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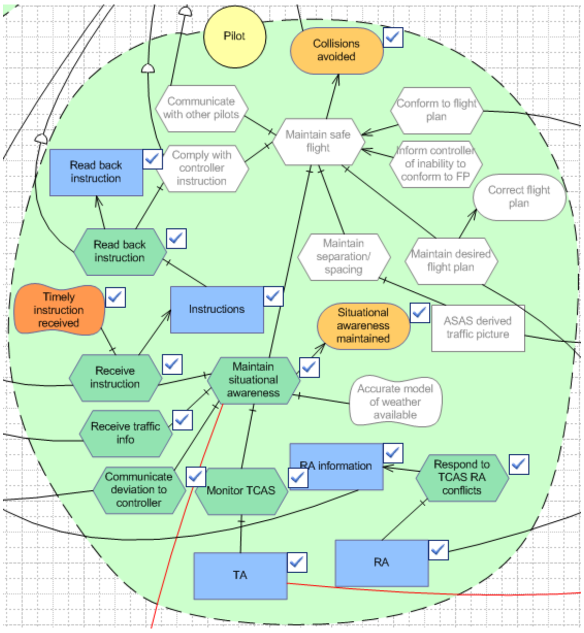
Executive summary

Using i* Modelling as a bridge between Air Traffic Management operational concepts and agent-based simulation analysis



Objective

This paper presents experiences of exploring how i* modelling can be used as a bridge between informal air traffic management (ATM) operational concepts and formal agent-based simulation. The paper reports on an EU airspace design project that describes a revised concept of operations for lower level airspace around airports, and includes simulation based safety analysis of the critical scenarios.

Description of work

The paper describes research towards using i* to address two challenges – how to model the revised concept from the informal concept of operations document, and how to present safety critical scenarios to operational experts. Modelling strategic aspects of a concept of operations is new to ATM, and the paper draws upon experiences to provide lessons learned and directions for future work.

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Future work

In parallel to the i* modelling described in this paper, a Petri net model is under development for the same operation using the formalism of Stochastically and Dynamically Coloured Petri Nets (SDCPN). This SDCPN model will be used to conduct rare event Monte Carlo simulations in order to assess mid air collision risk of the novel operation, and to identify the key safety critical scenarios in the new operation. For the presentation of these key safety critical scenarios to operational experts, the i* model is expected to form a complementary formalism to the Petri net model.Future work includes looking to find a new way to identify and mark up the model with potential problems e.g. the technical agent is doing something wrong, the human agent doesn't understand. Currently these are modelled as soft goals, but another consideration is to extend the model with 'what-ifs' related to abnormal behaviours and states for coordination.

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USING I* MODELLING AS A BRIDGE BETWEEN AIR TRAFFIC MANAGEMENT OPERATIONAL CONCEPTS AND AGENT-BASED SIMULATION ANALYSIS

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Contents

Using *i** Modelling as a Bridge between Air Traffic Management Operational Concepts and Agent-Based Simulation Analysis

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Abstract— **This paper presents our experiences of exploring how *i** modelling can be used as a bridge between informal air traffic management (ATM) operational concepts and formal agent-based simulation. We report our work on an EU airspace design project that describes a revised concept of operations for lower level airspace around airports, and includes simulation based safety analysis of the critical scenarios. We describe our research towards using *i** to address two challenges – how to model the revised concept from the informal concept of operations document, and how to present safety critical scenarios to operational experts. Modelling strategic aspects of a concept of operations is new to ATM, and we draw upon our experiences to provide lessons learned and directions for future work.**

I. Introduction

Despite one off setbacks and more recent downturns driven by the global economy, air traffic in Europe has seen prolonged and significant growth over the long term. Although current traffic levels are back to around the 2006 level, and although flat or weak growth is expected in the short term [1] – longer term the historical growth rate is predicted as likely to recover, possibly stretching to a 2030 traffic level between 1.7 and 2.2 times the 2007 level [2].

An airspace system based on national boundaries was seen as one of the barriers to capacity growth, and so European Union has conceived and implemented a "Single European Sky" approach which aims to increase the capacity of the airspace by restructuring airspace use by focussing on lines of traffic flow rather than national boundaries. Supporting this, the Single European Sky ATM Research (SESAR) programme developed the 2020 operational concept to switch from an airspace-based to a trajectory-based (4-D) ATM system. This requires a new approach to airspace design, trajectories agreed before flight and conformed to by aircraft and revised rules for aircraft separation. In this context, the RESET project [3] has taken responsibility for the investigation and development of reduced separation minima, and the case study reported here is based on work within the RESET project.

An important part of RESET is the description of a revised concept of operations for lower level airspace around airports. This concept makes greater use of available technology, and changes in aircraft performance in order to justify reduced separations between aircraft. The concept description (called TMA T1) is a paper document comprising text and pictures, and described the people, process and technology to be used to ensure a safety and effective concept. It is an informal description of the concept, and as such is prone to omission and contradiction in the same way informal requirements documents are.

Given the critical nature of this change, RESET is conducting a preliminary safety assessment using distributed multi-agent modelling and Monte Carlo [4, 5, 6]. This is a complex undertaking as the modelling must take into account equipment performance, human performance and environmental factors such as the weather. This modelling is a formalised process, requiring well defined terms, constructs and relationships. Based on earlier applications of this agent-based approach, the following needs have been identified:

- The need for gaps in the operational concept to be uncovered and addressed before modelling begins;
- The need for a relatively simple model upon which the main safety critical scenarios can be explained to operational experts.

To address these needs we explored how the *i** modelling approach could be used. Our objectives were to discover whether *i** could be used to describe the revised concept from the concept of operations document, and how *i** could be used to present safety critical scenarios to operational experts.

The remainder of the paper is in six sections. Section II provides a brief description of *i** and its use in requirements projects. Section III describes our experiences of modelling the concept of operations and the planning of trajectories in the new concept. Section IV assesses our objectives, and Section V details our lessons learned. The paper ends with our plan for follow-up research in this area.

II. Using *i** in Requirements Projects

*i** is an approach with which to model information systems composed of heterogeneous actors with different, often competing goals that depend on each other to undertake their tasks and achieve these goals [7]. It is an established approach for goal modelling, and has been applied successfully to model systems in a variety of domains, such as decision support aids in agriculture [8] and control systems in the automotive industry [9]. In the last 6 years we have applied *i** to model requirements for four major air traffic management systems, including a departure management system for major European airports [10] and a system that supports the scheduling of UK airspace [11]. We successfully used *i** as a language to communicate complex socio-technical systems to a range of stakeholders.

*i** supports the development of two types model. The first type of *i** model is the Strategic Dependency (SD) model. The SD model provides a network of dependency relationships among actors. The opportunities available to these actors can be explored by matching the depender who is the actor who "wants" and the dependee who has the "ability". Since the dependee's abilities can match the depender's wants, a high-level strategic model can be developed.

The second type of *i** model is the Strategic Rationale (SR) model. The SR model provides an intentional description of goal and task elements and the relationships linking them. An element is included in the SR model only if it is considered important enough to affect the achievement of some goal. The SR model includes the SD model, and hence actors in the SR model either accomplish something by themselves or depend on other actors. The SR model has four main types of element: goals, tasks, resources and soft goals. These four types can be linked using the four relationship links available within the SR modelling semantics: the dependency link, the task decomposition link, the means-end link and its specialization, the contributes-to soft goal link.

In our requirements projects we support *i** modelling with a software tool called REDEPEND [12], which extends Microsoft Visio with features specific to *i** to enable requirements analysts to model and analyse SD and SR models. It provides a graphical palette from which analysts can drag-and-drop then directly manipulate *i** model elements. It also provides simple model analysis features to verify SD and SR models that, due to their size, are difficult to verify manually. Indeed, both direct manipulation and automated model verification are seen as essential for scaleable *i** modelling.

III. Modelling the Operational Concept in i*

For our first objective, we explored the use of *i** to model aspects of the TMA T1, including the rationale and objectives of the operational concept, the support system requirements and the description of human roles and their operations. It was important from the outset to create a broad view of the scope of the TMA T1 to identify potential areas of omission and contradiction in the specification.

We used REDEPEND to produce one SD model and one SR model showing key actors, dependencies, goals, soft goals, tasks and resources elicited from the operational concept. The *i** models were communicated between the authors via email, and were also discussed and reviewed via video conference. We report our main findings below.

A. Maintaining traceability between the i models and the concept of operations document*

In previous ATM projects [10, 11, 13] we used *i** modelling dynamically to elicit information with stakeholders, enabling us to clarify uncertainty and to reduce the likelihood of our own interpretations entering into the model. However, for this case study we did not have access to stakeholders during the modelling process, and worked remotely by reviewing the TMA T1 document. Therefore, we realised a need to maintain some form of traceability between concepts in the *i** models and the document.

As a result, we referenced each element of the SR model to the concept of operations document using a traceability function in the REDEPEND tool. This enabled us to trace back elements in the model to text in the TMA T1 document, and also indicate where we had introduced elements from a different source. We found this to be a useful cross referencing mechanism to ensure consistency and validity between the model and the TMA T1. We also introduced yellow notes on the model to indicate questions concerning potential missing dependencies. For example, we highlighted where it was unclear which actor provided a resource used in a task undertaken by another. Finally, we used an output function in REDEPEND to view a traceability report in MS Excel. Importantly, this showed the elements without a source which needed further investigation.

Figure 1 shows the three stages for applying traceability to the model using REDEPEND.

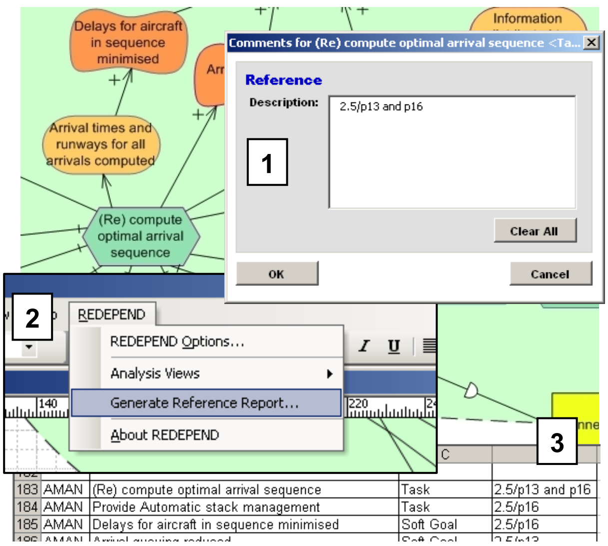

Figure 1. The three stages of applying traceabilty in REDEPEND: 1) Allocate reference to element; 2) Generate report; 3) Review Excel output

B. Reuse of components from an exisiting i model*

In order to address some of the gaps in the operational concepts SR model, we explored the possibility of reusing and referencing elements from one of our previous ATM projects [13]. Reuse in *i** is not a new concept, and has been shown to be cost effective in control system and software development [9]. With this idea in mind, we identified two actors that could be augmented using the previous model – the *Pilot* and the *Air Traffic Control Officer (ATCO)*. We brought in dependencies representing communications between the two actors and added tasks and goals related to general work practices. The existing model proved to be a useful source of information, as it was originally developed using expert input during modelling meetings and models of cognitive controller behaviour. Figure 2 shows the *Pilot* actor boundary, with over half of the elements being reused from the existing model (the elements from this case study are greyed out in the figure).

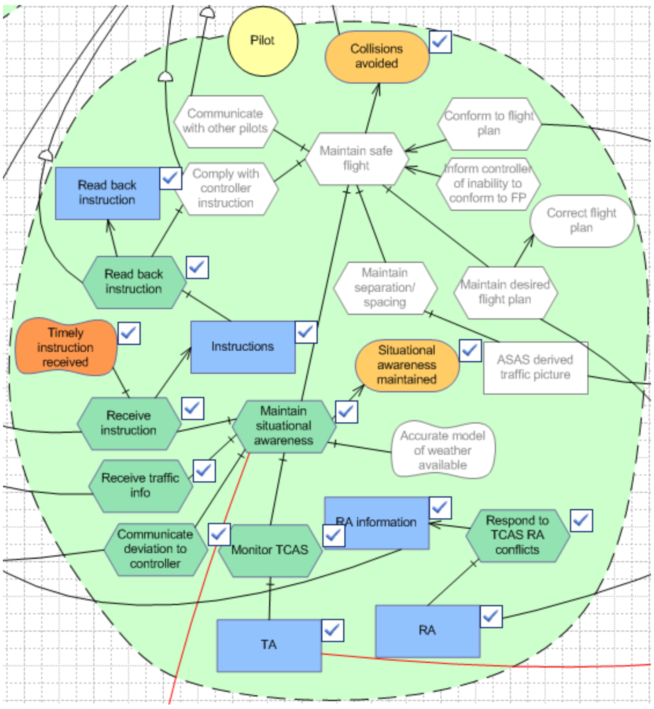

Figure 2. Reused elements from an existing *i** model highlighted in the Pilot actor from the operational concepts SR model

C. Aligning actors from the i model with agents in the simulation model*

As we planned to use *i** later on to communicate the scenarios, we needed to explore the alignment between the actors in the *i** models and the agents in the simulation models. The *i** approach models relationships between actors, including humans and machines, with strategic intent, that have objectives, rationales and commitments [7]. In the agent-based simulation models an agent is described as 'an entity that maintains and uses some form of situation awareness' and may include humans as well as systems.

We compared a list of agents from the simulation model with the *i** actors extracted from the TMA T1 document. We generally found consistency, except the simulation modelling also included an agent for each aircraft (with type, configurations and actual trajectory being flown) and an agent for weather (including wind for example). We had not modelled weather or aircraft type as actors in the *i** models and this presented a difference in the two modelling approaches. In essence, *i** is a class level view and the agent-based simulation approach represents an instance level. So, this raised two questions for modelling the agents in *i**: How do we model weather? and how do we model aircraft type?

Weather affects aircraft performance and therefore impacts on areas such as runway use and trajectories. In terms of *i**, weather does not have intention so should be modelled as a resource and not an actor. Interestingly, we identified more than one weather resource. The *Airline Operations Centre (AOC)* has a model of the weather which it passes to the *Pilot* via the *Flight Management System (FMS)* on-board the *Aircraft*, the *ATCO* has a model of the weather which it can also communicate to the *Pilot*, and the aircraft itself experiences 'actual' weather. Therefore, we concluded that *i** should not model weather as an actor, but provide 'hooks' in the form of resources to link with the weather agent instantiated in the simulation.

Aircraft is an agent as it has true state, while other agents just have estimates of its state. It was clear that we should model an aircraft as an actor in *i** at the class level, but it was no so clear how we should model the aircraft type, or the instantiation of an aircraft. It raised an interesting question of whether an actor in *i** could include a resource that tells it about itself e.g. I am aircraft type X. We concluded that *i** should remain at class level and stay abstract, while the simulation would instantiate different aircraft types. Again, we provided 'hooks' by modelling aircraft type as a resource within the relevant *i** actor boundaries.

D. Reviewing the models of the operational concept

The flat text-based TMA T1 document did not explicitly detail many of the dependencies between the actors. Obvious gaps were identified, for example we had not identified any dependencies between the *Executive ATCO* (*Tactical Controller*) and the *Planning ATCO* – two actors that we knew would communicate with each other with regards to the new concept. The *i** models also identified textual ambiguity between concepts in the TMA T1. For example, the name given to trajectories tended to vary depending on which actor was being described in the concept, which led to confusion as to whether it was indeed referring to the same entity. Applying dependency links between actors using such entities revealed some of these ambiguities. Many questions relating to the operational concept were raised which needed to be clarified, and these were documented in the Excel traceability report (Figure 1, Stage 3).

The development of the initial *i** models was much more demanding than we had anticipated. The problems we encountered mirrored those experienced during the agent-based modelling, with both approaches suffering from missing concept aspects. Our main finding was that whilst technical details were often well specified, key high level goals, roles and communication patterns were unclear. As a result, our *i** models reflected this and offered little as a bridge between the concept of operations and the agent-based simulation modelling. Therefore, we needed to be less technical and address some of the questions raised to develop a higher-level strategic model.

E. Moving to a more strategic planning based i model*

The key focus of the agent-based simulation modelling was the situation awareness of agents and the aircraft trajectories, therefore we needed a new *i** SR model view to zoom into this area. The SR model did not need to be complex, but needed to capture the relationships at a high level of abstraction to complement the more detailed agent-based simulation models.

The new SR model was drafted using existing meeting minutes from discussions between the authors and the originators of the TMA T1 document. These minutes covered the questions raised during analysis of the concept of operations, plus additional areas of interest to the planning of aircraft trajectories. The model was reviewed and improved following further video conference meetings.

We focused on the goals of human actors – *AOC*, *ATCO* and *Pilot* – rather than the support systems. Moreover, we decided not to allocate any goals to the support systems as we viewed the goals as belonging to the human roles that the technology supports. Common ATM goals were added, such as flights are safe, expeditious and efficient [14], but we wanted to draw out goals specific to the planning strategy, for example looking at any conflicting objectives of the AOC and ATC, and the position of the pilot.

The concept of operations contained some strangely formatted goals. For example, the Planning Controller goal to reduce Tactical Controller workload – an interesting goal, as the planner could send aircraft to another TMA if they really wanted to achieve it (albeit at the instance level). So, whose goal is it, and does the planner really have the goal to reduce the tactical controller's workload? The tactical controller clearly wants their workload reduced by the planner and depends on the planner for this i.e. they delegate the responsibility of this goal, but in terms of the ATM system it will only come about if this really is an objective of the planner. The Planning Controller's main objective is safety. Developing the model highlighted areas that needed to be considered in terms of goals and the ownership of those goals.

While producing the model, it was important to consider that different human agents can have different situation awareness, and that there are many things human actors can do that systems cannot. Another way of looking at it is that if a human has no clear role for coordination then they could be replaced by a system. For the simulation it was important to look for possible coordination tasks, which could be viewed as one actor looking out for another. Figure 3 shows the second SR model with an expanded section detailing the *Non-flying Pilot* actor. An important advance for this model was more detailed and accurate modelling of the coordination and goals related to the concept. For example, the new model specifies the *Non-flying Pilot*, rather than the *Pilot*, as the pilot-flying is not involved in activities related to the trajectories.

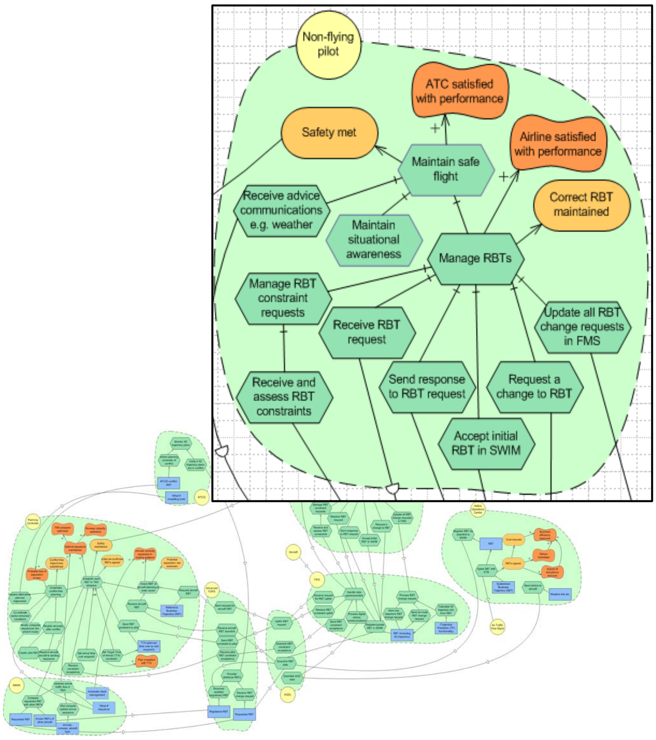

Figure 3. The second SR model with an expanded section showing the Non-flying Pilot actor

IV. Summary and Conclusion of the Modelling Process

Given the problems with the initial *i** models, the second *i** SR model has gone some way towards providing us with the basis for presenting the scenarios – our second objective. The model better reflects communication patterns and highlights the omission of goals in the concept of operations, raising further questions about the lack of high level goals in the TMA T1 document.

Whilst we met our first objective to model the concept of operations document in *i**, meeting our second objective was hindered by missing concept aspects in the TMA T1. Based on these findings, we would recommend that advanced ATM operational concept development could benefit by using an *i** modelling approach right from the beginning of the concept development process. Our experience of modelling the TMA T1 leads us to believe that *i** would be an effective method for uncovering gaps prior to the completion of a revised ATM concept.

V. Lessons Learned

We draw upon our experiences in this case study to outline lessons learned that we believe may be of interest to other RE practitioners. We divide these lessons into 2 types – lessons that describe how to apply *i** modelling in real-world requirements projects (A – F), and the final lesson that summarises the benefits that accrued from using *i** in this case study (G)

A. Communicate i via video conferencing to remove the need for face-to-face meetings*

The communication of *i** via video conferencing was a success and removed the need for face-to-face modelling workshops, thus saving on travel time (see figure 4). We broadcast the models electronically from REDEPEND – an advantage over teleconferencing – but also relied upon static PDF printouts for the review. The abstract nature of the *i** models helped to facilitate communication, as we were able to identify and address problems at a high level without the need for detailed supporting documentation. However, our meetings involved expert modellers, and there is clearly a need for the participants to have up-front detailed knowledge of the systems being modelled for this approach to work.

With goal modelling there is a meta-requirement for the case of comprehension – a detailed analysis of the visual syntax of *i** is presented in [15]. Therefore, we were interested to see how learnable *i** would be via a video conference link. The two authors new to *i** were able to understand the basic constructs after about 5 minutes of explanation, and their first impression of *i** as a visual language and a means for communication was good. They found the visual notation easy to learn, and managed to fully grasp the nuances of the SR model after about 30 minutes of analysing the models. A particular advantage they commented on was that the *i** models fit onto one page – unlike modelling techniques such as Petri nets and the 52 page concept of operations itself – whilst still detailing important relationships and quality aspects not available in other modelling techniques (e.g. UML)

Figure 4. Image showing a video conference and a printout of one of the *i** models under review.

B. Treat i modelling in terms of cost benefit analysis*

*i** modelling can be a very time consuming exercise, so we have found that it is important to maintain a record of the time and effort spent, and to think in terms of cost benefit analysis.

The initial *i** models were produced by the first and second authors during three ½ day meetings, with an equivalent time required to take on changes in between the meetings. The planning model required a total of 3 person days to produce. We held four video conferences each lasting between 1 to 1½ hours. The two simulation analysts spent approximately half a day each reviewing the models and formulating questions.

Our experience of developing the first *i** models highlighted that we spent too much time focusing on technical details of the support systems rather than taking a more strategic approach. This was partly due to the imbalance in the concept documentation itself. However, it is important to exploit the main advantage of *i** over other modelling techniques (e.g. UML) – modelling actor dependencies and producing high-level strategic models.

C. Reference i elements to source documents to improve traceabilty and understanding*

Without access to stakeholders, we realised the benefit of maintaining traceability between the *i** models and the source document. Referencing each element of the SR model gave us a mechanism to trace back elements in the model to text in the document, and also indicate where we had introduced elements from a different source. This enabled us to return to the document to remind ourselves why we modelled the element, and also indicated the areas that we needed to follow up with questions to the stakeholders.

D. Reuse components of existing i models*

The reuse of components from a previous ATM *i** model was helpful, especially as the original model was developed using expert input and models of cognitive controller behaviour, resources that were unavailable in this case study. This leads us to envisage a library of reusable agents, patterns and structures, likely to be representations of established systems and work protocols which could be 'plumbed-in'. However, our experience of plumbing-in components from the existing model introduced a level of detail and a flavour of goals that was not fit-for-purpose for the new exercise. In hindsight, it may have been more cost effective to have used the existing *i** model only as a referenced knowledge source rather than copying over sections of components and their relationships. We tended to be reluctant to remove carried-over detail, but it is important to remain strategic in the choice of elements and concepts to model.

E. Challenge goal ownership

Having identified a potential goal, choosing the actor to allocate it to in the *i** model can be more difficult than it first appears. Should you assign the goal to a technical system, the actor who desires it or the one who can achieve it?

In previous ATM projects [10, 11, 13] we have attributed goals to the technical systems as well as to the human roles. However, in this case study it made sense to model the goal with the actor using the support system i.e. we modelled the desired quality or objective of support service within the human actor boundary, rather than within the support system boundary itself. Modelling the goals within the human actor boundaries was more suited to modelling human behaviour for the simulation analysis.

F. *Use resources in i* models as 'hooks' to be instantiated in instance level modelling and simulation*

Our experience of trying to model weather and different aircraft types as actors in *i** led us to conclude that these were better modelled as resources. *i** is a class level view and although the simulation approach modelled weather and aircraft types as agents, we found that we could provide 'hooks' in the form of resources to link with the agents instantiated in the simulation.

G. *i* provides oportunities to improve the modelling of advanced ATM concepts*

Our main finding from this case study was that the traditional approach to developing an advanced ATM concept is not working well. Often technical details are well specified, but the key high level goals, roles and communication patterns are unclear. Using *i** to model a concept raises questions and discussion that might otherwise have been overlooked. From our experiences, we believe that *i** would be an effective method for uncovering gaps prior to the completion of a revised ATM concept.

VI. FUTURE WORK

In parallel to the *i** modelling described in this paper, a Petri net model is under development for the same operation using the formalism of Stochastically and Dynamically Coloured Petri Nets (SDCPN) [4, 5, 6, 16, 17]. This SDCPN model will be used to conduct rare event Monte Carlo simulations in order to assess mid air collision risk of the novel operation, and to identify the key safety critical scenarios in the new operation.

For the presentation of these key safety critical scenarios to operational experts, the *i** model is expected to form a more useful formalism than the Petri net model itself. We will look to find a new way to identify and mark up the model with potential problems e.g. the technical agent is doing something wrong, the human agent doesn't understand. Currently we have modelled these as soft goals, but another consideration is to extend REDEPEND with 'what-ifs' related to abnormal behaviours and states for coordination. This work would be based on scenario generation techniques from ART-SCENE [18].

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