Supporting Threat Response Management in a Tactical Naval Environment

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Abstract

In this paper, we describe some of the initial results from applying a Cognitive Systems Engineering approach to develop representational aids to support single-ship threat response management on a Canadian Navy HALIFAX Class Frigate. We focused on the integration of the warfare plans by the ship's tactical coordinator within and across the air, surface, and subsurface warfare areas. We conducted knowledge acquisition sessions that included a review of related analytical, tactical, and doctrinal documentation and interviews with subject matter experts. A number of decision-making requirements were generated which were then used to develop three integrated design concepts: a common representation of the tactical situation that integrates the threats from each of the warfare areas; a representation of the response plan against the integrated threat picture; and a representation of multiple plans for comparison of the plans. This paper reviews various aspects in developing the first two of these aids. Together, these concepts form a powerful decision support tool for the ship's tactical coordinator and team to maintain an awareness of the current threat picture and to plan and implement responses to the threats.

1. Introduction

The work environment of shipboard Command and Control (C2) represents a complex sociotechnical system that is evolving in concert with a myriad of developments in sensor, weapon, communication and threat technologies. There are also accompanying changes in operational settings, organizational structures, and constraints. This can be seen, for example, by the current focus on littoral scenarios, asymmetric conflict, coalition operations, and network-centric warfare. These and other factors are leading to increased demands for time-pressured decision making in highly ambiguous tactical situations. They are also contributing to a rapidly growing data overload problem for a ship's Command Team.

Potential work demands on operators in this evolving environment can in fact take many diverse forms, from dealing with normal or routine activities all the way to unusual, and even unexpected, situations. Coping with these latter situations, in particular, may increasingly require operator knowledge and expertise that is simply not supported by current tactical and procedural doctrine. This is inevitably the case despite continual efforts to keep such sources of knowledge as current and comprehensive as possible. This can arise, for example, because the doctrine concentrates on providing tactical instructions and tactical procedures to operators to promote rapid, coordinated responses in sufficiently well understood or constrained situations. As such, it cannot deal completely with the domain's openness.

Advanced computer-based decision aids and displays represent a promising means of supporting operators in this type of work environment. For example, they can help alleviate the cognitive and collaborative demands operators need to deal with. Such technological solutions should also be instrumental in helping them, both individually and as a team, respond in an increasingly agile and adaptive manner in the face of growing complexity, novelty and change. However, few theoretical design frameworks exist that are explicitly aimed at tools for such a broad spectrum of work demands and situations [Vicente, 2002].

As the basis for developing tools to support shipboard Command Teams, we are exploring a work-centred, system-based design framework. This framework builds on emerging concepts in the field of Cognitive Systems Engineering (CSE) [Chalmers *et al*, 2002]. CSE is an interdisciplinary approach to the development of principles, methods, tools, and techniques to guide the design of computer-based systems intended to support human performance. It draws on cognitive science, computer science, human-computer interaction, human factors engineering, and related fields. One specific support paradigm we are investigating within this design framework is known as representational aiding [Bennett *et al.*, 1997]. Decision support in this paradigm is provided by one or more dynamic display units whose purpose is to transform data into information and organize the presentation of information to operators[1].

In this paper, we describe some of the initial results of our work applying representational aiding in the specific context of single-ship threat response management tasks of the tactical coordinator in the operations room of a Canadian Navy HALIFAX Class Frigate. We focus on supporting this operator with integrating warfare plans within and across the air, surface, and subsurface warfare areas, based on interactions with two warfare directors.

2. Support paradigm

2.1 *Background*

There are important lessons from operational experience, field research, simulation studies, incidents and accidents in a number of applied work domains about the significant challenges for designing computer-based tools to support the perceptual, cognitive, and collaborative components of the work in dynamic, complex work environments [Sarter *et al*. 1997], [Christoffersen and Woods, 2002]. For example, examining the consequences of the changes brought by intended technological solutions has revealed pitfalls in focusing too narrowly on optimizing the performance of the machine element. This focus has resulted in insufficient

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[1] Our use of the term 'information' is based on Woods' perspective about the relational nature of information as distinct from that of data [Woods, 1999]. There is no difference in the physical nature of data and information. However, unlike data, information is a relation between data, the world the data refers to, and the operator's expectations, intentions, and interests. This underscores that what is meaningful about data (its information) depends on the current context, which includes the current goals and expectations of its observer(s). In this use of the term, information carried by data is therefore relative, not absolute.

consideration of the work to be performed, the role the operator will play, and its impact on overall work performance. This can easily result in suboptimal, and even reduced, performance (e.g., [Sarter *et al.*, 1997]). Another common pitfall is to focus display design on providing the data required to complete domain tasks, while failing to also consider the demands on the operator to perceive and mentally integrate the data to extract the information required in the particular task context. The contrast in this case is between designing to support data availability as opposed to designing to support information extraction by the operator.

2.2 *Representational aiding*

To create decision support tools that are robust under the widely varying conditions of C2 work, we are looking at ways to design from a work-centred perspective that results in a cooperative system consisting of operators and computer-based tools. We are using a framework based on representing the environment's cognitive and collaborative demands and their support requirements. Our concern is with both the design process itself and its conceptual and physical design products.

One specific support paradigm compatible with this focus is representational aiding. Its principal motivation can be summarized as follows: provide operators with displays to allow them to 'see' directly the information they require rather than infer it using more cognitively intensive levels of data processing. By substituting efficient perceptual processing for more demanding cognitive processing, the expectation is that the demands on operators to determine and extract the information they need are reduced. This expectation is based on an important finding in the cognitive science literature that a problem's representation has a profound influence on the ease or difficulty of its solution [Zhang, 1997]. Zhang argues that external representations are so essential to many cognitive tasks that they guide, constrain and even determine cognitive behaviour. These remarks serve to emphasize the importance of external representations for helping operators reduce their demands to access and process data, comprehend its meaning, identify meaningful patterns of change, and take appropriate action. This support paradigm has also been referred to in the literature as information visualization [Card *et al.*, 1999].

Another important consideration in developing external representations for this environment stems from the possibility of also providing tools to share such representations among groups of operators (e.g., as in a group or collaborative display). This may offer the opportunity to alleviate some of the demands associated with co-located or distributed cognitive work (e.g., shared intent, shared awareness, interaction and participation of team members).

To usefully exploit the power of representational aids, we need to understand how to develop representations to describe the semantics of tasks matched to the operators' expectations, intentions, and interests. We also need to understand how to map these representations to operator displays so as to reduce the cognitive demands to extract the information, and make tactical decisions.

3. Response Management on a HALIFAX Class Frigate

The tactical coordinator on a Canadian Navy HALIFAX Class frigate is the Operations Room Officer (ORO). The ORO serves as the 'integration point' of the air, surface, and sub-surface warfare areas, as well as of both internal and external events that pertain to own ship. This operator must therefore be alert to developments and changes in each area, and what they mean in the context of the mission and the ongoing tactical plan, so as to be able coordinate responses to threats. The ORO is supported by two warfare directors, who direct and control tactical operations in their own warfare areas. One of these is the Sensor Weapons Controller (SWC) who focuses on the Above-Water Warfare, comprising both the Anti-Air Warfare (AAW) and Anti-Surface Warfare (ASuW) areas. The other director is the Assistant Sensor Weapons Controller (ASWC) who focuses on the Anti-Submarine Warfare (ASW).

The ORO's response management (RM) tasks can be defined generally as encompassing all actions and activities aimed at: assessing and prioritizing threats; preparing and implementing response plans; making changes or adapting those plans in the event of plan failures or newly developing constraints; managing the direction and control of operator and combat resources for implementing these plans; and assessing the outcomes of implemented actions.

Recognizing the breadth of these RM tasks, we decided to limit the scope of our initial design work to one area, plan integration, where there are significant demands on the ORO's expertise and active involvement. We identified this area as follows. In the first place, we considered the extent of coverage in current tactical doctrine. Not surprisingly perhaps, doctrine in each warfare area tends to focus on responses to individual threats. Tactics to defeat multiple threats that occur simultaneously, and within one or several warfare areas, receive less coverage. Yet such situations introduce significant cognitive and collaborative demands on the ORO due to dynamically changing interconnections between goals and response actions to deal with individual threats in one or more warfare areas (e.g., goal-subgoal relations, mutually constraining or conflicting goals, resource constraints). Interviewing an ORO with recent operational experience also indicated that although aided by his various warfare directors in their separate areas, in order to successfully understand the context and appropriateness of a response plan the ORO must also be continually generating and establishing the details of his own response plan[2]. This happens as the individual concerns and proposed plans of his two directors are generated, validated, and then integrated or coordinated into a single plan, and the impacts on other own ship operations assessed by the ORO. For simplicity, we refer to these activities collectively as plan integration.

4. Method

Our approach is based on the framework for exploratory design described in our earlier work [Chalmers *et al*., 2002]. However, in light of the scope of the current work, we placed less emphasis on developing formal models of the ORO's work demands, and more on conducting knowledge acquisition to directly identify decision-making requirements related to plan

[2] The use of the masculine pronoun throughout the paper is not intended to be gender specific.

integration. The specific design approach we followed included:

- identification of cognitively-based planning models to develop a preliminary, high-level understanding of the ORO's cognitive demands;
- knowledge elicitation with subject matter experts (SMEs) to determine the cognitive demands of plan integration, difficult scenarios in plan integration, and how they impact the decision-making process;
- construction, aided by SME inputs, of an operational scenario involving multiple threats spanning the AWW and ASW areas to serve as a mechanism for knowledge elicitation as well as a context for a storyboard mockup of the resulting design concepts;
- generation of decision requirements within the problem space to serve as the analytical basis for constructing design seeds [Patterson *et al*., 2001] for decision support concepts;
- generation of design seeds to support the ORO's plan integration task; and
- a review of the design concepts with SMEs to get feedback on the display representations and to identify gaps in capturing the demands of the work space.

5. Cognitive models of planning

In designing to support plan integration it is not enough to understand the planning processes themselves. From a CSE perspective, system designers also need to understand the cognitive processes and information processing strategies that this operator could employ. This is needed to ensure that computer-based tools can indeed support his tactical decision making. There are many descriptive models of human decision-making processes in the cognitive science literature that can provide insights for this purpose. However, as [Andriole and Adelman, 1995] point out, there is substantial empirical evidence demonstrating that human information processing and decision making are extremely sensitive to task characteristics. This can make it difficult to generalize basic research findings to complex organizational settings.

We examined the planning portion of the Canadian Forces Operational Planning Process and a number of descriptive process models of decision making to explore the cognitive demands associated with planning. Various components of the operational plan can impact directly or indirectly the ORO's tactical planning. The descriptive models, drawn from the Naturalistic Decision Making literature [Zsambok and Klein, 1997], provided insights into the types of intuitive strategies one could expect an ORO to employ in developing an integrated tactical plan based on inputs from the SWC and ASWC.

The various planning models helped suggest a number of areas where representational aiding could be a useful paradigm to support the ORO. These included developing an explicit, external representation (i.e., in a display) of the plan that he could interact with, as well as use for structuring interactions with his directors about their own plan proposals. This representation could support war gaming, plan rehearsal, and plan execution. It could also support plan generation and plan selection based on generating and explicitly representing temporal or other constraints and relationships among plan elements, plan quality, etc.

One aspect of the operational environment that is not adequately captured in existing models relates to the incremental generation, maintenance, and iteration of plans over time and as the situation and knowledge of that situation changes. An important consideration is the impact on these processes of time pressure and uncertainty. To address this, we adopted a rolling horizon decision-making framework that breaks planning into three discernible phases. In this framework, summarized below in Fig. 1, initial plans are created in a ‘deliberative planning’ phase of operations. In the present work environment, this would be during the pre-mission preparations, as a result of the Operations Task (OPTASK) briefing on a HALIFAX Class frigate detailing the anticipated threats and associated responses. In deliberative planning, tentative courses of action are drawn up given the available knowledge about the potential situations that could arise. As the time perspective becomes shorter, these initial plans are assessed, revised, and refined to a greater level of detail in a ‘forecasting’ phase. This would be analogous to updates to the OPTASK, or changes in weapon, sensor and information system settings based on anticipated threat location (e.g., setting an engagement sector to automatically engage a known type of supersonic missile threat). Finally, as the events unfold and replanning becomes necessary in response to known specific threats, there is a ‘reactive replanning’ phase. In this phase, real-time reactions are required to implement plans or make changes to the existing plan.

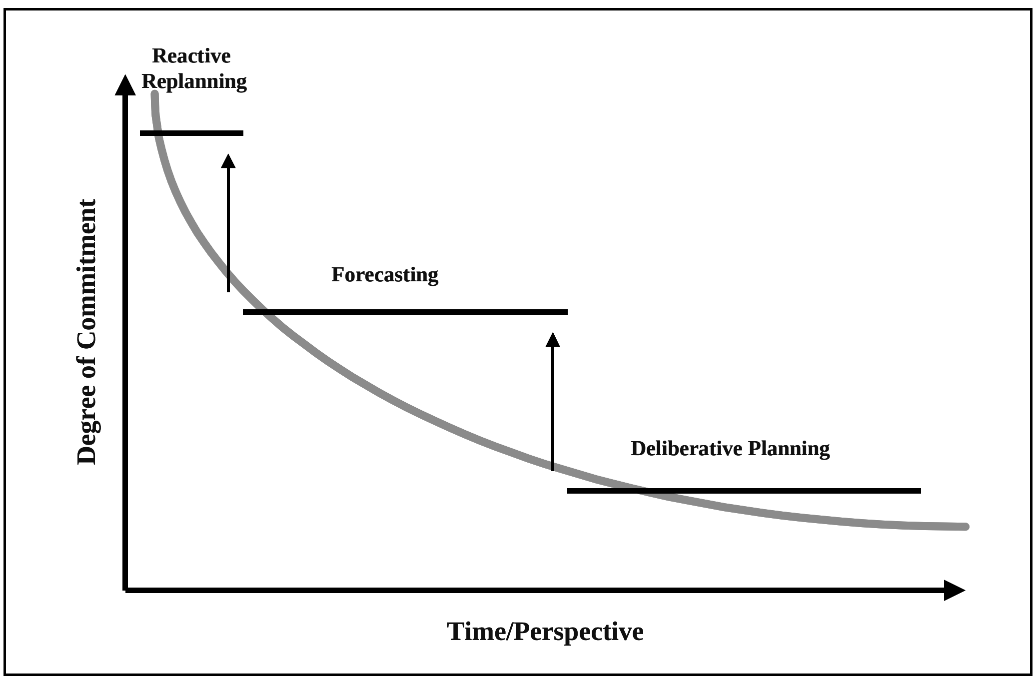

Figure 1. Rolling horizon framework for modeling decision-making behaviour

A key point in this framework is that forecasting and deliberative planning are required in order to prepare for the anticipated situation as there is simply not enough time and cognitive resources for operators to cope without advance preparation. A second significant aspect is that the decision-making process for the three planning phases is not significantly different other than the processing breadth and depth required in each phase. As the situation evolves from deliberative planning through forecasting to reactive replanning, knowledge about the situation improves and the planning depth increases while its breadth decreases. Alternatively, there is an increasing degree of commitment to the decisions that specify and constrain the actions to be taken. For example, in deliberative planning, only broad, high-level responses need to be defined. However, these responses must be prescribed for all anticipated threat situations. In reactive replanning, specific, detailed procedures are specified, but only for the particular threat situation.

Evidently, the planning process should operate fluently and seamlessly across the complete planning spectrum in Fig. 1 so as not to impair the ebb and flow of the work and its various intermediate products among the ORO and his directors. This has implications for designing tools to support this whole process. In fact, from this work-centred perspective, there appear to be benefits from developing this framework even more generally to encompass both operational and tactical planning as a basis for determining planning representations and planning products that can be shared, as needed, to facilitate planning across the various C2 levels.

6. Support requirements

6.1 *Knowledge elicitation*

Knowledge elicitation sessions were used to supplement a variety of other sources of knowledge about the work environment, including current documents on tactical doctrine and a previous Cognitive Task Analysis of the ORO position [Matthews *et al*., 1999]. Two days of semi-structured interviews were conducted with three SMEs drawn from various operator groups. All had extensive and recent operational experience on the HALIFAX Class. One was currently an ORO instructor concerned with tactics and team training. Two were actively involved in producing and evaluating naval tactical instructions and tactical procedures for the AWW and the ASW. They were interviewed as a group to also facilitate discussions and help highlight different perspectives on the problem domain. Topics covered included:

- critical issues of the plan integration task (e.g., constraints, demands, required expertise);
- scenarios that can stress the decision-making processes involved in plan integration; and
- identification of the difficulties or problem areas for plan integration.

This knowledge elicitation produced a representative set of decision-making requirements, as well as the basis of a tactical scenario around which a storyboard mockup of the resulting design concepts could subsequently be developed.

6.2 *Decision-making requirements related to plan integration*

Decision-making requirements correspond to various aspects of the decision-making processes involved. They include the cognitive demands, the decisions that need to be made, and the information the ORO needs to make those decisions. Decision-making requirements were defined in five areas. We describe these at a high level.

Situation Awareness

The ORO must maintain a level of situation awareness appropriate to each planning phase in Fig. 1. In particular, he is actively involved in gaining an understanding of the threat picture as well as own ship's resource and response capabilities to be able to develop his plans without 'sitting back' and waiting for plans to be proposed by his warfare directors. This is consistent with his broader focus on the mission, the warfare areas, and overall ship operations.

Plan Generation

To understand the context and appropriateness of a threat response plan, the ORO must be engaged in his own planning considerations. This includes: determining the main issues to check, including task group tasking; determining courses of action, including an assessment of how they fit with pre-plans and the existing plan; assessing first reactions, including necessary ship manoeuvres or changes in the ship's readiness; determining operations room staffing, state of preparedness, and the status of current tasks; determining action constraints such as rules of engagement (ROEs); and determining deadlines for existing plan elements.

Plan Assessment and Validation

There are a variety of ORO decisions related to the evaluation of the SWC's and ASWC's proposed warfare plans. Essentially, he is asking whether the director has dealt appropriately with a number of aspects, such as: "Does the plan cover all factors and all perceived threats in the warfare area?"; "Is the information used to plan correct?"; "Are the tactics proposed to defeat a threat applicable or appropriate to the situation?"; "What are the risks to own ship with the proposed plan?"; and so on.

Plan Integration

In plan integration, the ORO is concerned with developing his own plan, as well as integrating response plans from his directors with his own to develop a single, unified plan. To do this, the ORO must apply a single threat assessment scale across all warfare areas (e.g., is a torpedo more threatening than a missile, or is an enemy surface ship more threatening than the potential loss of own ship's helicopter?). He has to combine engagement orders to assure the maximum effect for the various tactics involved. This also requires checking that critical go/no-go decision points in a plan leave an adequate time-to-decide for each warfare area and that the required resources can be deployed as and when needed. Multiple perspectives may also need to be considered (e.g., own ship's, the threats'). The ORO must also assess the quality and risk of the resulting plan, its completeness in dealing with all threats, and its compliance with existing ROEs.

Impact Assessment

These requirements relate to the ORO's assessment of the impact of a tentative integrated plan on own ship's capabilities, vulnerabilities, and mission objectives. There are also assessments of a plan's impact on current and planned own ship operations and those of the task group.

An effective plan is susceptible to changes due to changes in the problem domain, e.g., new targets, unexpected other ship manoeuvres, depletion of nonrenewable resources, degraded systems and equipment. As a result, the ORO will need to revise and re-evaluate the integrated plan. The reevaluation will include the issues mentioned previously such as validation of the underlying inferencing and reasoning behind the plan, effectiveness of the plan in addressing all targets, and effectiveness of the tactics.

7. Design seeds

According to [Patterson *et al.*, 2001], a design seed is some specific and relatively independent support concept that can be explored by a design team to support users. A seed can be individually evaluated for its usefulness, as well as iterated based on feedback from SMEs.

There is considerable scope within the various areas of decision-making requirements identified in Section 6.2 for representational aiding. The knowledge elicitation sessions helped identify critical frames of reference that capture meaningful relationships in plan integration for the ORO. The purpose of a representation aid is to make such information frames externally visible to the ORO and help shift task related cognitive activities to more mentally economical forms of processing (e.g., more parallel, more perceptual, more automatic). We developed design seeds to represent visual displays of such relationships. In our work, a design seed was defined by:

- the rationale or basis for the design concept;
- the design concept itself – a description of the characteristics and behaviour of the concept;
- the decision support that the concept is aiming to provide;
- the requirements for machine inferences or other automation support; and
- an instantiation of how the design concept plays out in the domain.

We have developed three design seeds to date:

- A common representation to support planning that integrates Air, Surface, and Sub-Surface threats (Integrated Threat Picture);
- A representation of a response plan against the integrated threat picture (Response Plan Manager); and
- A representation of multiple plans for plan comparison purposes (Response Plan Comparison).

We briefly describe the rationale and concept of the first two seeds, and the support they are expected to provide.

7.1 *Integrated threat picture*

7.1.1 *Rationale and design concept*

A key insight from this effort is the need for a mechanism to integrate air, surface, and sub-surface threats into a single representation. Moreover, given the importance of time in response management, time needs to be a critical part of an organizing framework for the integration. While doctrine and historical practice tend to focus on distance and relative positions of objects as the critical consideration in engagement management, technological developments suggest that time, not distance, should be the critical metric. This is because the relative potential velocities of platforms and weapons now vary to a much greater extent than previously. In addition, it is no longer necessary for weapon delivery mechanisms to be pointed at the potential target for engagement, nor for weapon platforms to be at their closest point of approach before engagement. These and other factors have contributed to an increased importance of time as the variable driving decision making in responding to threats. Unfortunately, current systems provide little insight into the time that is available for decision makers to develop tactical plans and integrate the inputs from the different warfare areas.

It is also important for the ORO to be able to differentiate between individual threats so that the appropriate resources can be assigned to defeat them. Satisfying both individualization and integration issues is critical to addressing one of the major challenges of the ORO’s position.

To make ‘time-to-decide’ more explicit, we developed a design concept for tracing targets individually, as well as in an integrated manner, with respect to time to own ship for self-defence and time to high value targets. This type of temporal representation should be in addition to the more common geo-referenced, tactical displays, not a replacement to them, because positional and trajectory information also provide key information for many decisions (e.g., identification of tracks). There are a number of possibilities for incorporating ‘time-to-decide’ in a representation. For example, [Chalmers *et al*., 2000] represented temporal distance to a threat by the sum of the time the contact is projected to reach its closest point of approach (CPA) and its CPA distance from its target transformed into units of time (e.g., the contact’s CPA distance divided by its speed). This was meant at the time to preserve the concept of CPA as an integral part of the ORO's model of the threat situation. However, an interesting alternative concept that emerged in the current knowledge elicitation sessions is to base time-to-decide for engaging a platform on its likely weapon release point.

The sample visualization in Fig. 2, shown in simplified form, uses ‘time-to-weapon-release-point’ plus ‘time-to-impact-of-weapon’ as the approach for organizing air and surface contacts. In particular, ‘time-to-weapon release point’ is defined as the time (based on speed/distance/heading calculation) until the weapon platform can reach the maximum weapon range of its weapon. Then, ‘time-to-impact-of-weapon’ is defined as the time for the weapon to reach own ship (again, based on a known maximum speed/distance calculation). Each contact is plotted on the graph based on the sum of these two metrics. Each contact also has a leader extending to the left to depict the ‘time-to-impact of weapon’ component. Thus, if a threat platform is outside its maximum weapon range, its leader will not reach the left edge of the graph. As a platform travels within the envelope of its maximum weapon range, the leader will then indicate the 'time-to-impact-of-weapon' if launched from that point. As technologies are incorporated to improve localization of ASW threats, it may make sense to also use this approach for ASW threats. Fig. 2 indicates another approach based on making localization uncertainties explicit in the representation. It shows a reported submarine threat that is localized only with respect to its Furthest on Circle. In this case, the submarine icon is not placed on the time axis and the left point of its leader indicates the time to go before this Furthest on Circle reaches the submarine's target.

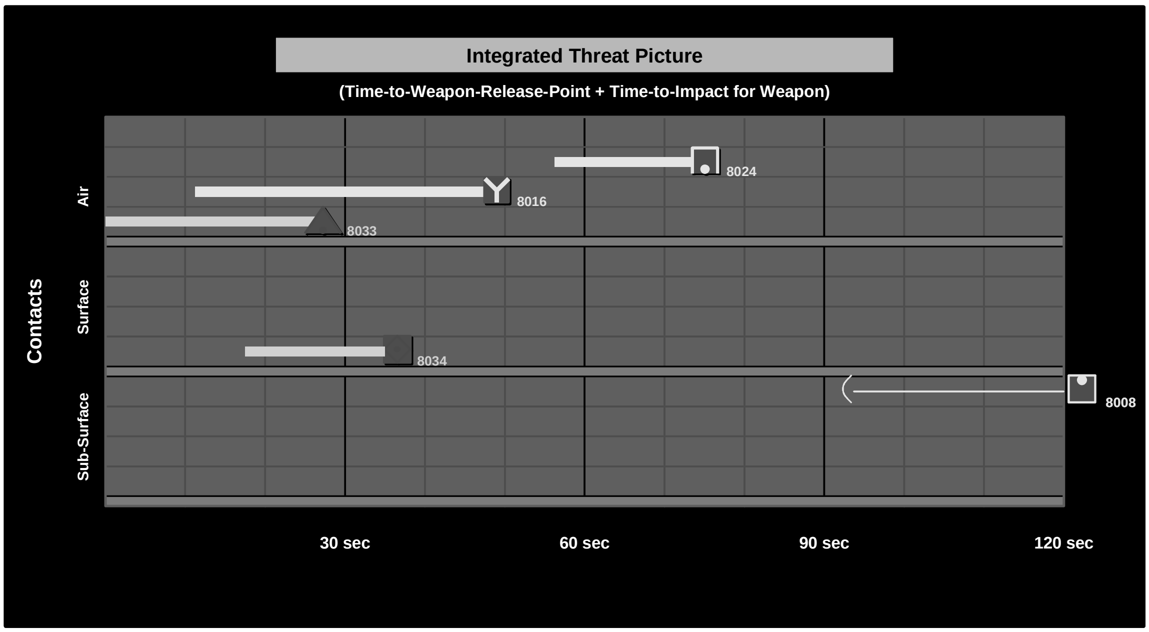

Figure 2. Integrated threat picture display concept

7.1.2 *Support provided*

This design concept will provide the ORO with an integrated representation of the most threatening contacts in the order of importance (based on temporal proximity). Specifically, this visualization will support the ORO in easily determining various times that are critically important in making prioritization tradeoffs in responding to multiple threats across the warfare areas.

7.2 *Response plan manager*

7.2.1 *Rationale and design concept*

Geo-spatial representations in standard tactical displays provide critical information for developing plans (e.g., placement of static targets, the identification of regions of interest, the relative distance between physical objects). However, such representations do not provide a means for easily determining if an asset is not only at the right place, but also there at the right time. One of the challenges faced in current naval operations is that plans can be proposed with timelines that cannot be maintained. Without a means to monitor the timeliness of an operation it is difficult for decision makers to gain experience that allows them to accurately estimate the time necessary to accomplish a specific task.

In this vein, current systems do not support the representation of planned engagements in the context of an integrated threat picture as well as when targets are engageable by own ship weapon systems. The characteristics of weapon systems and those of the target will impact when a target becomes engageable. From a response management perspective, the ORO has to develop plans that satisfy a number of constraints, e.g., capabilities of own ship's weapons systems, ROEs, the ship's manoeuvrability.

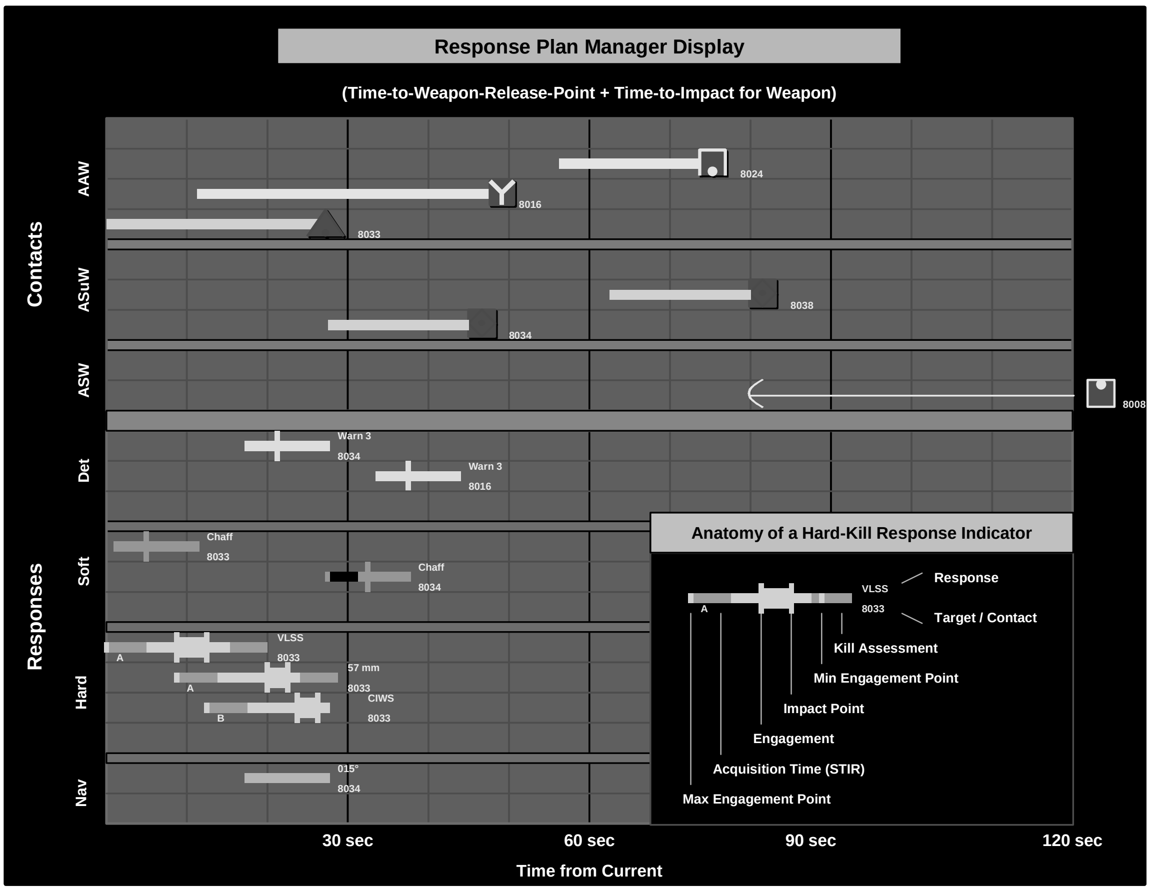

Figure 3. Integrated plan manager display concept and the anatomy of an individual hard-kill plan element

To support the ORO in keeping track of target engageability constraints, decision support is needed to portray this information. The necessity of also developing design concepts that more generally address the temporal nature of plans is also a natural consequence of the requirements identified in Section 6.2. The response plan manager is one support concept in this direction. The integration of geo-spatial representations, an integrated threat picture, and a temporal plan representation should then provide a more effective means for assessing and revising tactical plans.

This design seed is an extension of the previous design concept such that a temporal representation of the response plan is presented in concert with the integrated threat picture. The goal is to provide the ORO with a means of assessing the current response plan in the context of the temporal constraints of the threats. In this manner, constraints and bottlenecks in the response plan can be identified visually and an assessment made of the plan's viability.

Figure 3 illustrates one concept for displaying a response plan that consists of deterrence (e.g., warnings), soft-kill, hard-kill, and manoeuvre types of responses. Each response type serves as an organizational grouping. The temporal dimension (the abscissa of the graph) is anticipated time based on the calculations for the individual targets.

In conjunction with the integrated threat picture provided by the 'Integrated Threat Picture' display concept, this 'Response Plan Manager' display concept presents the response plan in the context of these threats. At a detailed level, each of the plan elements has a contact identifier attached to the plan indicator. The navigation component of the plan contains the own ship orientation changes over time, with the resulting orientation indicated at the end of the manoeuvre time. An example of the anatomy of a detailed plan element for a hard-kill engagement is also shown in the insert in Fig. 3.

7.2.2 Support provided

This display presents the ORO with an integrated picture of the response plan (AAW/ASuW/ASW) in the context of the current threat situation. In addition to the points already made, it is worth noting that this display concept also supports the 'Planning as a Rolling Horizon Decision-Making Process'. All of the planned responses are based on assumptions and estimates about the behaviour of the threats. When threats are 'far away' from their targets (in space and time), the responses are, by necessity, imprecise and vulnerable to changes as time passes. They will inevitably need to be revised as the threat approaches own ship and more precise information is known about the threat. Response plans for threats that are 'close' to their targets must be more precise (as the time for revision shortens). As a result, the degree of commitment to these plans increases until the point at which the plan must be put into action.

It may be helpful (given the apparent similarities) to summarize the principal differences between this display concept and the 'Response Manager' portion of the one developed in the TADMUS (Tactical Decision Making Under Stress) program [Morrison *et al.*, 1997].

Proposed 'Response Plan Manager'	**TADMUS 'Response Manager'**
• Portrays the collection of planned events in response to the collective set of threats	• Portrays the set of doctrinal response windows on a track-by-track basis
• Portrays range as time	• Portrays range as distance
• Encompasses limits on individual weapon systems; not ROEs	• Encompasses ROEs and battle orders
• Portrays future expected events	• Shows what actions have taken place

8. Conclusions and ongoing work

We have described how a Cognitive Systems Engineering approach has been used to first identify decision-making requirements for the plan integration tasks faced by Operations Room Officers in threat response management onboard a HALIFAX Class Frigate and, second, to explore 'design seeds' in the form of visual representational aids to support these tasks. Three integrated design concepts have been generated to date – a common representation to integrate the air, surface, and sub-surface threats (the 'Integrated Threat Picture'), a representation of the response plan against the integrated threat picture (the 'Response Plan Manager'), and a representation of multiple plans for comparison (the 'Response Plan Comparison').

There has only been a limited review of the design concepts by SMEs so far. To do this, we developed a tactical scenario involving multiple threats and a storyboard mockup to dynamically illustrate how the various display concepts appear and how the display representations change as the events in the scenario take place. Although very favourably received, reactions by SMEs to the concepts also indicated that OROs will need to be able to actively control, according to their specific needs, the level of detail in the information presented.

Further work needs to be conducted to expand the problem space of design concepts, increase the usefulness of the design concepts, and instantiate the various concepts as a basis for more in-depth assessments by SMEs. Finally, although we have not examined this aspect here, looking at the automation requirements for the various seeds readily suggested a number of automated aids that would be natural extensions to the current support concepts. For example, planning needs to respect a large number of constraints. It is easy to see how a plan that the ORO is developing could contain a number of errors or be inconsistent with applicable tactical procedures. Computer aids to analyze plans for constraint violations or for their proposed tactics naturally emerge as an area for providing additional support capabilities.

9. Acknowledgements

We would like to acknowledge the help of several naval officers from the Canadian Forces Maritime Warfare Centre and the Canadian Forces Naval Operations School who provided SME inputs through interviews related to this work. In alphabetical order, they are: LCdr Michael Hambley; LCdr Mark Higginson; LCdr Guy Lavoie; and LCdr John Zorz.

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