Material*.
3.5	Use of closed procedures on to	Closed procedures, i.e. automatic turns on to final approach, increase the	Closed procedures, i.e. automatic turn on to final approach, should receive particular care in their design	**Closed** - by incorporation of the requirements into

	Safety Issues	Explanation and Cross Reference	International/European Standards and Guidance Material	Current Status
	final approach	opportunity for flight deck confusion and controller error. [Reference 14, paragraph 8.2.5] *E/R - Direct intercept of the final approach segment via an RNAV instrument approach is unacceptable for independent parallel approach operations. RNAV arrivals/approaches which include a non-ATC initiated turn from the downwind leg onto the final approach segment are not universally acceptable to ATC.*	in order to minimise the opportunity for error. *EUROCONTROL Guidance Material addresses.*	FSRs and safety assessment mitigation.
3.6	Waypoint naming confusion	Duplicates and similarities in waypoint names can cause confusion and database errors. [Reference 14, paragraph 8.2.5] *E/R - There is evidence of widespread duplication of waypoint 5 letter names and waypoint/navaid names (with 5 letters). All five letter names should be globally unique.*	*E/R - The Guidance Material already stresses the need for unique 5 letter waypoint names which is covered in existing ICAO requirements* *A process has been put in place to ensure the name duplication problem is resolved.*	**Closed**
3.7	Inconsistency between auto flight modes assumed in procedure design and in practice	This issue is subject to the operational approval of the operator. Hence standards and guidance do not have to cover this item. [Reference 29, A-6]	a) EUROCONTROL Guidance Material needs to be updated to bring to the attention of State regulators the importance of the required training for pilots to ensure that the assumptions in TGL 10 are met. Stakeholders must demonstrate that their pilots' training addresses FMS/RNAV capabilities and potential failure modes. *Procedure design for P-RNAV procedures assumes, as does TGL 10, manual flight following CDI/HSI.*	**Closed**

	Safety Issues	Explanation and Cross Reference	International/European Standards and Guidance Material	Current Status
3.8	Waypoints and significant points	This is closely related to 3.6 above. Currently ICAO Annex 11 implies but does not specify the relationship between waypoints and significant points. [Reference 14, paragraph 8.3.4]	The relationship between waypoints and significant points, and their status in ATS routes (Area Navigation Routes) should be clarified in ICAO Annex 11.	**No further action** required
3.9	SID/STAR naming convention (see also 8.1 below)	There is no clear and unambiguous way to differentiate between SIDs/STARs for RNAV and conventional navigation. [Reference 14, paragraph 8.3.4]	A meaningful, RNAV oriented SID/STAR naming convention should be developed. *Note: The existing convention is considered acceptable. An amended convention may bring some additional benefits.*	Closed - proposals already presented to ICAO
3.10	Waypoint naming convention	Closely linked to 3.6 above but the use of 3 numbers in waypoint names can be confused with headings and FLs. [Reference 14, paragraph 8.3.4]	European waypoint naming "convention" should avoid 0s and 5s (some states use 400+). [Note: Other conventions may also offer benefits. It is recognised that it is impossible to eliminate possibilities for confusion and that certain error modes may be location specific.] *Guidance material is clear on this point.*	**No further action** required
4.	**Aircraft Systems**			
4.1	+/- 1nm not required for all recognised P-RNAV sensors	The TGL 10-assumed accuracy is more stringent than the certification requirements in AC20-130 and TSO-C115. TGL 10, section 6.1, item (4) states that the achievement of the assumed accuracy, i.e. +/-1nm, has to be demonstrated at certification. [Reference 29, paragraph R1] *The performance values in AC 9045A,*	Harmonise the accuracy requirements of TGL 10, AC20-130 and TSO-C115. *Additional interpretative material provided by JAA.*	See 1.1 above **Closed -** All TGL10 assumptions are addressed in section 8 herein.

	Safety Issues	Explanation and Cross Reference	International/European Standards and Guidance Material	Current Status
		TSO 115 and AC 20-130 may not be wholly equivalent to that required in TGL 10. This is mainly due to the different environments for which the documents were written. TGL 10 assumes that: the design of a procedure and the supporting navigation infrastructure (including consideration for the need of redundant aids) have been assessed and validated to the satisfaction of the responsible airspace authority demonstrating aircraft compatibility and adequate performance for the entire procedure. This assessment includes flight checking where appropriate. As a result, "Provided that the assumption ... has been shown to be valid in respect of typical DME performance, then, for RNAV systems that have been declared (e.g. in the Aircraft Flight Manual) to be compliant with the 2D navigation accuracy criteria of FAA AC 90-45A, AC 20-130(), FAA TSO-C115(), or JAA JTSO-2C115(), the intent of this paragraph is considered as satisfied and no further accuracy demonstration is required. "		
4.2	Different behaviour of Flight Management System	Different behaviour of Flight Management System in TMA-mode (low altitude) compared to en-route (high altitude), and there is no uniform transition (both ways). [Reference 14, paragraphs 8.2.2 and 8.4] [Reference 29, paragraph B-2]	a) Although there is an intermediate solution practicable, the long-term solution requires RF-leg compatible FMSs and ARINC 424 coding rules, respectively. b) Ensure the compatibility of current standards for FMS/RNAV turn algorithms with P-RNAV airspace and	

	Safety Issues	Explanation and Cross Reference	International/European Standards and Guidance Material	Current Status
		E/R - This item relates to the differences in turn performance between FL100 and FL220 resulting from different interpretations of the RNP-RNAV MASPS by the 2 major OEMs. This problem will probably only be resolved with the mandatory (?) use of RF and FRT for ATM critical turns. This issue must be taken into account by the designers.	ATC operational requirements. c) The applicability of current certification standards, particularly in relation to High Altitude Turn Transitions, for FMS should be reviewed given that the transition bi-sector is not defined by any Terminal Airspace procedure limits and could be as low as FL120 in certain circumstances. *The EUROCONTROL Guidance Document updated. Additional waypoints must be used to prevent early turns in places where this may cause difficulties to ATC.*	**Closed**
4.3**	Varying on-board aircraft systems capabilities	VOR/DME and INS/IRS can neither be considered to be covered sufficiently by the standards and guideline documents nor it is expected that the open issues may be closed to comply with the TGL 10 performance requirements. [Reference 29, paragraph B-3]	The variation in performance of the RNAV/FMS systems in respect to the use of navaids is in part a result of the lack of firm requirements at the time these systems were built, the developments that have occurred over the last 20-30 years period and the fact that equipment in use may be up to 30 years old. *TGL 10 lays down the minimum requirements. The limitations of the minimum equipment requirement in TGL 10 are covered if the guidelines are followed*	**Closed.** Use of VOR/ DME is ex-scope from current safety assessment/ argument. If used would need to be covered in local safety assessment/ case.
4.4**	Aircraft performance does not allow procedure to be flown correctly	Failure to adhere to the requirements of the EUROCONTROL Guidance document can result in procedures being unflyable. [Reference 29, paragraph A-1] *E/R - This is a procedure design issue which applies to all procedures.*	*Guidance material adequate*	**No further action** required
4.5**	Multiple aircraft lose RNAV capability at the	This may result from GPS failure or interference and ATC are unaware of actual RNAV performance of other	*TGL 10 assumes that the ATSP has reviewed the impact of such failures: The particular hazards of a terminal area and the feasibility of contingency*	**Closed** - by incorporation of the requirements into

	Safety Issues	Explanation and Cross Reference	International/European Standards and Guidance Material	Current Status
	same time	sensors. [Reference 29, paragraph E-1] *E/R - Widespread loss of RNAV capability through navaid outages such as GPS jamming, or DME failure in a region which has sparse DME coverage, is an issue.*	*procedures following loss of P-RNAV capability are assessed and, where considered necessary, a requirement for the carriage of dual P-RNAV systems is identified in the AIP for specific terminal P-RNAV procedures, e.g. procedures effective below the applicable minimum obstacle clearance altitude, or where radar performance is inadequate for the purposes of supporting P-RNAV.*	FSRs
4.6**	VOR/DME criteria are tailored to one specific receiver type	The ICAO PANS OPS criteria for VOR/DME do not take account of the capability of many VOR/DME based RNAV operations [Reference 29, paragraph R3] *VOR/DME is only normally used as a reversion mode(although at short rand VOR/DME accuracy can be better than DME/DME) . The existing VOR/DME criteria are considered to be adequate to cater for this application. Particularly as the designer must always use the larger of the protection areas associated with VOR/DME, DME/DME and Basic GNSS.*	*EUROCONTROL procedure design guidance provides adequate guidance to procedure designers* *Whilst the VOR/DME criteria were designed for VOR-mover equipment, the resultant obstacle identification surfaces are conservative and the current VOR/DME RNAV systems are considered to be adequately protected.* *The EUROCONTROL Procedure Design Guidance material identifies that Procedures are to be designed taking into account the lowest performance system allowed to be used on the procedure*	See item 4.3 above
4.7	Flightdeck map display and pilot interface to RNAV system	Operating RNAV without a map display can result in loss of situational awareness particularly if cross referencing using conventional navaids is not possible. [Reference 14, paragraphs 8.3.5 and 8.4] [Reference 29, paragraph E-4]	a) A flight deck map display would significantly aid flight crew situational awareness, however, there could be issues of space, weight and cost for some aircraft types. b) The introduction of enhancements to flight deck map displays, e.g. display other RNAV routes, would improve flight crew situation awareness. Such enhancements would, however, need careful	Complex procedure to be avoided where possible to ease the situational awareness problems for the non-equipped aircraft. [?] refers and no further action needed

	Safety Issues	Explanation and Cross Reference	International/European Standards and Guidance Material	Current Status
			management in order to prevent the display becoming too cluttered. [Note: These flightdeck equipment upgrades were identified as low priority items in the risk assessment] In the immediate future decommissioning of VOR not being considered so the removal of the ability to cross reference conventional Nav aids not an issue	
4.8	System redundancy	System redundancy - an assumption in TGL 10 is that the particular hazards of a TA and the feasibility of contingency procedures following loss of P-RNAV capability are assessed and, where considered necessary, a requirement for the carriage of dual P-RNAV systems is identified in the AIP for specific P-RNAV procedures. The benefits of such a measure will be related to the probability of loss of navigation function. The lower this probability for single systems the lower the benefits of requiring a dual system. [Reference 14, paragraph 8.3.5]	Already addressed in TGL 10.	**No further action** required.
4.9	Other aircraft equipment issues	A multi-sensor navigation capability clearly offers benefits from the viewpoint of failures affecting both single and multiple aircraft in the airspace.) [Reference 14, paragraph 8.4] Quick Align provides the pilot with a rapid method of aligning the INS/IRS with current position. [Reference 14, paragraph 8.4]	None of these potential equipment enhancements offered such clear benefits relative to practicability problems that they merit addressing in guidance material or standards. Individual stakeholders may consider equipment upgrades as part of their demonstration that risks have been reduced as far as reasonably practicable	**No further action** required.

	Safety Issues	Explanation and Cross Reference	International/European Standards and Guidance Material	Current Status
		The increased use of datalink would be a useful safeguard against some of the failure modes related to departure clearance errors. [Reference 14, paragraph 8.4] Runway auto-updating to reduce the opportunity for manual initialisation errors. [Reference 14, paragraph 8.3.5]		
5.	**Flightdeck and Airline Operations Issues**			
5.1**	Pilot actions, when proceeding past the last cleared waypoint	This leads to unpredictable aircraft behaviour and is not yet covered by the international standards and guideline documents. [Reference 29, paragraph C-9] *E/R - This issue is equally applicable to non-RNAV operations but, in the interests of safety and harmonisation, it was agreed that additional guidance material may be necessary.*	*Issue addressed in the ATC and pilot training*	**Closed** - by incorporation of the training requirements into FSRs
5.2	Clearance to a waypoint outside the normal procedure	Clearance to a waypoint outside the normal procedure leads to increased pilot workload and potential for errors. [Reference 14, paragraph 8.2.6.1] [Reference 29, paragraph C-5] *E/R - This is a specific RNAV application that must be covered during training.*	Clearances to waypoints which are not charted on the actual procedure chart are not yet covered by the international standards and guideline documents. Thus ICAO PANS OPS Vol. I, ICAO Doc. 4444 and/or Doc. 7030 require amendments, accordingly. a) Pilot and controller training addressed use of tactical waypoints and constraints. b) Appropriate training for procedure designers and	*Closed but the reporting of RNAV incidents should identify if the existing guidance is sufficient/appropriate*

	Safety Issues	Explanation and Cross Reference	International/European Standards and Guidance Material	Current Status
			close co-ordination between the procedure designer and the database provider/packer and adherence to the ARINC 424 rules are required.	
5.3**	High pilot workload may lead to errors	High pilot workload (head-down time) may cause deviation from RNAV procedure or inability to sustain RNAV navigation [Reference 29, paragraph C-6] *E/R - While this is agreed to be a true statement, the degree of pilot workload depends upon the complexity of the RNAV procedure and the methods by which the ATC improve traffic flow through "direct to" clearances.*	Appropriate pilot training is required to cope with the potential hazards of database driven systems. *Training requirement and the need to restrict design complexity are already identified in the existing standards.*	**Closed**
5.4	General aviation pilot education/training - little control on standardisation	The JAA (and NAAs) have not specified, and have little control on, standardisation for checking/training in the use of RNAV/GPS equipment and procedures for GA pilots. [Reference 14, paragraph 8.3.6] [Reference 29, paragraphs H-3 and C-6]	JAA and EUROCONTROL need to consider the requirement for an education/monitoring system, suitable for pilots of General Aviation (GA) and aerial work aircraft with an RNAV capability which, currently, fall outside the TGL training and approval process. States to demonstrate compliance with any training requirements that are promulgated.	CD Education material addresses needs of all airspace users
5.5	Terrain clearance responsibilities	See 6.1 below. [Reference 14, paragraph 8.2.4]	See 6.1 below.	See 6.1 below.
5.6	Training of pilots with respect to specific hazards	The following activities were associated with high risk failure modes and hence should be covered in training:		**Closed** - by incorporation of the training requirements into FSRs

	Safety Issues	Explanation and Cross Reference	International/European Standards and Guidance Material	Current Status
		• Potential flight planning problems (particularly in mixed mode environment) • Runway/ position updating • Mode selection errors • Navaid unavailability • Contingencies • Cross checking with raw data • Flight plan selection and revision • Use of non-official waypoints • Mistaking fly over and fly-by waypoints • Failing to remove database restriction [Reference 14, paragraphs 8.2.6 and 8.3.6] [Reference 29, C-3, C-4, C-7 and C-8]		
5.7	Flight planning	Need for operator procedures and training to be updated [Reference 14, paragraphs 8.3.8]	a) Airline/operator procedures for recording navigation equipment on Flight Plans need to be revised in accordance with the proposed amendment to new ICAO Doc. 7030 Serial No.: EUR/NAT-S 01/48-EUR RAC/16). b)Training of airline operations ground staff (and contractors) needs to include IFPS rules and the importance of ensuring the flight plan has the correct RNAV capability.	**Closed -** by incorporation of the training requirements into FSRs

	Safety Issues	Explanation and Cross Reference	International/European Standards and Guidance Material	Current Status
6.	**ATC Issues**			
6.1	Responsibility for terrain clearance by a 'direct to' not clear to all ATCOs and pilots	Experienced controllers and airline pilots identified a lack of clarity regarding their terrain clearance responsibilities particularly in relation to "direct to" clearances. For controllers, the interpretation varies from state to state. [Reference 14, paragraphs 8.2.4 and 8.2.6.2] [Reference 29, paragraph D-5] *E/R - The ICAO regulation on responsibility for terrain clearance is unequivocal. However, pilots are not always in the position to establish minimum safe altitudes when given "direct to" clearances to RNAV waypoints. In such cases pilots should not accept the clearances. This is a training issue that will be alleviated when Minimum Flight Altitudes/MRVA on charts becomes widespread.*	Terrain clearance responsibilities need clarification. ICAO Doc. 4444 and states' national ATS manuals should be amended to clearly specify controllers' responsibilities for terrain clearance depending upon type of service being provided and type of surveillance display system used. The proposed revision to ICAO Doc. 7030, Serial No.: EUR/NAT-S 01/48-EUR RAC/16 addresses this problem; this needs to be translated into appropriate ATS instructions and training material for controllers and flight crew. *ICAO Doc 7030 and other ICAO provisions clearly define the requirements.* *ICAO Doc 4444 PANS-ATM para 8.6.5.2:* *When vectoring an IFR flight and when giving an IFR flight a direct routing which takes the aircraft off an ATS route, the radar controller shall issue clearances such that the prescribed obstacle clearance will exist at all times until the aircraft reaches the point where the pilot will resume own navigation.*	**Closed** - by incorporation of the training requirements into FSRs
6.2	Possible errors in use of tactical waypoints	The use of tactical waypoints that are not on the RNAV procedure or are unfamiliar to pilots can cause a loss of situational awareness or pilot errors resulting in aircraft manoeuvring in an unexpected fashion. [Reference 14, paragraph 8.2.6.2] *This error is only likely to occur when the controller modifies the original procedure by issuing an instruction*	*There is no clear guidance for either the procedure designer or the controller on the use of tactical waypoints. EUROCONTROL to consider what additional guidance material is necessary.*	Closed – tactical waypoints are only used where their safe application can be demonstrated.

	Safety Issues	Explanation and Cross Reference	International/European Standards and Guidance Material	Current Status
		direct to a waypoint that is out of sequence. The error will occur if the aircraft is cleared to the wrong waypoint or if the aircraft proceeds to the wrong waypoint or if the modified route is not flyable or if the waypoint cannot be retrieved.		
6.3	ATCO gives clearance incompatible with aircraft equipage	An aircraft could be cleared to use a RNAV procedure for which it is not equipped if controllers are not provided with the relevant information. This also relates to 6.4 below. [Reference 14, paragraph 8.3.3, 8.3.11, 8.4] [Reference 29, paragraph D-2] *This envisages a mixed P-RNAV/B-RNAV environment. (See P-RNAV AIC para 3.6). The advent of P-RNAV together with the revised FPL and the ATS Automated Systems Adaptations for the display of information on individual aircraft equipage should reduce the incidence of such errors.*	ICAO and EUROCONTROL need to address the issues of flight planning and display of information to controllers with regard to the different levels of RNAV (i.e. B, P, and RNP). a) The opportunity for issuing inappropriate RNAV clearances could be significantly reduced if FDP Systems assigned routes to aircraft, and displayed the information to the controller, automatically as a function of the aircraft navigation capability included in the FPL/RPL. b) Minimise the mix of P-RNAV and B-RNAV routes in TA. In reality, practical constraints should minimise this in any case. See also 6.4 below.	**Closed -** by incorporation of the flight planning requirements into FSRs
6.4**	ATCO forgets to control conventionally equipped aircraft in mixed environment	A mix of monitoring and controlling can result in controller confusion and error. A mixed environment of conventionally, P- and B-RNAV equipped aircraft can also result in the issue of incompatible clearances. [Reference 29, paragraph D-3]	EUROCONTROL Guidance material seeks to discourage mixed modes of operation. *However mixed mode is inevitable in the existing timescales. Training material covers the issue of mixed modes operations. The mixture of modes of operation will remain until RNAV is mandated in terminal airspace but it is expected that he occurrence of conventional operations will be reduced rapidly over*	**Closed -** by provision of training material

	Safety Issues	Explanation and Cross Reference	International/European Standards and Guidance Material	Current Status
			the next few yeas.	
6.5	Navaid outages	The relationship between navaids and procedure is very different for RNAV procedures. The outage of a single navaid may suspend a conventional procedure whereas a series of outages is likely to be needed before an RNAV procedure is suspended. [Reference 14, paragraph 8.3.7] See also 3.1 and 3.2 above.	*The DEMETER tool allows assessments to be made of the anticipated coverage. The planned Flight Check facility should validate these assessments.* a) Implementers should assess the effect of navaid outages. b) The ATC response to navaid outages should be included in RNAV awareness education given the different relationship between navaids and procedures in an RNAV environment. c) Training with respect to navaid outages and identification of critical navaids should be given to procedure designers and flight planners. d) ATSPs need to develop, as part of their Safety Management System (SMS), a policy/ methodology on how to react to navaid failure outside their managerial control, including navaids outside their FIR, or navigation system failures affecting multiple aircraft (e.g. GNSS). *An assessment of the impact of navaid failures should be made* See also 3.1 and 3.2 above.	**Closed** - by incorporation of the requirements into FSRs and guidance material under issue 3.1 above
6.6	Complex switching between RNAV and all radar vectors	Switching between RNAV and all radar vectors, either for individual aircraft or all can cause confusion to controllers (and pilots). See also 6.4 above. [Reference 14, paragraph 8.4]	There is a distinct need for a sound Operational Concept for the introduction of RNAV in the TMA with acknowledgement of the actual system capabilities. *The Guidance Material already stresses the need for*	**No further action** required. Local ConOps expected to cover this issue.

	Safety Issues	Explanation and Cross Reference	International/European Standards and Guidance Material	Current Status
		[Reference 29, paragraph D-6] *E/R - There is a danger that controllers and pilots will be confused by over-complex procedures. This is a design and training issue. See also 3.4 above.*	*designers to co-ordinate closely with the ATC during the design phase.*	
6.7	ATC "sectorisation"	Poor procedure design or lack of appreciation of aircraft turn characteristics can compromise separation safety margins designed into sectorisation and airspace management. [Reference 14, paragraph 8.4]	The ATC "sectorisation" of TA and RNAV route planning should take account of the performance characteristics of P-RNAV aircraft. An assessment involving all relevant disciplines should be conducted prior to implementation of P-RNAV routes and/or related airspace. *This is already covered in the guidance material.*	**Closed**
7.	**Ground Systems**			
7.1**	Coverage by navigation infrastructure	Coverage by navigation infrastructure (e.g. VOR/DME or DME/DME) is not sufficient to allow the RNAV system to continuously compute its position with the desired accuracy. [Reference 29, paragraph A-1] [Note: The navigation infrastructure for TA is the subject of a separate EUROCONTROL study contract.]	TGL 10 should be reviewed and amended as, currently, it partially calls up inappropriate standards and assumes inappropriate prerequisites for the other RNAV positioning sensors. *E/R - See 1.1, 3.1, 3.2 and 4.1 above.*	See 1.1, 3.1, 3.2 and 4.1 above
7.2**	Use of offset DMEs by RNAV system	As long as pilots have no influence on which DME station will be used by the RNAV equipment, offset DMEs pose an unsolved safety concern. [Reference 29, paragraph G-1]	This is not considered a real issue. They should not be selected for the database if the FMS cannot use them. Some FMSs can successfully deal with offset DMEs while many do not use any DMEs associated with ILS for DME/DME navigation. Off-set DMEs are not widely used outside the UK.	**Closed no action**

	Safety Issues	Explanation and Cross Reference	International/European Standards and Guidance Material	Current Status
7.3**	Use of TACAN information and pre-1989 DMEs	There are discrepancies between a) the certification baselines and current avionics and b) the relevant regulatory material. [Reference 29, paragraph G-3] *E/R - The existing DME/DME obstacle clearance criteria are based upon the performance of pre-1989 DMEs. There is a clear ICAO requirement for any TACANs which are published in the AIP to meet the pre-1989 requirements. The database providers are only authorised to provide data from official government sources - viz the AIP.*	a) It still has to be determined, whether DMEs commissioned prior 1989 could be excluded from current navigation databases, and which impact this would have on the radio update capabilities. *DME Equipment only meeting the Pre 1989 requirements should not prevent attainment of 1 N Mile accuracy* b) Action is needed to resolve the discrepancies between; i) the certification baselines and current avionics on one hand and ii) the assumptions in the EUROCONTROL Guidance document, TGL 10 and ICAO PANS OPS. *E/R - The database providers should NOT provide any information on TACAN stations that are not published in the AIP unless specifically authorised by the State responsible for the TACAN.*	**Closed** - by incorporation of the requirements into FSRs
7.4	OLDI requirements	Any change after departure in the RNAV capability of an aircraft currently needs to be the subject of a separate, manual inter-centre co-ordination message. This could be forgotten too easily if OLDI is normally used. [Reference 29, paragraph 8.3.9]	The requirements of the EUROCONTROL OLDI Standard need updating to enable changed RNAV information to be updated. ATSPs' should ensure: a) That their Flight Data Processing (FDP) systems can process, transmit and display aircraft RNAV capability. b) Compliance with a revised OLDI Standard.	**No further action** required.
7.5	Decommissioning navaids and	TGL 10 requires flight crews to cross check the RNAV solution with raw	The TGL 10 requirement is compatible with the EUROCONTROL Navigation Strategy which does not	**Covered in the Nav**

	Safety Issues	Explanation and Cross Reference	International/European Standards and Guidance Material	Current Status
	requirement to cross-check RNAV solution with raw nav data	navaid (e.g. VOR/DME) data. [Reference 14, paragraph 8.3.10]	foresee the total decommissioning of VOR before the P-RNAV requirement is replaced by the requirement for the carriage of appropriate RNAV systems When evaluating the possible removal of navaids, consideration should be given to the impact for cross checking RNAV solutions using raw navigation data.	**Strategy – closed**
8.	**Communications**			
8.1**	Conventional arrival and RNAV arrival have similar identifications [See also 3.9 above.]	Conventional arrival and RNAV transition have similar identifications, which leads to: a) Confusion with the pilot (not sure which clearance is given by the controller), or with the controller (not sure which arrival / transition the aircraft will follow, even after pilot confirmation). b) Too long R/T to identify the correct transition c) Ambiguity over which vertical profile to follow for the pilots [Reference 29, paragraphs F1 to F3]	International standards and guidance documents need to address this issue. A harmonised Operational Concept is required. The R/T has to be adopted accordingly.	Closed – avoid the use of common names for different procedures
8.2	RTF phraseology concerning turn direction	A “Direct To” clearance can cause aircraft to turn in an unexpected direction due to the relationship between aircraft heading and desired track. (Reference 14, paragraph 8.3.1) *E/R – The inclusion of a turn direction when issuing a “direct to” clearance can improve pilots’ situational awareness.*	Consideration should be given to amending ICAO Doc. 7030 with additional RTF phraseology to include turn direction when issuing “Direct To” clearances (as with a radar vector) to aid pilots in detecting unexpected turns. *E/R - EUROCONTROL to consider what additional regulatory or guidance material is necessary (PANS-ATM, ATC Guidance and Procedure Design Guidance)*	No action considered appropriate at the present time. If ATC need to defined the turn direction existing phraseology can be applied

TABLE A.2 – Issues From Safety Argument (v2.0)

Issue	Section Reference[6]	Comment	Status
Use of Offset DME	9.3.1	Covered in 7.2 in table above	No further action needed
Retention of VOR	9.3.2	Covered in 7.5 in table above	No further action needed – however, extra text added in main report section 12 to highlight this issue
Integrity of Aeronautical Information	9.3.3	Covered in sections 2 and 3 in table above. Also covered in FSRs and SIRs in updated safety assessment.	No further action needed
Reliance on GNSS	9.3.4	Covered already in TGL10 and FSR ADF08	No further action needed
Critical DME	9.3.5	Covered already in TGL10 and FSR ADF09	No further action needed
Requirements for Dual P-RNAV Systems	9.3.6	Covered already in TGL10 and FSR ADF10	No further action needed
Availability of Radar Service	9.3.7	Covered already in TGL10 and FSR ADF11	No further action needed
Availability of Correct and Current Aeronautical Information to Controllers	9.3.8	Covered by FSR AIS03	No further action needed
Use of Closed Procedures up to Final Approach	9.3.9	Covered in 3.5 in table above	No further action needed
Serviceability Reporting – Navigation Infrastructure	9.3.10	Covered already in TGL10 and FSR NSS05	No further action needed
Training	9.3.11	Covered in FSRs already concerning training	No further action needed

[6] Section number in v2.0 of previous Safety Argument