FLEXIBLE UAV MISSION MANAGEMENT USING EMERGING TECHNOLOGIES

Track: **C2 Decision Making & Cognitive Analysis**

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Flexible UAV/UCAV mission management using emerging technologies

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Abstract

This paper discusses recent results and proposed work in the application of emerging artificial intelligence technologies for flexible mission management, especially for unmanned (combat) airborne vehicles. Military user needs are discussed for planning, monitoring and control tasks, along with relevant emerging technologies. A storyboard is described that depicts these military needs in the context of a scenario for countering mobile target threats. The paper concludes with a brief discussion of technical and non-technical barriers to integrating these emerging technologies within fielded systems, and an outline for the next steps.

1. Introduction

The increasing threat of highly mobile threats and the need to engage high-value targets of opportunity rapidly, make it essential that the mission management process for unmanned (combat) air vehicles (UAV/UCAV) occurs in a flexible, and (where appropriate) autonomous manner. The prevalence of joint and coalition operations has stimulated greater demand for more collaborative planning and systematic tasking, and greater responsiveness to in-mission changes.

Emerging artificial intelligence (AI) technologies promise support for key future needs, including the following:

- Flexible mission management, including mission planning, monitoring & control [1,2,3,4,5,6,7,8]
- Support for autonomous mission management [9,10,11,12]

This paper reports on research within QinetiQ on flexible mission management (especially planning, monitoring and control)[2] and has the following objectives:

- Determine and validate requirements for a flexible mission management tasks
- Demonstrate the benefits and limitations of emerging technologies to achieve this
- Define a strategy for migrating these new military capabilities into fielded systems

This research started in April 2001 funded under the UK Ministry of Defence (MoD) Applied Research Programme (ARP) and is aiming at military capabilities for the medium-term 2005-10. This paper briefly discusses relevant emerging technologies and describes recent work in generating a storyboard that depicts how they could contribute to flexible mission management capabilities.

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[1] QinetiQ was formerly an agency of the UK MoD known as Defence Evaluation & Research Agency (DERA). QinetiQ is now a private company fully owned by the MoD.

[2] Research on autonomous mission management techniques is being pursued in other QinetiQ teams.

2 Review of military needs and relevant emerging technologies

2.1 Military needs for flexible mission management

The usage of UAVs in military deployments as an ISTAR (intelligence, surveillance, target acquisition and reconnaissance) asset has risen dramatically in recent years. However, this rise has not been met with an increase in Command and Control (C2) personnel or communications bandwidth to service the need for integrated UAV C2. As UCAVs begin to be deployed more in hostile and high-risk environments, this demand will increase.

Under UK MoD funds, QinetiQ is investigating how emerging AI technologies can assist the C2 process, reduce the burden on UAV operators and support a more dynamic re-planning process. Although AI planning technology has been available for the past ten years, primarily in academia, it is only now that military systems are in place to exploit this technology fully, potentially in support of high-tempo military missions, as part of complex and distributed C2 systems.

Specific user needs in the area of flexible mission planning, monitoring and control include the following:

- **Planning** – Audit trail of key mission planning and scheduling decisions providing a shared understanding of plan rationale and critical information justifying these.
- **Monitoring –** Shared representation of assets and force package capabilities, including measures of performance (MoP) and effectiveness (MoE), but also task and mission progress and completion, especially for joint and coalition operations.
- **Control –** Validation of overall mission objectives, managing tradeoffs of mission constraints and resource conflicts, and dissemination of relevant commands and directives to mission forces at the right time.

Future UAV/UCAV missions are likely to be deployed and controlled from different ground stations and airborne assets, often for prolonged periods. UAV controllers will need to keep track of single and multiple UAV packages, with knowledge of all tasks planned and mission constraints. This knowledge must be passed on seamlessly to other (shift) controllers for long-duration missions, and shared with coalition partners.

As the demand for UAV/UCAV missions increases, especially deep into unfriendly territory and dangerous environments, so does the need for more autonomous mission management systems since UAV deployment is likely to outstrip both the communication bandwidth and available UAV remote pilots. To reduce operator workloads and provide greater precision for delivering payload, greater autonomy will be required for route selection and threat avoidance; weapons selection and release; and bomb damage assessment.

2.2 Relevant emerging technologies for flexible mission management

Mission/Collection Planning – Recent advances in knowledge-based planning techniques [1,2,3,7,8] and constraint-based scheduling technologies [5,13] and their successful application to complex military logistics problems[3], show that they are now mature enough to support mission/collection planning tasks. Together with

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[3] Fielded systems in Operation Desert Shield/Storm and recent advances in the DARPA Advanced Logistics Program (ALP).

commercially-available group working tools, they promise to provide a foundation for more collaborative/distributed processes, supporting the following:

- Generating new plans from past mission plans and generic plan fragments
- Auditing plans to comply with rules of engagement and other mission constraints
- Validating and testing the robustness of plans to alternative scenarios
- Propagating mission changes to specific plan decisions and viewing alternatives

The key for these techniques is to make use of explicit plan description languages that record planning decisions and capture plan rationale. These languages could provide the basis for an explicit ontology[4] for the mission/collection planning process. Controlled natural language understanding, generation and translation techniques also offer promise to reduce ambiguity of mission directives and tasking, particularly for coalition partners [16]. However, these may not be mature enough until circa 2010. The language must be such that words and phrases have a clear and unambiguous meaning. Not only does this aid the commander in conveying his intent; it also aids the audit process, and allows for plans to be translated into many forms for non-English speaker coalition partners or even intelligent machines.

Mission Monitoring & Control – Commercial workflow and group-working techniques are already gaining acceptance by the business community, especially when integrated with distributed database systems [15]. Other emerging technologies that could enhance the mission monitoring and control process, include:

- Procedural reasoning systems for monitoring the execution of mission plans and highlighting pre-defined contingencies in response to minor situation changes [2]
- 3D visualisation techniques, including stereo and virtual reality (VR) headsets, for operational and tactical views, rather than 2D for strategic overviews only
- Simulated annealing and genetic algorithms to optimise scheduling decisions
- Agent-based technologies for autonomous search and retrieval of past mission plans and plan fragments that best match the current mission [8,14]

So why use a computer aided planner for UAV/UCAV missions? If we were talking about a disjoint command and control network, the benefits would be outweighed by the cumbersome requirements of the humans-computer interface. However, the UAV is already a digital device, enabled by a link to a ground control unit. The planner is then the key element that ties together all of the components of a digital battlespace; the planner provides a method of linking human and AI elements, distributed working and, importantly for a restricted bandwidth operations, a compact representation of very detailed mission plans. Moreover, the plan can be handed over from user to user to machine, to user again without losing the mission's intent since its intent is implicit in the hierarchy of the planning goals.

The rest of this paper discusses the application of AI planning techniques for future UAV/UCAV missions in the context of a storyboard.

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[4] Ontologies provide standards not only for data within a specific domain, but also for the processes that use the data. For instance, a mission management ontology should include data models that describe mission activities, and also explicit representations of the mission management process and how information is used and updated within those processes.

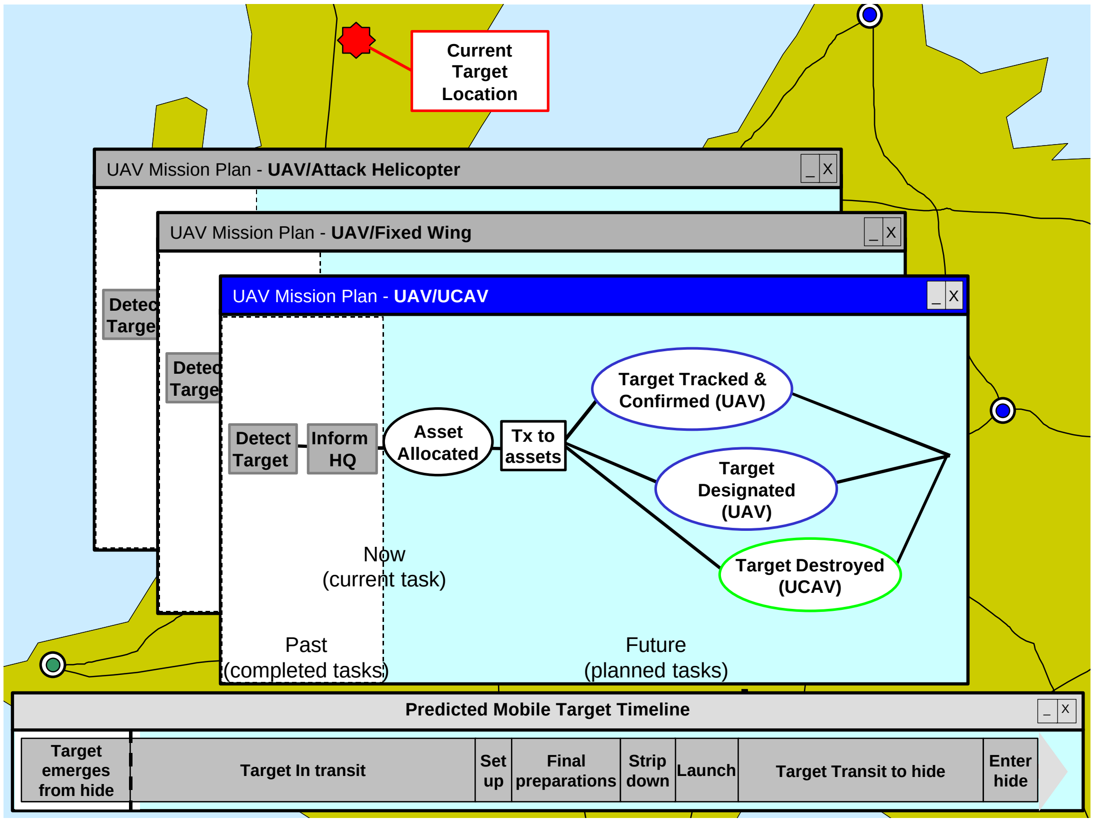

Figure 1. Several high-level mission plans and predicted timeline for mobile target.

3. Recent progress on storyboard development

An initial storyboard has been developed depicting how AI planning technology could contribute to a flexible mission management process. It describes a specific mission to destroy a mobile target, by re-directing UAV/UCAV assets already in-flight.

The storyboard begins with the detection of the mobile threat and projection of possible friendly targets. It shows the development of the high-level mission plan at the Combined Air Operations Centre (CAOC) and the allocation of mission assets and resources. Next comes the development of detailed mission plans by tactical wings and squadrons, involving UAVs for reconnaissance and the attack platforms, both UCAV and manned aircraft. Feasible assets are explored that best match mission constraints, and specific resource allocations made.

Figure 1 shows several high-level mission plans (HLMP) for dealing with mobile threats. These involve combination of UAVs together with UCAVs, fixed wing aircraft, or attack helicopters. A timeline shows the different stages of a mobile target launch. The stippled areas show completed tasks or past events, and the rest of the plans and timeline depict future plans and events. Figure 1 shows that the target has emerged from its hide, has been detected and CAOC has been informed.

Once assets have been allocated by CAOC, detailed planning is undertaken by the tactical wings and squadrons in order to achieve their objectives within the HLMP. Mission constraints and other plan rationale are also provided within the HLMP. The plan evolves in a hierarchical manner, with checks to ensure that constraints are not violated, activities do not interfere with each other and resources are not over-utilised.

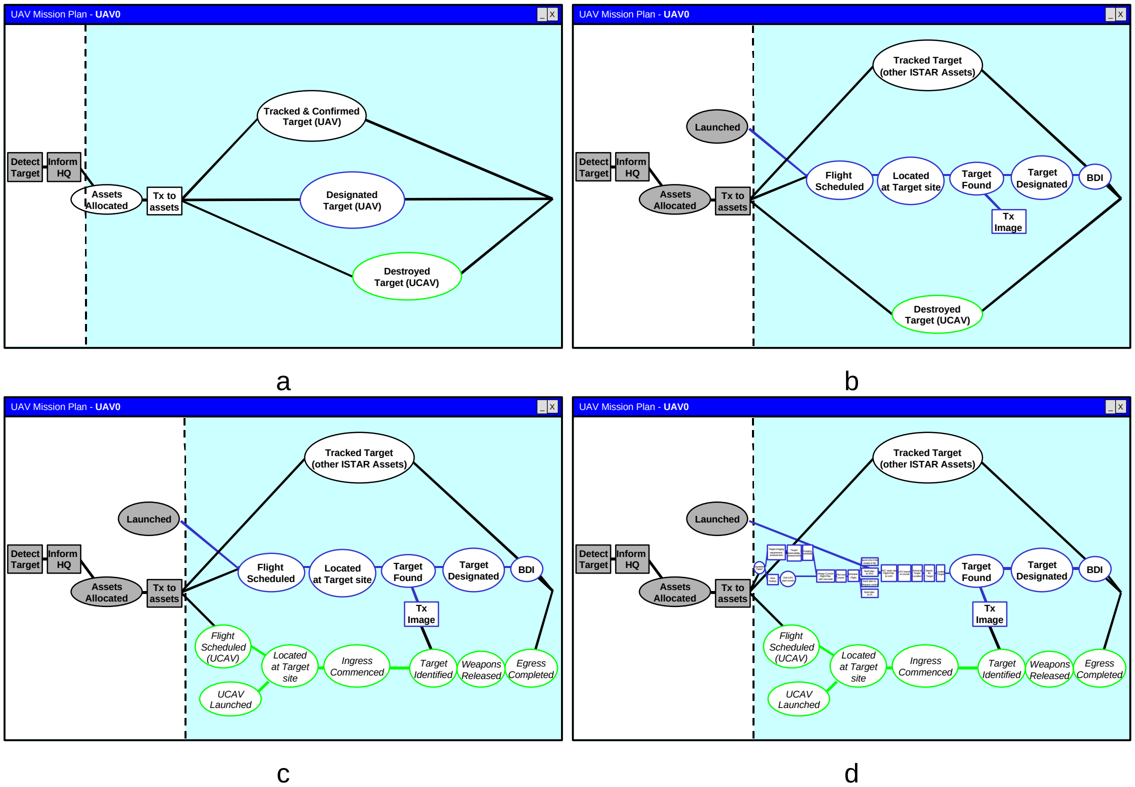

Figure 2. The evolution of a plan from HLMP (a), through more detailed steps (b)-(d).

Figure 2 shows the evolution of the high-level mission plan through more progressively detailed planning steps. Step (a) depicts the original HLMP with three remaining objectives to be achieved, denoted by ovals. Step (b) shows the decomposition of the `target-designated` objective into further sub-objectives, involving UAVs as reconnaissance assets. Specific activities are then planned for each sub-objective. As specific assets and resources are allocated to these activities, relevant constraints are imposed that may affect the duration and need for further detailed planning. Step (c) shows the decomposition of the `target-destroyed` objective, involving UCAVs. Dependencies between the UAV and UCAV missions are recorded, and these are further refined as specific activities and resources are determined. Step (d) shows the decomposition of sub-objectives into specific activities for UAV scheduled flight and transit to target area.

At each stage of the hierarchical planning process, the current state of the plan may be shared with other planners so that initial checks for consistency may be performed. Eventually, the detailed planning will be completed to an appropriate level of detail so that the entire plan may be checked for consistency and executed. Inevitably, early elements of the plan will need to be executed while remaining elements are being developed. The stippled areas in the plans above show the activities that are currently being executed or have been completed.

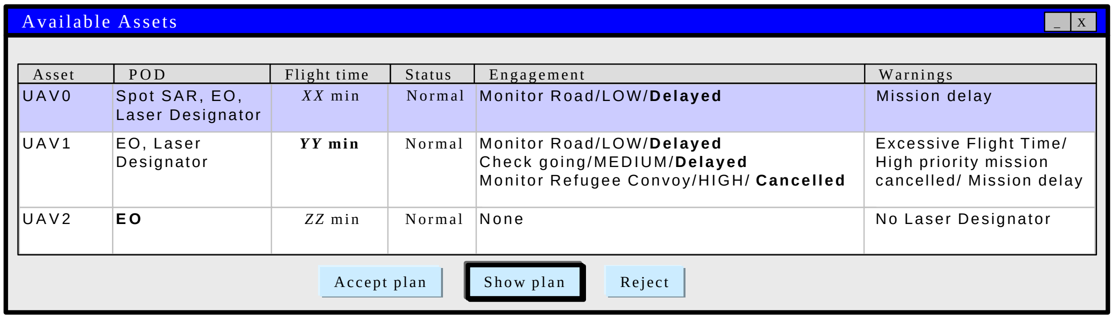

Figure 3. Available UAV assets and status information

Figure 3 shows available UAV assets for the achieving the `target-designated` objective. These are already in-flight with activities planned for other missions, but are within the area of interest for the current mobile threat. UAV0 is selected because the other UAVs are either too far from the projected launch site or do not have the relevant capabilities to achieve all mission objectives.

Figure 4 highlights a resource conflict denoted by the over allocation of UAV0 for two different missions. Figure 5 shows that the `monitor-traffic` activity can be achieved, since it is relatively close to the projected mobile target launch area, and a minor revision of the transit route can be accommodated.

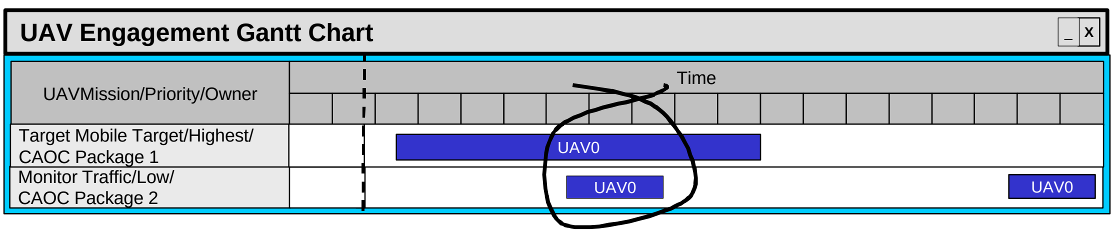

Figure 4. Gantt chart graphically showing the resource conflicts of two missions

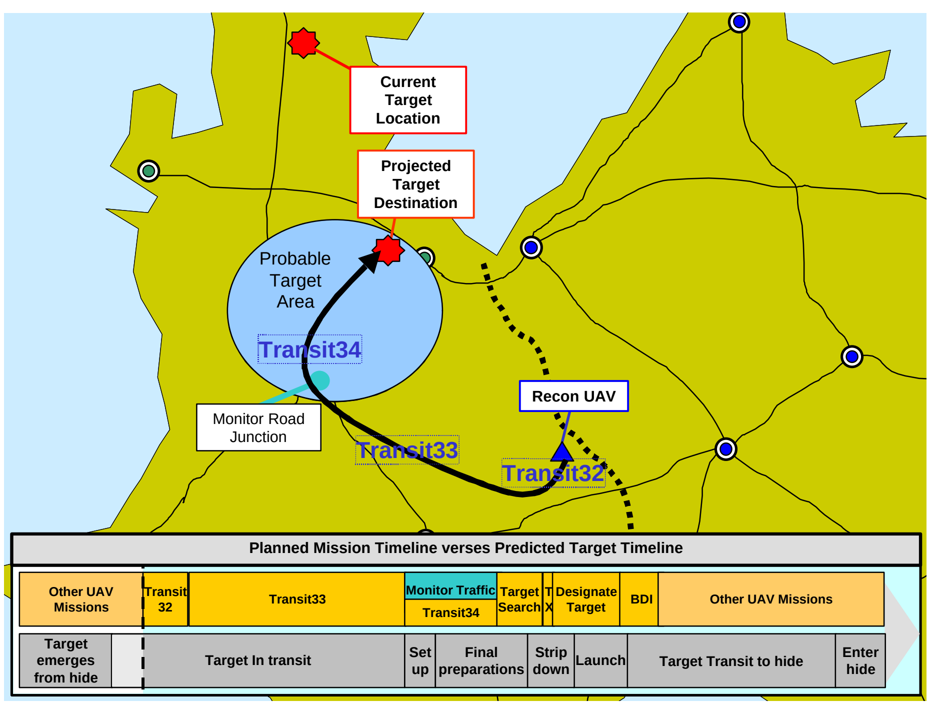

Figure 5. Incorporating the monitor traffic activity by modifying the transit route

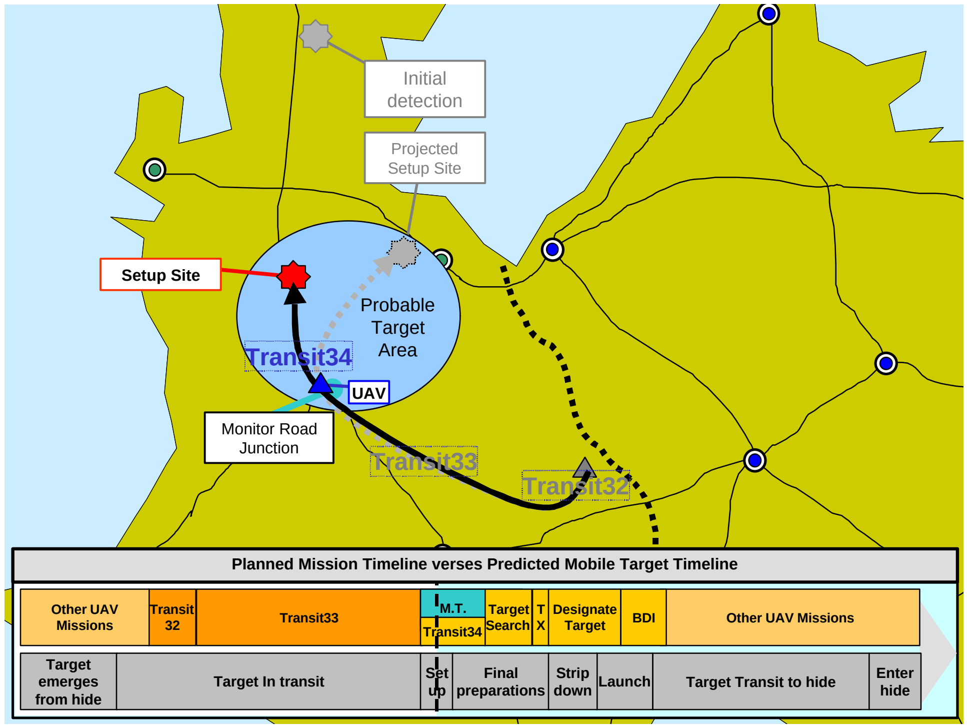

Figure 6. New mobile threat launch site with revised transit route

Once completed, the overall plan is distributed to entire mission team. By sharing the plan rationale with the UAVs remote pilot, the launch crew, the navigator, image analyst and airspace control, everyone can see not only their own element of the plan, but also how it fits with the whole.

Invariably, the situation changes and some of the planned activities are jeopardised because of operational delays, requiring contingencies and reserves to be brought into the main mission. Also, lower priority tasks may be achieved due to early completion of other more critical tasks. However, when activities fail to achieve their objectives, the plan needs to be reviewed to determine the consequence on other objectives, and appropriate revisions made to recover the situation. While some revisions may be minor, others may involve revision of higher level objectives that could affect major elements of the overall plan.

Figure 6 shows an example of a minor revision to the projected mobile threat launch site co-ordinates. As a consequence the transit route needs to be re-plotted to determine whether the UAV can reach the destination before it launches its mobile target, and also to determine whether the additional `monitor-traffic` activity can still be accommodated. In this case, both are feasible.

The storyboard provides a means of representing a variety of potential user needs that can be reviewed with end-users and prioritised for further experimentation. The graphical nature of the storyboard also supports early design for screen displays and human interaction issues. The storyboard will be continually updated to reflect the results of experimentation with emerging technologies, and will support the delivery of validated user requirements for flexible mission management capability, including support for mission planning, monitoring and control tasks.

4. Barriers to integrating AI technologies within fielded systems

The emerging technologies described here, especially hierarchical task network (HTN) planning, have been under development within several research laboratories worldwide for the past 15-20 years [1,2,3,4,5,6,7,8]. Several papers have been presented at previous CCRT symposia describing the application of HTN planning techniques for joint operations planning [5,6,7], but the technology still has not achieved widespread applicability. The technologies themselves have reached a good level of maturity, yet there are still technical and non-technical barriers to integrating them within fielded systems.

Many of the technical barriers have been resolved over the past 5 years. Processing power and the availability of large amounts of memory, even at the affordable end of the computer market, have now reached a sufficient stage to support mission management. The prevalence of web-enabled services and technology makes the sharing of information between different networks much easier. Likewise, emerging standards for explicit plan description languages and commercial collaborative group working environments also provide the glue between disparate planning tools (e.g. launch planners, flight path/route planners).

The real barriers are non-technical. Whereas the plan fragments within HTN planners are capable of representing military doctrine and expert knowledge, military standards still need to be agreed. Interoperability is the perennial problem. Wrappers around databases will help to support mapping information between databases, but at the end of the day, common or shared terms are critical. Another key barrier is security. As more explicit rationale is including within plan fragments, the more severe the security problem, since information will become more classified.

5. Next steps & Summary

The next steps involve experimentation and prototyping of capabilities described within the storyboard. The results of the experiments will inform and validate military user requirements for flexible mission management. The exact details of this experimental programme are still to be confirmed.

This paper has reviewed the military needs and emerging technologies for flexible mission management for UAV/UCAVs. It has described a storyboard for depicting these needs in the context of a mission for countering mobile threats. It has briefly discussed technical and non-technical barriers to integrating emerging technologies into fielded systems.

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