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# Human-Centred Automation and the Development of Fighter Aircraft Support Systems

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## Abstract

In modern fighter aircraft, several fully automatic or semi-automatic support systems have been implemented so as to aid the pilots in performing their tasks and accomplishing their missions. However, both positive and negative effects of automation have been reported. Amongst the positive effects, decreased physical workload and increased situation awareness have been documented. Amongst the negative effects, researchers have reported out-of-the-loop performance problems, such as skill degradation, as well as high mental workload. Research concerning Human-Centred Automation (HCA) has proven that, if carefully implemented, such automation problems can be avoided or diminished. Thus, the concept of HCA ought to be a crucial component in the system development process in the fighter aircraft domain. However, how to incorporate the concept of HCA in this particular domain has not been investigated. This paper presents the results from a literature study regarding how to apply the concept of HCA in the fighter aircraft domain, where focus has been on Simulator-Based Design (SBD) which is a commonly used development method within the field. The results from this study are expected to aid developers of fighter aircraft support systems design with the concept of HCA in mind.

**Keywords**: Human-centred automation, simulator-based design, system development, guidelines, fighter aircraft.

## Introduction

Technological advancements have made it possible to develop automatic support systems in a range of different domains. For example, within the civil and military aircraft domains there are flight management computers that calculate fuel-efficient paths and that detect system malfunctions and abnormalities, while at the same time aiding their operators to fly the plane (Skitka, Mosier, & Burdick, 1999). Future fighter aircraft will most likely include a range of new support systems, aiding the pilots to handle new complex situations and tasks. As argued by Svenmarck and Dekker (2003), fighter pilots must analyse and act upon large amounts of possibly ambiguous data from several sources in order to assess situations and evaluate how to fulfil the mission goals. To aid fighter pilots in performing their tasks and to ease their workloads, several research programs have been conducted within the domain with the focus on developing automatic support systems (see for instance Svenmarck & Dekker, 2003; Banks & Lizza, 1991; Onken & Schulte, 2010). As Svenmarck and Dekker (2003) argue, a gradual evolution of support systems within the domain is likely in pace with new technological developments, such as those within the information fusion domain (see for example Dasarathy, 2001) where ways of fusing and analysing data from several sources are investigated. Such support systems could aid the pilots to automatically integrate multiple observations of the same objects into a coherent picture of the environment (Svenmarck & Dekker, 2003). However, important is also that the presentation on the displays conforms to the pilots' expectations and forms of reasoning (Svenmarck & Dekker, 2003). Otherwise, the expected positive effects of automating some of the pilots' tasks, such as decreasing their workload, reducing the number of errors they perform and improving their awareness of the situation, might not be realized.

To make sure that the positive effects of automating an operator's tasks are enforced as well as at the same time avoid negative effects, researchers have acknowledged the importance of designing the automated technologies with the human operator in mind. One approach to achieve this is to make the automation human-centred. According to Billings (1997), Human-Centred Automation (HCA) is an approach to create an environment in which humans and machines collaborate cooperatively in order to reach stated objectives. To achieve such automation, it is important that careful investigations are performed so that appropriate tasks are automated, as well as that the tasks are automated at a suitable level of automation (Atoyan et al., 2006; Kaber & Endsley, 1997). Furthermore, to ensure that the operators trust the automated functions appropriately is crucial in order to ensure efficient and safe utilization of these functions (Atoyan et al., 2006). Recent research concerning trust in automation, suitable levels of automation and support for team collaboration has resulted in a set of guidelines that are expected to support system developers in designing automated functions (see for instance Atoyan et al., 2006; Kaber & Endsley, 1997; Banbury et al., 2008; Helldin & Falkman, 2011; Billings, 1997). However, how to apply such guidelines when designing automated functions in the fighter aircraft domain has not been investigated.

According to Alm (2007), a commonly used development approach within the fighter aircraft domain is the Simulator-Based Design (SBD) approach. This is due to the possibility to involve the operator in the design, development and testing of new products (García & López, 2008). By following this development approach, it is possible to let the test users (i.e. pilots) try out different concepts, test new functionalities etc. without having to perform expensive real flight tests. This paper argues for the importance of incorporating the concept of HCA when developing automated functions within the fighter aircraft domain and suggests how to incorporate the ideas of HCA within the SBD development approach. A short description of the concepts of HCA and SBD is presented as well as how the concept of HCA could be incorporated into the development process. The conclusions drawn from this literature study are that the inclusion of the concept of HCA (in the form of a style guide) within the SBD approach seems feasible, but that further investigations together with fighter aircraft system developers must be performed so as to propose a possible development strategy as well as to further evaluate the HCA guidelines and structure them into a style guide applicable in the domain.

## Method

To investigate the possibility of complementing the SBD approach with the concept of HCA within the fighter aircraft domain, an initial literature study has been conducted. Journal papers, conference papers and thesises in which research concerning HCA (trust, automation surprises etc.), SBD, fighter aircraft research programs and situation awareness has been reported. Research concerning these areas was found after searching for the above stated keywords in databases such as the IEEE Xplore and the ACM. During the literature study, recent research (here, research conducted during the 21th century) was regarded first and foremost, but somewhat older sources of information were used when explaining the core concepts of, for example, HCA and situation awareness. The major results from this study are presented and analysed in the following sections.

## Possible effects of automation

According to Atoyan and Shahbazian (2009), the ultimate goal of any new technology is to be of help for its intended end users. As stated by Wright (2002), automation is intended to lighten the operators' workload and provide support for decreasing the number of errors made. Since computers are able to process large amounts of information much faster than humans, automated decision aids can provide pieces of advice that take into account more information than a human decision maker would be able to do. Endsley (1996) states that automation can reduce many types of human errors and improve situation awareness by reducing workload. However, there are also examples of negative effects of automation. Wright (2002) discusses that automation might lead to mode confusion, complacency and skill degradation. Related to the problem of "mode confusion" is the problem of decreased situation awareness. Endsley (1996) argues that automation can directly impact an operator's situation awareness by, for example, allocating a passive, monitoring role to the operator (which might lead to skill degradation and difficulties of understanding what the automated system is doing) and through making the system less transparent (which might lead to difficulties of understanding how the system works and interpreting the status of the automation). Furthermore, poor system feedback can result in "automation surprises" which might occur when an operator is confronted with unpredictable and complex system behaviour (Sarter, Woods, & Billings, 1997). Each of these factors can contribute to the out-of-the-loop performance problem, i.e. problems that might arise when an operator is removed from the control loop due to allocation of system functions to an automated/computer controller (Kaber & Endsley, 1997).

One approach that has been suggested for ameliorating out-of-the-loop performance problems is the careful implementation of different levels of automation (LOA). This implies investigations of the optimal assignment of control between a human operator and the computer in order to keep both involved in the system operations (Kaber & Endsley, 1997). This is also highlighted within the research area of Human-Centred Automation, which is the focus of the following section.

## Human-Centred Automation

One approach to make the human operator more involved in the automated processing is to make the automation human-centred. According to (Billings, 1997) Human-Centred Automation (HCA) is an approach to create an environment in which humans and machines collaborate cooperatively in order to reach stated objectives. As such, issues related to the out-of-the-loop performance problems might be avoided (see page 4). To achieve such automation it is important that careful investigations are performed regarding which tasks to automate, at which level of automation these tasks should be implemented , as well as that the operators have appropriate amount of trust in the automated functions. Research within the area of trust in automation has resulted in several guidelines that are expected to aid system developers to design automated functions in which the operators have suitable reliance (see for instance

Atoyan et al., 2006).Furthermore, HCA guidelines have been identified from the research performed by for example Banbury et al., 2008; Parasuraman et al., 2000; Billings, 1997; Helldin and Falkman, 2011. Examples of such guidelines are that it should be explicitly indicated to the operators if data is missing or incomplete, i.e. that the system should present how reliable the results from its calculations are, that the automation should be collaborative and that appropriate feedback should be provided to the operators. A summary of these guidelines can be found in Helldin and Falkman (2011).

According to Parasuraman et al. (2000), there are four broad classes of functions that automation can be applied to, namely the acquisition of information, the analysis of this information, decision and action selection and action implementation. These classes of functions also illustrate the range of different levels of automation – ranging from low (gathering and possibly analysing the data) to high (generating recommendations based on the available data as well as selecting the best action for implementation). Furthermore, Parasuraman et al. (2000) have suggested an iterative model that is expected to aid developers in designing automated functions with the concept of HCA in mind, see Figure 1. Following this iterative model, the automation designer is first to investigate which tasks that should be automated, as well as identify which types of automation that these tasks involve. Thereafter, the designer should decide upon which level(s) of automation that should be applied to the selected tasks. After these steps, the designer is to apply the primary and secondary evaluative criteria. The primary evaluative criteria involve the human performance consequences of the automation such as its implications for operator mental workload, skill degradation and situation awareness, whereas the secondary evaluative criteria involve issues related to automation reliability and the costs of action consequences. However, the evaluative criteria selected may be adapted according to the specific types of automated systems being developed. Furthermore, the model does not prescribe what should or should not be automated, which must be carefully investigated for each type of system. However, according to Parasuraman et al. (2000), the application of the model provides an objective basis for the automation designer, which approaches based on technological capability or economic considerations do not.

However, how to apply HCA guidelines (such as those presented in Helldin & Falkman, 2011) or how to incorporate the model proposed by Parasuraman et al. (see Figure 1) during the system development process within the fighter aircraft domain has not been investigated.

The next section describes a common development approach used within the aviation industry, namely the simulator-based design approach.

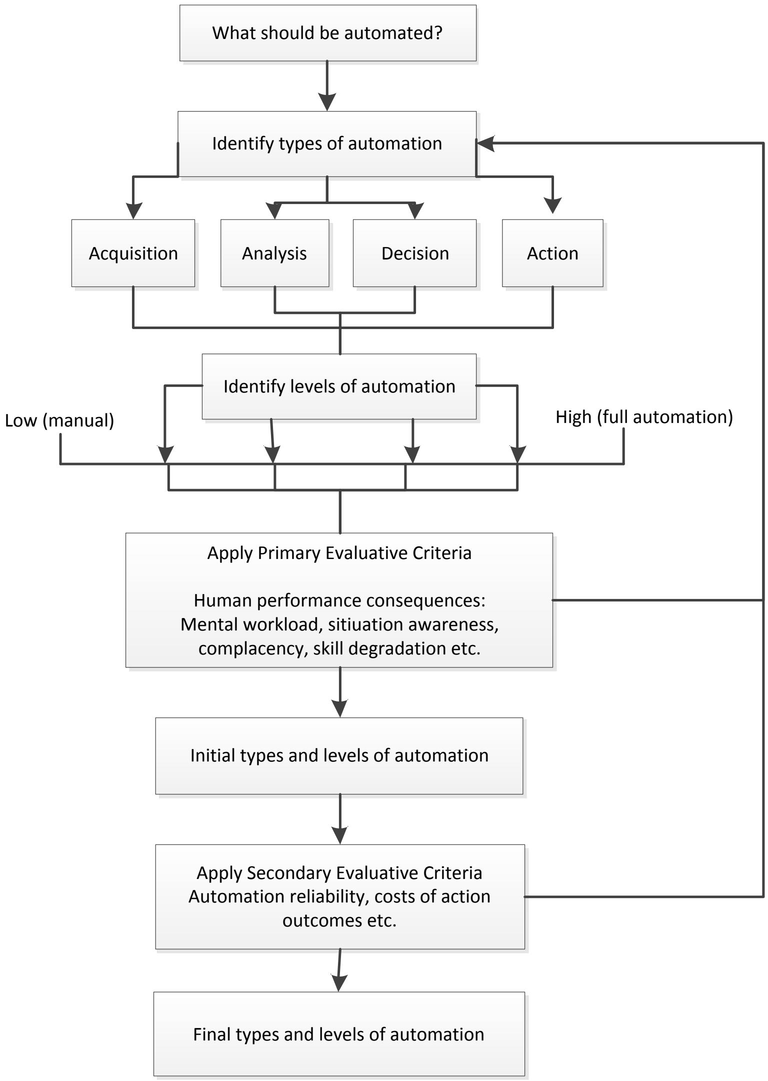


Figure 1 – A flow chart depicting the application of the model of types and levels of automation (adapted after Parasuraman et al., 2000).

## Simulator-based design

Simulator-based design (SBD) can be considered a more specific application of simulation-based design. Simulation-based design is a process in which simulation is the primary means of design, evaluation and verification (Shephard et al., 2004), and in which simulator-based design focuses on the simulator itself (García & López, 2008). SBD has been used for decades within the aviation industry and is now also used for example within the car domain (Alm, 2007). One positive effect of using this design approach when developing new functions or systems is the possibility to involve the human operator in the design and evaluation, which has been identified as a crucial factor (see for instance (Alfredson, Holmberg, Andersson, & Wikforss, 2011; Alm, Alfredson, & Ohlsson, 2009). One reason for this is that it is difficult to simulate human behaviour, especially the cognitive parts of the behaviour (Alm et al., 2009). Furthermore, by using the SBD approach, money can be saved, while at the same time avoid jeopardising human lives and the equipment used during the evaluations. It is also possible to test the same scenario over and over again and having control over the parameters used from test to test.

Alm (2007) describes the SBD development process as an iterative process where evaluations are performed at different stages, see Figure 2. In the beginning, the questions asked may be on a conceptual level, while later evaluations could answer questions regarding design details. To speed up the development process, focus should also be put on reusing resources such as scenarios, scripts and hardware from previous projects as well as within the current project (Alm et al., 2009).

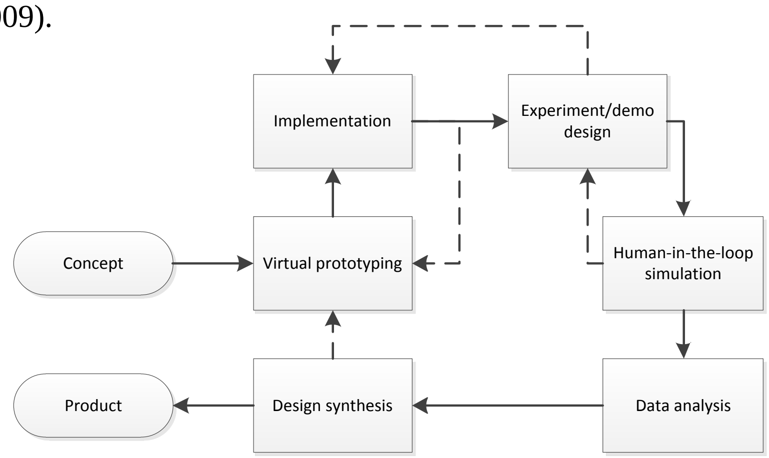


Figure 2 – The main steps in the SBD process. The dotted arrows indicate iterations (figure adapted from Alm, 2007).

Flight simulators have been used since before World War II and the first one might be the “Linktrainer”, developed in 1929 (Alm, 2007). This was a mechanical simulator where it was possible to learn the basics of flying. During the 1960s, simulators where used within the domain to train mission and emergency procedures, and nowadays, simulators are also used to verify new functions. Today, most new functions and subsystems within the Swedish fighter aircraft program are not verified in real flight at all (Alm, 2007). Thus, the SBD approach has established a solid ground within the fighter aircraft domain and is now also an approach commonly used within the car domain (Alm, 2007).

## Towards Human-Centred Automation design

Over the years, automation has greatly impacted the pilots' roles and actions in the aviation domain. However, as discussed in the section "Possible effects of automation", reports of both positive and negative effects of automation have been documented. As argued in this paper, it is expected that HCA guidelines (for example those presented in Helldin and Falkman, 2011) will aid system developers avoid the possible negative effects of automating the pilots' tasks while at the same time boost the positive effects. However, since the use of guidelines can be static and stereotypical (Alm et al., 2009), it is important that the developers iteratively evaluate the design choices taken during the development process together with the intended end users so as to create support functions that are usable and will be used effectively and safely. As discussed by Alm (2007), to fully understand the impact of automation, the human operator must be included in the loop, preferably in simulator studies. When evaluating the support functions developed, human-in-the-loop simulations can be of great help when evaluating positive and negative effects of automation and, as such, aid the developers optimize the functions implemented.

The development of the human-machine interface design in the cockpit has encompassed a process of design tradition, user involvement, structured design processes, human factors knowledge etc. (Alfredson et al., 2011). It is discussed in the paper by Alfredson et al. (2011) that the use of style guides could be a good means of implementing design principles into the design process. Such style guides must be developed with International Organization for Standardization (ISO) and military standards in mind, general HMI guidelines as well as the developers' own experiences within the domain (Alfredson et al., 2011). However, the use of a style guide should not exclude the need for evaluating and verifying the design made as well as conducting other human-in-the-loop design activities during the development process (Alfredson et al., 2011).

In a study performed together with system developers within the fighter aircraft domain, it was shown that the developers regarded the concept of HCA as crucial for developing support systems that will be used efficiently, safely and that will provide the appropriate support for the pilots (Helldin & Falkman, 2012). It was found that the system developers implicitly incorporate many of the HCA guidelines found in Helldin and Falkman (2011) during the development process, but that it might be good to introduce these HCA guidelines explicitly, for example as an additional component to or incorporated into a HMI style guide. We argue that to let such a (HCA) style guide influence the SBD development process is of great importance for developing human-centred automated support systems. Furthermore, to include HCA evaluations at an early stage during the development process was considered important by the system developers so as to make sure, at an early stage, that suitable and usable support functions are implemented. Thus, we argue that it is important to conduct HCA evaluations when making the first prototypes of the support functions (for example during the "virtual prototyping" step of the SBD process) as well as to evaluate these functions during human-in-the-loop simulations (see Figure 2).

## Conclusions and future work

This paper has argued for the importance of complementing the simulator-based design approach, commonly used within the fighter aircraft domain, with the concept of human-centred automation so as to create a better foundation for good support system development. As such, we suggest that the benefits of using a human-in-the-loop approach during the development process can be augmented and that system developers will be able to create support systems that will be used efficiently and safely. Future work includes a further investigation and evaluation of how to complement the simulator-based design approach with the concept of human-centred automation. A deeper analysis of the guidelines presented in Helldin and Falkman (2011) and their impact on different support functions should be investigated so as to further refine the guidelines and make them easier to apply during the development process.

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# A HUMAN FACTORS ASSESSMENT OF MIXED-MODE AIR TRAFFIC ARRIVAL AND APPROACH PROCEDURES

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## Abstract

This study compares different air traffic arrival and approach procedures, based on different levels of flight deck automation, from a human factors perspective. Real arrival routes and procedures at Gothenburg Landvetter Airport in Sweden have been used as case studies. The study is partly based on input from both pilots and air traffic controllers who regularly use the procedures. In addition, specific aviation industry operational experience has been used. A number of human factors related topics have been identified, including changes to flight crew and air traffic controller roles and responsibilities, communication, workload, procedure predictability and situational awareness. Recommendations for the inclusion of additional descent speed information in the ICAO flight plan and ground support tools for air traffic controllers are presented.

Keywords: Human factors, air traffic, arrival, approach, automation

## INTRODUCTION

### Background

The advance in aircraft navigation capability in recent years has facilitated new types of air traffic arrival and approach procedures. Conventional arrival procedures during medium to high density traffic situations are based on tactical radar-vectoring and rely upon instructions from Air Traffic Control (ATC) to guide the aircraft onto final approach for the airport. This method is gradually being replaced by more automated procedures based on, e.g. satellite navigation technology. These new procedures require less tactical intervention from ATC and a higher reliance on the aircraft's Flight Management System (FMS) to follow a published arrival[1] or approach[2] procedure.

These new procedures have resulted in substantial benefits for both the flight crew and ATC. Benefits have included a reduction in workload for the flight crew and ATC by minimising radiotelephony (R/T), more efficient arrival routes and a reduction in the overall environmental impact of the flight by reduction of fuel consumption and/or noise exposure.

There is a close connection between the introduction of new automated procedures and the ICAO Assembly Resolution A36-23, and the slightly revised resolution A37-11 from November 2010, Performance Based Navigation (PBN) global goals. In the Assembly Resolution, ICAO urges all of its member states to implement Area Navigation (RNAV), Required Navigation Performance (RNP) Air Traffic Service (ATS) routes and approach procedures in accordance with the ICAO PBN concept laid down in the PBN Manual (Document 9613). It also resolves its member states on the "implementation of approach procedures with vertical guidance (APV) (Baro-VNAV[3] and/or augmented GNSS,

[1] The arrival phase of flight is defined as the flight segment linking entry into the Terminal Manoeuvring Area (TMA) and a point from which a published instrument approach procedure can be commenced (typically the Initial Approach Fix).
[2] The approach phase of flight is defined as the flight segment between the point from which a published instrument approach procedure can be commenced and the beginning of the landing flare.
[3] Barometric vertical guidance.

including LNAV[4] only minima) for all instrument runway ends, either as the primary approach or as a back-up for precision approaches by 2016 with intermediate milestones as follows: 30% by 2010, 70% by 2014”. The purpose of this Assembly Resolution is primarily related to flight safety and efficient operations. The first aspect is connected to the reduction of accidents associated with Controlled Flight into Terrain at airports with Non-Precision Approaches, i.e. airports with relatively poorer infrastructure in terms of navigation aids and the latter aspect is connected to minimising the environmental footprint of aviation.

The introduction of these new automated arrival and approach procedures has changed the roles and responsibilities for both the flight crew and ATC, in addition to the way onboard automation is used at the flight deck (Chidester, 1999). The transition to new working methods has resulted in a number of human factors related topics for both the flight crew and ATC. Barhydt & Adams (2006) carried out a review of some of the key human factors associated with a transition to more automated flight procedures (during all phases of flight). They found that conventional ATC terminology was less able to accommodate the new procedures, created additional complexity at the flight deck due to the more detailed coding of these procedures in the aircraft’s FMS, and issues related to the clarity of the approach procedure naming.

At some airports handling air traffic with mixed-mode navigation capabilities (i.e. a mixture of aircraft that are capable of flying automated procedures and those that still require tactical radar-vectoring), different types of arrival and approach procedures may be used simultaneously. The use of mixed-mode procedures therefore requires effective forward planning from ATC to manage the traffic flow. This is especially true in a non-ground support tool environment (e.g. without an Arrival Manager (AMAN)). The human factors associated with operating in a mixed-mode environment will become increasingly important as more airports start to introduce more automated arrival and approach operations in parallel with more conventional tactical radar-vectored procedures.

[4] Lateral navigation.

This paper presents an assessment of some key human factors topics from both a pilot and ATC perspective, associated with the transition from tactical radar-vectored procedures to automated arrival and approach operations. In addition, the human factors aspects associated with operating mixed-mode arrival and approach procedures are considered. Note that the paper does not consider any aspects related to flighty safety as this is intrinsic to the aviation system.

The evaluation is based on a case study at Gothenburg Landvetter Airport (ICAO code ESGG) in Sweden, which currently operates mixed-mode arrival and approach procedures. Feedback has been received from air traffic controllers based at ESGG and from pilots, who regularly fly both the conventional and the new state-of-the-art arrival and approach procedures.

## Arrival and approach navigation procedures

### *Tactical radar-vectoring*

This is a method used by ATC to guide aircraft during the arrival phase. The technique is known as ‘radar-vectoring’ and consists of a series of speed, altitude and heading instructions provided by ATC to the flight crew over R/T.

Some published arrival routes to airports, known as Standard Terminal Arrival Routes (STARs), are terminated by a geographic fix (for example, a waypoint), known as the Initial Approach Fix (IAF) of the Instrument Approach Procedure (IAP), without any specified trajectory afterwards. These STARs can be referred to as “open” STARs and are designed to be conducted by tactical radar-vectoring from leaving the IAF, or before, until intercepting, e.g. the Instrument Landing System (ILS) and its lateral component, the Localizer (LLZ), which is typically intercepted 10 - 12 Nautical Miles (NM) from the runway threshold. The routing after the IAF is laterally unconstrained (except for obstacle clearance and noise abatement requirements) and the trajectory is not known to the flight crew prior to the arrival, even though the flight crew may ask for how many track miles to expect from ATC.

The “open” STARs are used by ATC for separation management and are used to coordinate traffic into an appropriate sequence, typically using speed intervention. This serves to facilitate a manageable traffic pattern in order to maintain airport capacity. The aircraft then uses the Glide Slope (G/S) of the ILS (if available) for vertical guidance during the final approach phase.

*RNAV*

RNAV is a method of navigation that enables aircraft to fly on any desired path defined by waypoints. RNAV allows an aircraft to navigate from point to point either with or without reliance on ground-based navigation aids, primarily using the Global Navigation Surveillance System (GNSS) to precisely guide the aircraft. The European terminal airspace RNAV application is known as P-RNAV (Precision RNAV).

A P-RNAV STAR typically consists of a number of waypoints that are programmed in the aircraft's Navigation Data Base (NDB) used by the onboard FMS. A P-RNAV arrival is usually followed by an ILS approach.

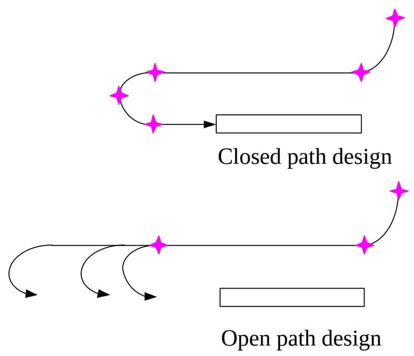


Figure 1: Open and Closed STARs (Ekstrand, Ziverts & Mitchell, 2011).

In contrast to a tactical radar-vectored arrival where the flight crew do not have prior knowledge of the lateral trajectory to be flown after leaving the IAP, a P-RNAV arrival may be flown along a "closed" STAR where the lateral trajectory is fixed, i.e. the aircraft follows a published route. The closed STAR allows the FMS to calculate the top of descent and an optimum airspeed according to airspace user strategies and assumed meteorological conditions with minimum ATC intervention. A schematic showing the difference between open and closed STAR designs is shown in Figure 1.

*RNP/RNP AR*

Airborne RNAV capable systems with RNP capabilities are a relatively recent concept and differ from conventional RNAV operations because RNP operations can be conducted in a non-radar environment, whereas P-RNAV procedures typically require ATC radar coverage. In addition, RNP procedures have a requirement for onboard navigation monitoring and alerting. RNP IAPs may also contain a vertical profile coded in the NDB after the Final Approach Point (FAP), which means that the G/S of the ILS is not required for vertical guidance during the final approach. In other words, a vertical profile is now available in a non-ILS environment.

The FMS systems on some state-of-the-art aircraft have been designed to allow the aircraft to fly curved segments with high navigational precision via fixed radius (RF) legs. This is an advance on the conventional RNP concept and is known as RNP AR (Authorisation Required). This concept of operation includes unique aircraft capabilities that require aircraft and flight crew authorisation by the applicable Civil Aviation Authority (CAA), similar to ILS Category II/III operations.

The RNP AR concept has facilitated the design of more flexible arrival and approach procedures containing curved segments, which is particularly beneficial in regions of congested airspace, around noise-sensitive areas and through demanding terrain. This has led to the possibility to design "curved" RNP AR approaches, where aircraft may fly curved flight paths before/after the FAP and thus align with extended runway centreline at much lower altitudes than, e.g. required for an ILS approach. RNP AR IAPs have an additional requirement that the navigational precision of the aircraft is always ≤0.3 NM during the approach phase.

**Gothenburg Landvetter Airport (ESGG)**

Gothenburg Landvetter Airport is a medium size airport on the west coast of Sweden. It is the second largest airport in Sweden (after Stockholm Arlanda Airport) and has an average of 230 movements per day. The airport has a 3300 m single runway, which may be operated as Runway 03 or 21 depending on the prevailing wind direction and/or other circumstances.

ESGG can accommodate arriving aircraft that are RNP AR, P-RNAV and non-P-RNAV capable, i.e. mixed-mode operations from an Air Traffic Management (ATM) perspective. P-RNAV operations were introduced at ESGG in January 2009. There are two types of P-RNAV STARs available depending on the traffic density at ESGG. During relatively high to medium density traffic situations the P-RNAV STARs are terminated at an IAF and aircraft are tactically radar-vectored onto final approach by ATC, where they join the ILS. Figure 2 shows examples of the possible lateral trajectories for aircraft arriving from the south-east to Runway 21. The dashed line indicates a typical tactical radar-vectored arrival and the associated radar-headings are shown in red.

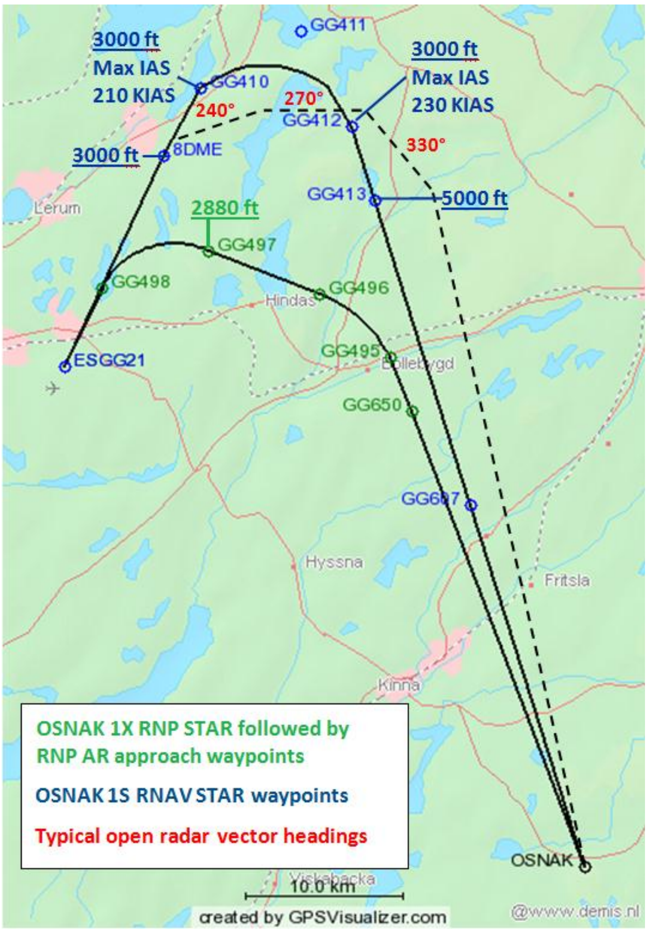


Figure 2: Published southern RNP STAR[5] (OSNAK IX) and the following RNP AR approach, and P-RNAV (OSNAK 1S) STAR followed by ILS to Runway 21 at ESGG. The dashed line indicates a typical open STAR used with tactical radar-vectoring (although is not meant to be accurate in geographical terms).

During relatively low density traffic situations closed P-RNAV STARs are available that lead the aircraft to the ILS. The OSNAK 1S closed P-RNAV STAR is shown in Figure 2 and the waypoints and associated speed and altitude restrictions are shown in blue.

There are two published RNP STARs followed by RNP AR approaches at ESGG, which were first validated at ESGG in spring 2011. The aircraft follow a closed RNP STAR to the IAF and then a curved RNP AR approach down to the runway threshold using vertical as well as lateral navigational guidance as suggested by the FMS.

Unlike the closed P-RNAV STARs, the RNP STARs and RNP AR approaches at ESGG do not contain any speed constraints. This allows aircraft to descend with a speed selected by the flight crew or FMS. The only constraint is that the aircraft must be at the FAP (waypoint GG497) at the correct altitude to intercept the vertical trajectory of the final approach, based on Baro-VNAV. The OSNAK 1X RNP STAR followed by the RNP AR approach is shown in Figure 2 and the associated waypoints are shown in green.

Note that ATS-Landvetter do not currently have any ground support tools to assist with arrival sequencing.

[5] The terminology RNP STAR is in accordance with the Swedish AIP, but there is variation in terminology.

### Mixed mode arrival and approach procedures

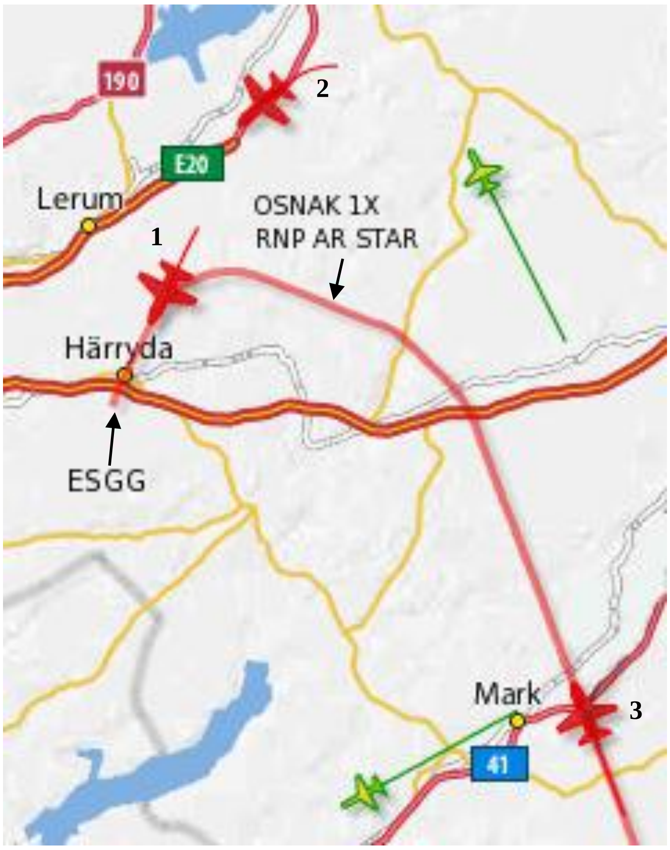


Figure 3: Geographical representation of a traffic arrival scenario at ESGG at 14:31 CET on 1st July 2011. Aircraft number 1 in the arrival sequence is established on the ILS, aircraft 2 is flying along a closed P-RNAV STAR (about to intercept the ILS) and aircraft 3 is on the RNP STAR, intending to conduct an RNP AR approach. Note that approaching traffic is shown in red and over-flying traffic is shown in green. Credit: Web Track.

An example of a mixed-mode traffic scenario at ESGG is shown in Figure 3, which shows the positions of arriving aircraft at 14:31 CET on 1st July 2011. The approaching aircraft are shown in red and the aircraft are numbered according to their landing sequence. Aircraft number 1 in the sequence is established on the ILS after having flown one of the P-RNAV STARs, aircraft 2 is flying a closed P-RNAV STAR (just about to intercept the ILS) and aircraft number 3 is on the RNP STAR, intending to conduct an RNP AR approach.

Note that from this point on, arrivals along open P-RNAV STARs followed by tactical radar-vectoring and an ILS approach will be referred to as 'open P-RNAV operations'; arrivals along closed P-RNAV STARs followed by an ILS approach will be referred to as 'closed P-RNAV operations'; arrivals along RNP STARs followed by a RNP AR curved approach will be referred to as 'RNP operations'.

## METHOD

In order to gain an insight into the key human factors related topics associated with the transition from conventional tactical radar-vectored operations to more automated arrival and approach operations (such as RNP operations), in addition to operating in a mixed-mode traffic environment, informal one-to-one interviews were conducted with air traffic controllers and pilots actively working with the procedures. These interviews were mainly performed using the focus group technique (Krueger & Casey, 2000). One group contained ATC staff and one contained pilots. Based on the feedback from the study participants, the human factors topics were grouped into a number of categories: 1. roles and responsibilities, 2. communication and technology, 3. workload, 4. predictability and 5. situational awareness.

Five air traffic controllers from the Radar Approach unit at Gothenburg Landvetter Airport and five pilots were interviewed. Note that due to the limited number of interviews conducted, this should not be viewed as a quantitative survey, and thus is not intended to represent the views of the entire ATC and pilot community. Rather, the feedback has been used to provide some initial insight into the relevant human factors topics.

## RESULTS - HUMAN FACTORS TOPICS ASSOCIATED WITH MIXED-MODE ARRIVAL AND APPROACH PROCEDURES

The human factors topics associated with a transition to more automated arrival and approach procedures in a mixed-mode traffic environment are discussed below. A brief introduction to each of the topics is given (based primarily on a literature survey), followed by a summary of the responses received from the pilots and air traffic controllers interviewed.

## Roles and responsibilities

New automated air traffic arrival and approach procedures have changed the roles and responsibilities for both flight crews and air traffic controllers.
From the perspective of the flight crew, the introduction of closed P-RNAV and RNP operations vs. an open STAR environment has resulted in a change from tactically controlling the aircraft based on instructions from ATC to strategically monitoring the onboard navigation systems. According to Mosier et al. (2007), this requires a new set of cognitive processes to perform the task.

New Standard Operating Procedures (SOPs) of the airspace user(s) have been introduced regarding the follow-up and management of the aircraft's navigation systems when conducting automated arrivals and approaches. Traditional back-up monitoring of ground-based navigation equipment has been replaced by checking and monitoring of the aircraft´s navigational capabilities in respect of RNP operation. This represents an example of the operational shift in flight crew duties.

Despite the changes in role for the flight crew during automated arrival and approach procedures, the Commander is always responsible for the safe conduct of the flight mission irrespective of a RNP, closed P-RNAV or open P-RNAV operation. In other words the concepts of authority and mission rules do not change, regardless of the level of automation of the arrival and approach procedure.
The introduction of automated arrival and approach procedures has led to a similar shift in role for ATC from a tactical role to primarily a strategic monitoring task. Although ATC retain the authority to provide tactical radar-vectors at any point during the arrival, they are expected to facilitate uninterrupted closed P-RNAV or RNP operations where possible.

In addition, air traffic controllers are now required to handle simultaneous mixed-mode arrivals, where some aircraft may require radar-vectors and some may fly more automated procedures (e.g. RNP operations). In order to manage such mixed-mode arrivals with multiple arriving aircraft, air traffic controllers must be able to plan ahead effectively in order to ensure adequate separations are maintained between the aircraft once they arrive on final approach. This is especially true in a non-ground support tool environment. The controllers must also be prepared to switch to tactical radar-vectoring if, for example, the arriving traffic is flying a closed STAR, and the traffic situation demands it. Note that this is in general not different from their fundamental day-to-day task, to maintain adequate separations between aircraft, irrespective of what kind of navigation technique used.

*Pilot feedback*

All of the pilots interviewed felt there had been a shift in their role and responsibilities with the introduction of more automated arrival and approach procedures. One pilot commented that their role had changed to more of a "system operator instead of a pilot". Importantly, however, the pilots felt that they had not suffered a loss of control of the aircraft as a consequence of automation and that flying a mixture of different approach procedures ensured they did not lose any important flying skills. One pilot believed that air traffic controllers could be conservative when changing function from tactical operations to a monitoring function and were occasionally reluctant to relinquish the ability to tactically radar-vector the aircraft.

*ATC feedback*

All of the air traffic controllers interviewed agreed that the introduction of automated arrival and approach procedures had changed their role and working methods. There was a varied reaction to this change, but all of the controllers acknowledged that they must learn to adapt to the new role. One of the controllers felt that it was essential that controllers change the way they work in order to meet new air traffic demands, including more automated flight procedures. The same controller also considered that ATC education and communication was essential to understand the new procedures and the purpose of them.

There was a concern amongst some of the controllers interviewed that the automation of air traffic arrival and approach procedures could lead to some loss of radar-vectoring skills in a future fully automatic system scenario. This may result in it taking longer to resolve a situation that requires unexpected tactical radar-vectoring. However, one of the controllers noted that these skills would be replaced by a new set of skills, such as the ability to plan ahead when dealing with mixed-mode operations, which may be much more relevant to the modern and future air traffic environment.

### Communication and terminology

Communication between ATC and the flight crew is normally performed via two-way R/T for all three types of arrival and approach operations described in Section 1.2. The open P-RNAV operation requires that the flight crew reads back assigned headings, speeds and altitudes received from ATC during tactical radar-vectoring. Closed P-RNAV and RNP operations only require an initial conditional clearance from ATC and then minimum communication should be needed until the aircraft reaches its intermediate or final approach and communication is established with the tower controller.

A human factors study by Bearman et al. (2011) on the implications of the lack of verbal communication resulting from new aircraft and ATC technology found that key non-verbal information could be lost in some situations. They concluded that both the flight crew and controllers derived information beyond the operational content of voice communication: for example, controllers issuing tactical radar-vectors via voice communication are able to convey the urgency of a situation or their workload through non-verbal features of the communication. Similarly, ATC can also identify when a situation arises at the flight deck.

*Pilot feedback*

The pilots interviewed did not feel that the reduced communication associated with closed P-RNAV and RNP operations was problematic for the flight crew or ATC. Their impression was that ATC "know exactly what we are doing and what we are going to do". Interestingly, one pilot mentioned that they regularly provide ATC with updates during RNP operations, even though it is not required.

*ATC feedback*

The air traffic controllers interviewed maintained the perception of the pilots that the reduced communication associated with closed P-RNAV and RNP operations is not problematic; one controller preferred the reduction in communication because they felt they could use the time to focus on other tasks. Interestingly one of the controllers believed that they maintained the same level of R/T communication with the flight crew during RNP operations as with open P-RNAV operations – this was a result of the controller making non-essential information requests to the flight crew in order to maintain situational awareness. In particular, controllers were requesting additional information from the flight crew during mixed-mode arrival operations as they found this information useful to ensure the correct separations between aircraft could be achieved. One controller noted that they occasionally found the radio silence to be "uncomfortable" during closed P-RNAV or RNP operations.

### Workload

One of the primary goals of the closed P-RNAV and RNP operations was to lower the workload of both the flight crew and ATC. These new procedures require less tactical intervention and R/T communication from both parties and in theory should free up time to be spent on other tasks.

From an ATC perspective, when used in isolation, automated aircraft arrival and approach procedures should lower workload; however, during mixed-mode operations when controllers are responsible for maintaining at least the minimum vertical and lateral separation criteria between aircraft flying different procedures with different trajectories, the additional cognitive effort required can slightly increase workload.

From a flight crew point of view, in some cases (depending on the specific STAR), closed P-RNAV and RNP operations can be more complex than open P-RNAV operations and may require more time and energy for the flight crew to program and to brief up on. Various constraints in terms of speed, altitude and a number of waypoints must be checked and briefed thoroughly. Since the main bulk of the arrival and approach preparation is performed well before the procedure itself, late runway changes and/or approach procedure changes may create a situation with increased workload for the flight crew at a non-optimal time. ATC changes of speed and/or altitude when already conducting a closed P-RNAV or RNP operation may result in a situation where the flight crew has to abort the arrival and ask for tactical radar-vectors, just like in any conventional procedure. It can therefore be argued that the introduction of closed RNAV and

RNP operations simply shifts the workload to another phase of the flight mission for the flight crew.

According to some studies (e.g. Endsley & Kiris, 1995a) there is a risk that during automated procedures the reduction in tactical intervention required at the flight deck reduces workload when the flight crew already has little to do, and at other times, increases workload when the situation is already eventful. These are two relatively extreme effects of the efforts of trying to reduce workload. The latter of these two effects has been addressed to as *Clumsy Automation*, a result of poor design and coordination between humans and technology (Wiener, 1989).

*Pilot feedback*

Overall the pilots interviewed were in agreement that workload is least during RNP operations as they can "concentrate on flying instead of communicating with ATC". The pilots interviewed felt that the workload differences between closed P-RNAV and RNP operations, compared to open P-RNAV operations, become highlighted when operating in a mixed-mode environment. Using different arrival and approach procedures, maybe several times a day, requires that the flight crew maintains a high level of vigilance to distinguish between them. One pilot commented that workload is increased if the planned approach is aborted in the STAR and the flight crew is forced to change the approach set up (e.g. insert a new approach in the aircraft FMS). They noted that if it happens in the later stages of the arrival phase, it might also result in additional tasks; however, they also pointed out that this is a very common phenomenon when operating into, for example, airports with multiple runways and the assigned runway is given at a late stage by ATC.

*ATC feedback*

There was an overall agreement amongst the air traffic controllers interviewed that the closed P-RNAV and RNP operations reduce the workload for ATC when used in isolation and during quiet traffic periods.

One controller commented that during open P-RNAV operations the controller must monitor the arriving aircraft carefully otherwise it is easy to become distracted and miss turning the aircraft onto the extended runway centreline. They noted that this is not a problem for closed P-RNAV and RNP operations as the lateral trajectory of the STAR is fixed and allows the controller to focus on other tasks. The controllers noted, however, that when the traffic level increases, it can be demanding for ATC to solve aircraft separation problems with speed control alone in a closed STAR structure, especially when more than one closed STAR is in use. In these situations, controllers move to tactical radar-vectoring. Exactly where this threshold level is depends on the situation and the individual controller.

From an ATC perspective handling mixed-mode arrivals is the most challenging because the aircraft trajectories differ compared to uniform descent behaviour. Most of the controllers interviewed felt that there was a small (but manageable) increase in workload during mixed-mode traffic situations because they had to monitor the situation constantly to ensure adequate separations were maintained. However, one controller felt that there was no substantial increase in workload when handling mixed-mode traffic provided they had been made previously aware of the situation and could plan ahead for it. One of the air traffic controllers commented that despite the increasing number of air traffic arrival and approach procedures in use, there is no additional technical ground tool support available than before the introduction of closed P-RNAV and RNP operations, when all aircraft were tactically radar-vectored. The controller added that the additional support from an AMAN system would be beneficial in these situations.

**Predictability**

Both ATC and the flight crew expect the respective side to function in a predictive way; a given clearance can be followed without any additional constraints and any given aircraft must follow a clearance as expected. From an ATC point of view the closed P-RNAV and RNP operations must be predictable due to terrain, noise as well as other traffic, and from a flight crew point of view a given arrival and approach clearance allows for planning and descent profile optimisation. ATC must be able to create a mental picture of how the traffic situation will look up to, e.g. 15 minutes in advance; this is especially true in the absence of a ground support tool. Therefore, predictability is important to them.

Although ATC know the lateral trajectory that an aircraft will follow during an RNAV or RNP operation with a high degree of accuracy, this is not always the case with the vertical profile if this is unconstrained and prescribed by airline SOPs. Therefore, predictability should be divided into lateral and vertical predictability. Lateral predictability is associated with the geographical drawing of the route (in 2D) and can be seen as relatively accurate in a closed loop scenario. The vertical trajectory depends very much on given constraints in the route structure, intended descent speed, type of aircraft and its performance characteristics, meteorological conditions, etc. Therefore, the vertical trajectory differs very much from one airspace user to another.

*Pilot feedback*

The pilots interviewed considered the closed P-RNAV and RNP operations to be the most predictable *if* ATC do not intervene. They found the operations to be predictable in terms of knowing the distance to the runway threshold and planning the start of descent (i.e. lateral and vertical predictability). They felt that open P-RNAV operations were the least predictable in both the lateral and vertical dimensions, which is understandable, since the aircraft cannot calculate a proper descent point. One pilot commented that although the flight crew needs predictability to optimise the descent profile, they do not always know in advance if the flight will be disrupted because this is dependent on the traffic situation at the time of arrival, i.e. ATC can choose to break off an aircraft in the arrival phase in favour of tactical radar-vectoring. Another pilot believed that predictability associated with closed P-RNAV and RNP operations increases safety because the flight crew can plan further ahead and thus foresee divergences earlier.

*ATC feedback*

Whilst the air traffic controllers interviewed all had confidence in the track-keeping ability of RNAV and RNP equipped aircraft (i.e. lateral predictability), they commented that there are differences in the vertical behaviour of the aircraft during the arrival phase. One controller observed that some airlines choose to execute a slow descent to the airport with a low rate of descent, whilst others select to fly "high and fast" for as long as possible. The controllers therefore emphasised the importance of having knowledge about the intended speed of the aircraft as early as possible (if deemed necessary), particularly during automated arrivals where communication is reduced.

**Situational awareness**

One of the fundamental requirements for both the flight crew and air traffic controllers is the ability to "stay in the loop". One way of describing situational awareness is the assessment of where the aircraft has been, where it is now and where it is going (Endsley, 1995b). It is therefore closely linked to predictability.

Advanced operations such as RNP AR require that the flight crew maintains a high level of situational awareness due to the curved flight path followed immediately before intercepting the extended runway centreline (similar to low weather minimum ILS approaches). By comparison, open P-RNAV operations require a lower cognitive effort from the flight crew close to the approach phase as radar-vectored arrivals typically intercept the extended runway centreline several track miles from the airport. On the other hand, the flight crew needs to increase their situational awareness during tactical radar-vectoring due to the uncertainty of the intended radar-trajectory. One way of solving this, can be to ask the controller about "track miles to go".

Despite the requirement for increased situational awareness during automated approaches, it has been argued by Dorneich et al (2011) that there can be a penalty in human attention and situational awareness when interacting with automated systems. It may also be argued, however, that the increased predictability associated with automated closed arrival and approach procedures serves to increase the situational awareness of the flight crew. Furthermore, the reduction in workload during an automated approach allows the pilot to spend more time assessing the surrounding terrain and traffic situation, hence enhancing their situational awareness.

*Pilot feedback*

The pilots interviewed all agreed that when flying closed P-RNAV and RNP operations they have a greater situational awareness compared with open P-RNAV operations as the workload is lower and ATC "don't fly the aircraft" with tactical radar-vectors. One pilot commented that closed P-RNAV and RNP operations also force the flight crew to be more aware of any speed and altitude constraints. The pilots also observed that situational awareness is increased when flying closed STAR arrivals because the flight crew and FMS will always know the remaining distance to fly.

*ATC feedback*

The controllers commented that their situational awareness was highest when closed P-RNAV and RNP operations were in use during quiet traffic periods; however, they felt it was slightly lower during operations when they had to spread their attention across many aircraft operating into the airport. Some controllers used verbal communication with the flight crew to request additional information in order to increase their situational awareness.

## DISCUSSION AND CONCLUSIONS

The evaluation presented in this paper is based on the feedback from ten study participants, and therefore is to be regarded as a limited study. In spite of this, some general ideas as well as indications can be drawn.

A transformation towards more automated arrival and approach procedures is taking place on a global scale in accordance with e.g. ICAO PBN goals. The transition to these new procedures has been associated with a number of human factors topics. This has been linked to fundamental changes in air traffic operations from both the perspective of both the flight crew and air traffic controller (Barhydt & Adams, 2006). This conclusion is supported by the responses from interviews with air traffic controllers and pilots using the closed P-RNAV and RNP operations at ESGG.

Based on the interviews with the air traffic controllers and pilots at ESGG, some key conclusions, questions and recommendations are presented below.

1. It emerged from the interviews that there can be uncertainties from an ATC perspective related to the vertical trajectory of aircraft in the arrival phase on closed STARs. This is due to the variability in aircraft descent and speed profiles along closed STARs and this is in turn related to many factors, including airline SOPs and flight crew preference and experience. In addition, this is related to lack of information about the aircraft planned decent speed in the ICAO ATC flight plan. As a result ATC must sometimes request additional information from the flight crew about their speed. Therefore, a more standardised behaviour in the descent phase could possibly be of great benefit. Another option could be to include the planned descent speed in the ICAO flight plan, at the moment, only speed in the en-route phase is included.

2. The benefit of ground support tools such as an AMAN was highlighted amongst the interviewed air traffic controllers, when working in a mixed-mode environment. This would help to reduce workload for the controllers during busy periods and improve overall efficiency of the ATM system.

3. Given the shift from a tactical to an increasingly strategic monitoring role for both pilots and air traffic controllers, it is important to assess how this might affect job satisfaction and expectations. For example, how does a pilot feel about becoming a "system operator"? There is a challenge in this, as this type of shift in role could result in some unwanted side-effects: when reducing flight crew duties, and thereby workload, periods with low activity will be the result. The flight crew may over time become bored, tired and under-stimulated as well as feeling over-reliance on automation. This may lead to non-critical thinking, resignation and even surrendering to the idea that automation is performing much better than humans. A mental state like this may be referred to as *Complacency* and is found not only in the aviation industry but in fact in many other areas and during extended periods of time (Wiener, 1981).

An observation raised by both the pilot and air traffic controller groups interviewed concerned the potential loss of tactical skills when working for extended periods in a more automated environment. Therefore, consideration must be given to whether more simulator training will be required as procedures become increasingly automated.

4. A key observation from the interviews concerned the assertion from both pilots and air traffic controllers that they were satisfied with the reduction in

voice communications associated with more automated arrival and approach procedures, yet members of both groups were maintaining non-essential communication over R/T during the procedures. It appears that this is related to habit and in some cases ATC request extra information to increase situational awareness. Again, the availability of a ground support tool and information regarding the planned descent speed in the ICAO flight plan would most likely reduce the need for superfluous R/T communication.

5. Finally, consideration must be given to the effect on flight crew workload when a planned closed P-RNAV or RNP operation is broken off by ATC in favour of tactical radar-vectoring. One of the pilots interviewed noted that the situation increases workload if the procedure is broken off late in the STAR; therefore, an assessment of how flight crew workload correlates to the stage of flight where the STAR is broken off would provide an informative study.

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