THREAT ASSESSMENT AND RESPONSE MANAGEMENT SYSTEM TARMS: AN ON-BOARD AIRCRAFT SECURITY SYSTEM

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Abstract

*A group of leading European companies and research institutes has joined forces in the innovative project SAFEE (Security of Aircraft in the Future European Environment) *[1]. The main goal is to ensure a fully secured flight from departure to arrival destination by construction of advanced aircraft security systems designed to respond to on-board threats.*

A key SAFEE system is the Threat Assessment and Response Management System (TARMS), which is envisaged as a decision-support system for the network of on-board actors. It will first gather threat information from on-board sensors and databases. Then, by using an on-board knowledge base, TARMS will assess the threat level and recommend a response to detected threats. Expert knowledge gathered by multiple interviews with aviation security experts, pilots, cabin crew, and operators, forms the basis of the knowledge database.

A key point for the successful construction of TARMS is an extensive validation and testing phase with the end-users in the loop. In 2007 three periods with validation experiments took place in NLR's Generic Reconfigurable Aircraft Cockpit Environment (GRACE) simulator. The experiments were based upon a number of experimental scenarios developed by consulting experts in airborne security operations. Over 50 operational users (pilots and cabin crew) participated in the exercises.

The experiment results show that the presence of TARMS raises the overall level of threat awareness. The feedback received provides support that TARMS suggests different courses of action to a given threat than crew do without the presence of TARMS. The main impression was that TARMS and the SAFEE concept are interesting and have great potential for enhancing the security on-board an aircraft. The majority of participants felt that there was value in having a security based system such as TARMS on board the aircraft.

1 Introduction

When does a passenger become a security threat or a hijacker? What signs can be picked up to unmask a hijacker or terrorist? How can the flight and cabin crew anticipate a security event and stop it happening? How can the crew take measures before a threat is clearly identified and the terrorism act is already in progress? All these are burning questions since the 11th September attacks. In the wake of these attacks, air security has become a key concern for the aerospace industry. Subsequent investigations have highlighted the need to better equip flight deck and cabin personnel, and they have recognised that better security procedures and systems could have helped the crew to handle the situation better.

A group of leading European companies and research institutes has joined forces in the innovative EU FP6 Aeronautics Project SAFEE (Security of Aircraft in the Future European Environment) [1], [2]. SAFEE envisages the construction of a set of innovative aircraft security systems that will make a significant

[1] EU FP6 Aeronautics Project

contribution towards the assessment of on-board threats and the response to in-flight security events. These systems will improve the security level inside an aircraft by reducing the vulnerability, limiting the impact of hostile actions and enabling the aircraft to return safely to the ground.

The assessment of the overall threat level to the aircraft at any given time requires the processing of large amounts of information. Clearly, the threat information received from on-board sensors provides a major source of measured observations, but there are many other sources of information that contribute to the assessment, including intelligence information, passenger profiles, behaviour models and expected threat scenarios. There is therefore a requirement for an information processing system that can perform a threat assessment by fusing observations with knowledge models, and finally recommend the appropriate course of action.

The innovation in SAFEE is to build a system able to cope with these requirements. This system must be capable of conducting a reliable assessment of a wide range of possible threats, utilising multi-source data. It will then use this information to generate a prioritised menu of courses of action for decision-makers, that are feasible, safe and conform to relevant governmental and airliners policies.

The foreseen on-board system is the **Threat Assessment and Response Management System** (TARMS) which is envisaged as a decision-support system for the network of on-board actors. This system will gather information from on-board sensors, crew members and databases to determine the on-board threat level.

2 Defining requirements for TARMS

As explained above, TARMS is at the core of the SAFEE system. Key issues to be addressed include understanding the functions it should perform and the constraints under which it must operate. In order to address these issues prior to embarking on the system design the preliminary task in the TARMS development was to define the system requirements.

A four step process was adopted, based on proven techniques, each of which is supported by appropriate software tools (e.g. Objectiver) [3]:

– **Step 1**: identification of right stakeholders and their interviews, extended with the security regulations currently in place.
– **Step 2**: elicitation of end users' needs, and transformation of needs into Use Cases (UC) of Unified Modeling Language (UML).
– **Step 3**: merging of all the UCs into one large global UC, identification of conflicts, and transformation into the End Users' Requirements Document
– **Step 4**: derivation of the TARMS System Requirements Document.

The steps of the process are summarised in Fig. 1.

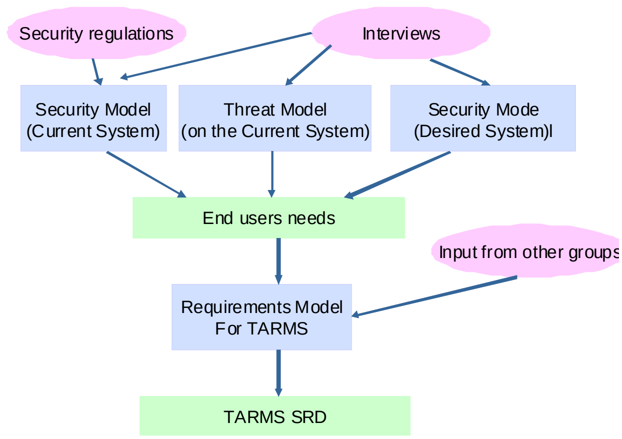

Fig. 1. TARMS Requirements Process

Requirements have been collected from different sources:

- Interviews of a large set of stakeholders involved in the security of commercial flights: pilots, cabin crew, sky marshals, security managers, air traffic controllers, security authorities, and airlines.
- Existing security regulations for air navigation from ICAO (International Civil Aviation Organisation) [4] and ECAC (European Civil Aviation Conference) [5].

- Other security projects in progress (e.g. Eurocontrol ERRIDS project aimed at centralizing and despatching security information about flights at the European level).
- The summary report on terrorist attacks upon the USA on the 11th of September 2001 [6].

The resulting System Requirements Document (SRD) produced from the requirements analysis process is compliant with the IEEE-830 standard. It contains a glossary of all specific terms used in the SRD (a by-product of the Objectiver Object Model), a top-down presentation of the goal graph motivating all the requirements and expectations, an inventory of all the responsibilities for each SAFEE sub-system, the conceptual model of the domain and the system (providing a first architecture of the system based on the problem at hand) and a definition of the interface between subsystems in terms of controlled and monitored objects.

3 TARMS overview

3.1 TARMS architecture

A software framework has been developed for TARMS with three modules - the **Threat Assessment Module (TAM)**, which will use the relationships between security input data to make useful inferences about potential threats, the **Response Management Module (RMM)** which will provide suggestions to users and may activate external actuator systems in order to mitigate the threat level of the flight, and the **User Management Module (UMM)** which will allow users to enter observation inputs and to interact with the decision support system [7].

Fig. 2 presents the architectural decomposition of TARMS and clearly identifies three major modules.

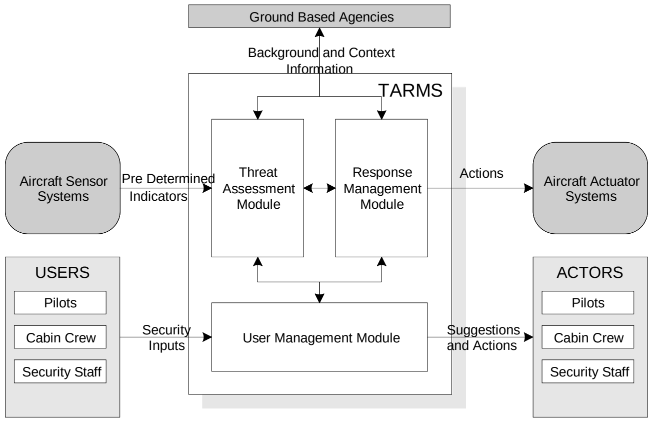

Fig. 2. TARMS high-level architectural design

3.2 TARMS expert systems

TARMS contains two expert systems within the TAM and the RMM. Both modules need to be able to assess information from a set of heterogeneous sources and to make inferences from that information – for threat assessment and response selection respectively.

Expert systems can be constructed from training data, expert knowledge or a combination of both. In the air transport domain, there are very few examples of terrorist threat events, and even for those rare events, there is very little data recorded. That means there was no training data available. Therefore the expert systems were built entirely from expert knowledge, and this was achieved through a series of knowledge elicitation exercises.

The knowledge elicitation process involves interviewing experts in the field of aviation security. The types of people interviewed included airline security managers, approved aviation security consultants, pilots, cabin crew, ground check-in staff and experts in explosives and nuclear, biological and chemical warfare.

In the interests of keeping complexity to a minimum and progressing development quickly, it was decided to initially consider the four most likely and prevalent SAFEE threats as highlighted by the experts interviewed. These four threats were:

- Take control of the aircraft and fly into a target (Hijack the aircraft for use as guided missile)
- Hijack the aircraft to divert or negotiate (Hijack the aircraft to negotiate)
- Blow up the aircraft with explosives onboard (Bomb)
- Endanger occupants with aggressive behaviour (Unruly Passenger)

There are many ways of representing an expert system. For the TAM, we have selected Bayesian Nets (BN), while the proposal for the RMM is currently rule-based. BNs were chosen for threat assessment because they provide transparency both in knowledge capture (experts can understand how their knowledge has been encoded) and in application (the model provides an implicit explanation of its analysis of the situation).

A BN is a probabilistic graphical model where the nodes of the graph are variables in the domain of interest. In the case of aircraft security, there are different types of nodes e.g.

- *Threat* nodes such as 'Hijack', 'Bomb', etc.,
- *Evidence* nodes that represent observations made of the passengers on the plane e.g. 'Suspicious Appearance' and 'Avoiding Crew Instructions', and
- *Context* nodes that represent information known before the flight e.g. 'High Risk Flight' and 'Suspicious Ticket'.

Graphical links (see Fig. 3) between the nodes represent a probabilistic relationship describing how one node influences another. An example is that a person with suspicious ticket purchasing behaviour is more likely to be a possible threat to the aircraft than a person with normal ticket purchasing behaviour. Once created, these models will be used operationally by TARMS to predict how likely it is that any given passenger is a threat. The models will be triggered by passenger evidence data entered manually by the crew, or by automatic detections provided by an on-board sensor system.

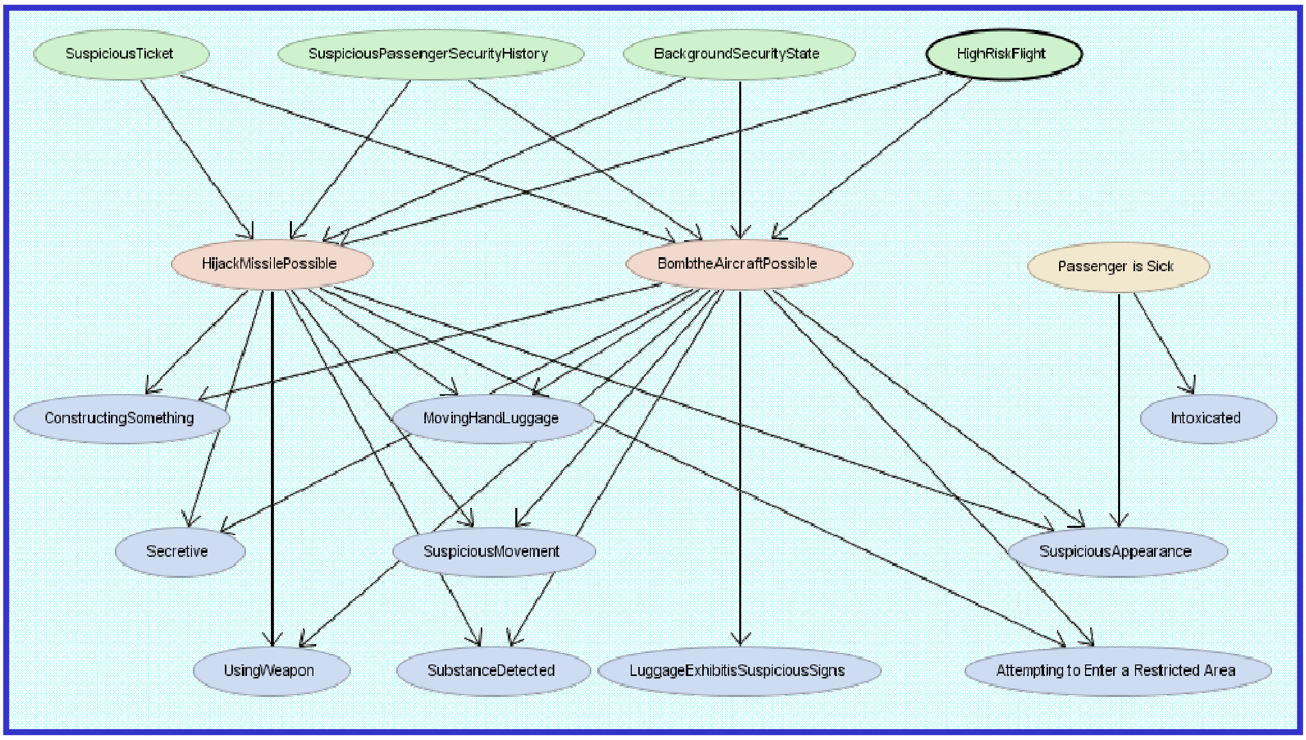

Fig. 3. Example of TARMS threat assessment knowledge base

3.3 TARMS implementation

The design of a software framework to support TARMS objectives has created a significant number of challenges. One important goal was not to restrict TARMS to interact with a specific set of external systems, i.e. it should be possible to interface TARMS with any external sensor/actuator system that complies with some basic requirements. This guided TARMS design to be as scalable and modular as possible. Another important goal was that TARMS should provide responses to threats in a timely fashion. The use of novel reasoning technologies in the TAM created some problems and uncertainty in the performance of such system. The possibility of distributing modules among different resources was the solution proposed to mitigate this problem.

The use of JADE, a JAVA agent-based framework was adopted to cope with the aforementioned requirements. JADE provides a distributed environment where agents implementing components of the software can be deployed seamlessly across several computing platforms. Also, the addition of new sensors and user interfaces can be accomplished by adding new agents to the system that support the specific interface with those external systems. JADE also provides agent communication protocols between agents using standard technologies, such as Ethernet protocols, providing TARMS the required modularity.

3.3.1 Threat Assessment Module TAM

The TAM aims to discover hidden relationships between different security input data received from onboard sensor systems, users and from ground intelligence agencies, and make useful inferences about potential threats arising from inside the aircraft. The approach to the design of the TAM is to use probabilistic models in the form of Bayesian graph networks. A probabilistic approach has a number of advantages: the model can be conditioned on evidence (i.e. observations), summarised predictions can be made and information can be predicted or removed from the model.

These models would be used operationally by TARMS to predict how likely it is that any given passenger is a threat. They would be triggered by passenger evidence data entered manually by the crew, or by automatic detections provided by an on-board sensor system. Using the structure of the Bayesian network, and how one node influences another, the threat nodes and therefore the threat level can be inferred. If this threat level goes over a given threshold, then an alert is sent to the operator in charge – usually the pilot – and to the RMM.

3.3.2 Response Management Module RMM

The RMM is the component that allows TARMS to provide suggestions to users and to activate aircraft systems, in order to mitigate the threat level of the flight. The chosen methodology for the RMM was a rule-based system based on a simple security methodology. The response model is a mapping from threats to responses. The model is populated based on the knowledge from domain experts. The system only processes one threat at a time, therefore the threats are prioritised.

3.3.3 User Management Module UMM and User Interfaces

The UMM is responsible for receiving observation inputs and providing suggestions of actions from/to the users of the system. Different users have different profiles, task loads and roles inside an aircraft and this must be taken into account when designing a user interface. The UMM must be capable of making the bridge between these different user interfaces and the other modules of TARMS.

Human Machine Interfaces (HMI) were implemented for the cockpit crew and for the cabin crew. The cockpit crew was provided with an HMI on the electronic flight bag which gives them access to TARMS. The cabin crew HMI was provided on the central control panel in the cabin. In addition, a small wearable alerting device is suggested whose function is to alert individual cabin crew members to take action. This device was not developed in the SAFEE project. The HMI was designed with three main principles in mind [7]. The system:

- is a decision support tool
- displays information to the user adapted to the situation
- is a visual support to voice communication

To provide visual support to the user instead of just providing raw data, the system displays a map of the cabin for the users to be able to assess where a reported threat is located. Users can report different types of situations: emergencies; unruly and suspicious passenger behaviour; or events. Fig. 4 shows an example of the TARMS HMI for the cockpit crew.

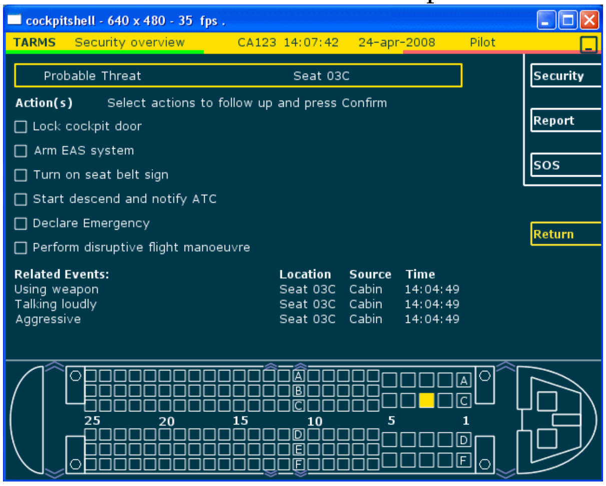

Fig. 4 : TARMS HMI

4 Validation exercises

TARMS is a multi-user system for the assessment of threats and the generation of appropriate responses to these threats. A key point for a successful construction and user acceptation of TARMS is an extensive validation and testing process. Therefore TARMS and some supporting SAFEE systems were deployed in the Generic Research Aircraft Cockpit Environment (GRACE) simulator at NLR in Amsterdam, allowing the cockpit crew to interact with TARMS in a realistic situation. To allow the cabin crew to interact with TARMS a special room was prepared where a TARMS HMI was provided. A presentation of the events taking place in the cabin was displayed, while extra detail and explanations were given by a story teller (Fig. 5). The cabin crew had a headset and microphone to contact the cockpit crew while the cockpit was able to trigger a gong to signal the cabin crew to contact the cockpit.

4.1 Validation aims

The main objective of the validation process was to validate the operation of TARMS. Therefore the following **validation aims** have been established:

1. Validation of the usefulness of TARMS in assessing threats
2. Validation of the RMM in TARMS
3. Validation of the TARMS HMI

Fig. 5: Briefing room for cabin crew during experiments

4. Assess the workload for the cockpit and cabin crew
5. Validation of the SAFEE-TARMS concept

4.2 Scenarios

The scenarios are the story lines used to validate TARMS in various security situations. In a series of workshops a dedicated group of experts which consisted of aviation security specialists, terrorism consultants, flight crew, pilots, a sky marshal, psychologist, Red Team specialist, explosives expert and former intelligence agents, has developed a set of scenarios, based on realistic threats. This group was independent from the TARMS developers and the validation experts. The group's objective was to make the scenarios as realistic as possible, relying on possible modes of hostile actions relevant information and appropriate security system and procedures. For the final

Scenario	Description
Dr No	Hijacking attack in order to crash into target, using a medical diversion performed by “professionals”.
Baby Boom	A female suicide bomber smuggling innocent liquids in order to assemble them into explosives.
Take My Breath Away	Chemical attack in multiple flights, simultaneously.
Chain of Events	2 unruly passengers.
With Bare Hands	Group of unarmed, well-built hijackers
The Inside Job	Attack using help from an insider

Table 1: Validation scenarios

check the scenarios were presented to GIGN (Groupe d'Intervention de la Gendarmerie Nationale), the French Gendarmerie's elite counter-terrorism and hostage rescue unit. All the scenarios gained extensive approval from this unit.

The scenarios include the pre-determined indicators (aggressive behaviour, substance detected, etc.) which would be detected by SAFEE systems and sensors, aircraft systems, and cabin crew as the scenario unfolds. Six scenarios have been developed in consideration of the TARMS validation (see Table 1). Five of these have been augmented with these indicators. The 6th scenario (The Inside Job) is dealing with a threat that does not have any indicators during the flight. It was considered that this would not contribute to the validation trials and therefore was not used.

4.3 Participants

The participants in the validation trials consisted of three-person crews; a pilot, a co-pilot and one cabin crew member, though in one experiment a crew with two cabin crew members was available. A total of twenty cockpit crew and ten cabin crew members were involved. All flight crew were active pilots on Airbus, Boeing or Fokker aircraft. The experience of the pilots varied from trainee pilot up to very experienced. The crew members worked for well-established European airlines from four different countries.

All participants were trained in security issues, the SAFEE concept of operations, and the use of the TARMS and its HMI. This training was performed just before the validation trials. For the pilots there was also a simulator familiarisation run to become accustomed to the Airbus A330 simulator. Especially for the Boeing and Fokker pilots there was a briefing about the specific Airbus features in the cockpit.

Each crew was present at NLR in Amsterdam for two days which included the training session and the validation trials. The half day training session covered; the SAFEE concept, the TARMS and a training run with TARMS in the GRACE simulator to enable each participant to have experience with the system prior to the validation trial.

For the validation trial each crew was involved in the five different scenarios. The pilots were situated in the cockpit simulator and the cabin crew member in an adjacent room throughout each scenario.

4.4 Data gathering

Each of the scenarios could be conducted with or without the use of TARMS and each crew completed one scenario without TARMS. Over the course of the trial all five scenarios were conducted at least once without TARMS. Each scenario was divided into blocks. At the end of each block the crew filled in a questionnaire detailing their assessment of the current threat situation on board, the suggested response, their interaction with the TARMS system and their communication with the other crew members. At the end of the experiments the crew filled in an electronic questionnaire dedicated to HMI issues. Finally the crew was debriefed in a classroom setting where they were able to give their final feedback and comments.

At the end of each experimental scenario the participants returned to the debrief room for a quick discussion about the scenario and received a briefing on the next scenario in the trial. After all five scenarios had been completed each participant filled in a separate questionnaire about the TARMS HMI. Each of the different types of questionnaires was designed to capture data to answer the questions corresponding to each questionnaire's objectives. The two day trials finished with a final debrief session.

5 Results

The results will be discussed for each of the data gathering methods.

5.1 Scenario questionnaire

The mean threat assessments made by the participants and by TARMS in the 'With TARMS' experimental condition for each of the potential threat situations were calculated. Fig. 6 shows as an example the mean threat assessments of 'Unruly Passenger' for the Dr No scenario. 'Unruly Passenger' is a passenger who shows unruly or disruptive behaviour. The 'With TARMS' condition was exposed to 14 pilots and 8 cabin crew, the 'Without TARMS' to 4 pilots and 2 cabin crew. A threat assessment score of zero indicates that the participants thought that a threat was not at all likely, while a score close to 1 indicates a threat situation was believed to be highly likely. A visual inspection of the analysis of the Dr No Scenario results indicates that the presence of TARMS yields higher mean threat assessments across the majority of stop points when compared to the threat assessments made in the 'Without TARMS' condition.

Over the course of the trial all five scenarios were conducted at least once without TARMS.

The results of the experiments showed that for the aims described in section 5.1:

- Aim 1: No evidence was found to support the hypothesis that posits that crew with TARMS can make 'better' threat assessments than crew without TARMS. Though one interesting result found was that crew provided a significantly higher threat assessment for the unruly passenger than any other threat! This is possibly due to crews seeing this threat much more often than the other threats. See Fig. 6 for an example of the threat assessment of an unruly passenger at the stop points in a scenario.

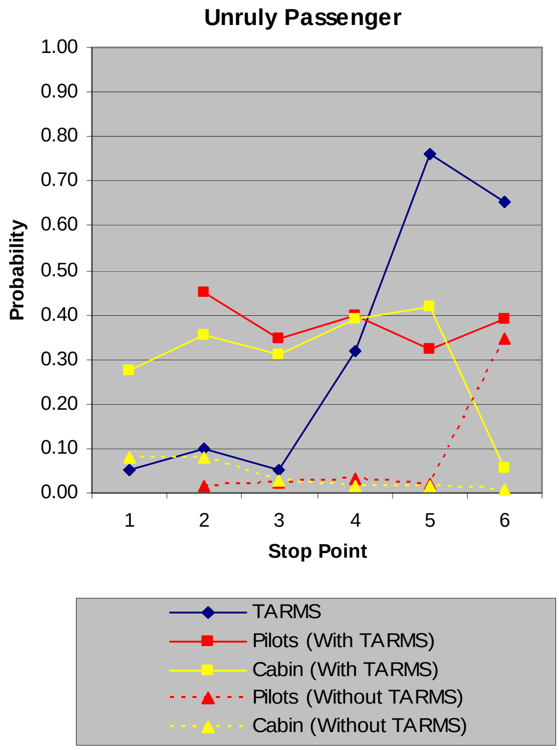

Fig. 6: Threat situation assessment at stop points in Dr No scenario

- Aim 2: TARMS does suggest different courses of action to a threat than a crew does without TARMS, and while the participants agreed that most of the recommendations were sensible, the majority of participants commented on the need for these recommendations to be customised to airline company procedures.
- Aim 3: The validation of the HMI showed that the majority of ratings provided by the participants were positive. The issues that were raised though focused mainly on the

flexibility and alignment with airline company procedures.

- Aim 4: Feedback from participants showed some concern about the increased workload required to operate TARMS. It is believed though that increased training and the development of TARMS related policies and procedures would increase the effectiveness and efficiency of TARMS and mitigate some of the workload concerns.
- Aim 5: The main impression was that TARMS and the SAFEE concept are interesting and have great potential for enhancing the security on-board an aircraft. However, in its current state many participants had reservations about the value of having TARMS on board the aircraft, and in particular about the response management aspect of TARMS. Participants felt that the strength of the system is in the detection of indicators rather than in their interpretation and decision making.

5.2 HMI questionnaire

The mean scores obtained on questions related to TARMS capabilities are presented in Fig. 7. TARMS capabilities speed, response time, reliability, failures and possibility of undo operations were rated higher than 3 on scale 1-6. Comments that were provided through the questionnaire were that the system could never replace the communication between cabin and cockpit and that a camera view of the cabin available in the cockpit would be a very useful addition to TARMS. Especially the lack of ability to undo or cancel a threat was considered an important inflexibility of the system. Furthermore, it was mentioned that one could not rely on the system. And cabin crew reported that in emergency situations the system is too slow and it presents too much information. In general there will be little time to attend to the system. Some reporting items were mentioned to be missing: smoking in the toilet, disrespectful behaviour, and not listening to crewmember.

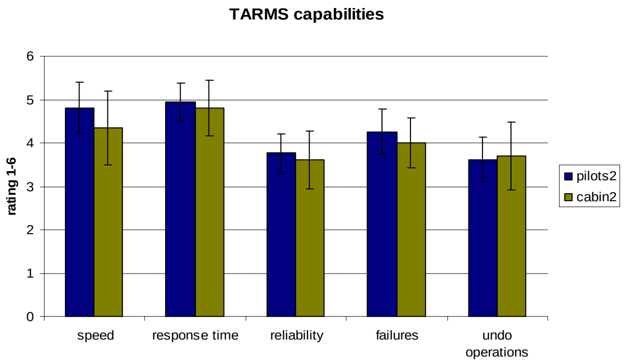

Fig 7: Rating of TARMS capabilities

5.3 Debrief session

The majority of participants felt that there was value in having a security based system such as TARMS on board the aircraft, however many pilots have reservations about the response management aspect of TARMS. Some participants felt that it should be more of an awareness support system (not a decision support system) which provides information for a pre-assessment of a situation and triggers communication between the crew. During the trials it was indeed observed that the TARMS alerts often triggered communication between cockpit and cabin.

Comments were made about the lack of contextual information associated with a threat alert and how this can affect the perception of a situation.

Participants were also given the opportunity to comment on what aspects they would like to see in an improved TARMS. All pilots requested some visual information from the cabin, either in the form of cameras or a spy hole, however some felt that this may bias decision making especially if the situation in the cabin was particularly gruesome and upsetting.

6 Conclusions and the way forward

The conclusions from the trials have indicated that users are very interested in the concept of TARMS providing decision support to them in the early detection of possible airborne threat. One of the main problems the crew and current procedures have today is that they are all directed to react only after the threat was clearly identified, thus giving them a very short time to assess the situation and to counter it. TARMS gives them the opportunity to take actions to prevent the threat occurring. The trials elicited the users' responses to different aspects of the system and this leads to the following recommendations:

- Initiate a consultation with the user community to determine what form of decision-support system would now be required. This would include firstly assessing the benefits offered by the current TARMS functions, the collaborative working environment, and the expert-based threat assessment and response management. This should then lead to a more detailed specification of the information requirements, the collaborative decision-making processes and the user interfaces. One key recommendation is to create an additional facility to explain the reasons behind the advice provided on possible threats and appropriate responses.
- Assuming the threat assessment is considered beneficial, perform a further analysis to identify the value of sources of expertise, and then develop advanced methods for eliciting and representing this expert knowledge. This could include defining a common language to describe threats and responses with their consequences. Validation of the elicited knowledge will be a key step.
- TARMS made various assumptions about provision of indicators from the on-board sensors. Although some important capabilities in automatic detection of some indicators are demonstrated [8], the majority of the required indicators remain difficult to detect automatically. An assessment needs to be made of which systems are likely to be developed to sufficient maturity in the next 5 years, and significant work should then be instigated to accelerate the development of these systems. For the remaining indicators, the alternative of humans providing the information should be investigated.
- TARMS identified a number of interfaces to other SAFEE subsystems and demonstrated these as part of its trials programme [8]. A priority for any future integration project should be to define these interfaces in greater detail in the context of an overall system requirement.
- Through a joint trial with the European Regional Renegade Information Dissemination System (ERRIDS) project, TARMS has demonstrated how its on-board system could collaborate with a ground-based system. It is our belief that any future project must consider the full integration of the on-board system within a system-wide information management network. Technology, architecture solutions, data and information models and rules of operation should all be investigated. This should all then be demonstrated and validated in a large crisis management exercise with the operational users in the loop.

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