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Modeling the Human Decision Making Process in Maritime Interdiction Using Conceptual Blending Theory

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ABSTRACT: *This paper describes a model of the human decision-making process in maritime interdiction tactical operation using conceptual blending theory (CBT) and software blending mechanism. CBT explains how humans think using blending operations on mental spaces. This paper uses CBT to model Boyd's Observation-Oriented-Decision-Act Loop Theory, a mental process used by military commanders to make decisions. The software blending mechanism is implemented using the Naval Postgraduate School's first-generation Software Blending library. Military expert's experiences were captured using a similar strategy implemented in the threat assessment model created by Liebhaber and Feher. Probability Estimates of Event (PEoE) is used to represent the significant of each possible tactic used by potential threats. Several PEoE are used to represent the mental patterns for recognizing a threat situation. Finally, decisions are derived using linear assignment, an optimality approach that considers threat attack probability, goals and interdiction resource effectiveness. The model was tested in a simulated maritime threat environment in order to evaluate its ability to coordinate interdictions by patrol crafts. These test results were reviewed by experienced naval warfare officers who gave feedback on the quality of the software generated decisions.*

1. Introduction

The management of a busy shipping port such as the one in Singapore [1] is usually complicated by occurrences of piracy [2] and possible maritime terrorist attacks [3]. Sensors such as radars are usually used to monitor the shipping traffic [4, 5, 6] while interdiction resources such as unmanned surface vessels (USV) are used to conduct ship inspection and anchorage protection [7, 8, 9]. It is cognitively challenging for the command and control (C2) officers to track the intentions of each ship and to plan for maritime interdiction operations. The decision maker's ability to think is affected by confusion, senses overwhelmed, and debilitation [10]. The quality of the decision is also affected by cognitive tunnel vision in which attention is distracted due to cognitive overload. Henceforth, a decision-support system (DSS) based on the human decision-making process is desirable to support the decision-maker in the tactical operation.

The DSS is also useful in simulation systems. Many Simulation Systems for Stability and Support operation model the interdiction resources using scripted profiles such as the one used in NPS SEA Integrated Project for Port Security Strategy 2012 [11]. A Scripted profile does not correctly represent the decision-maker's plan for maritime interdiction. Henceforth, a decision-making model is desirable to manage the behavioral profiles of patrol resources for maritime interdiction.

This paper is organized into eight sections. Section 2 describes the theories used in the development of the decision-making model. Section 3 describes the previous works done. Section 4 describes the application of the theories. Section 5 describes the verification and validation processes. Section 6 describes an experiment conducted to evaluate the performance of the software model. Section 7 describes the conclusion and section 8 describes some recommendations, and possible future work.

2. Theories

2.1 Motivation and Overview

Boyd [12] wrote that in order to make a sound decision, there is a need for insight and vision, “to unveil adversary plans and actions, as well as foresees own goals and appropriate plans and actions”. Henceforth, the decision-making model can be organized into two parts: enemy course-of-action (ECA) inference, and own forces course-of-action (OCA) development. The first part is to determine possible ECAs for all shipping-contacts from the composite situational display in a Command and Control System. After which, all shipping-contacts can then be prioritized according to their inferred attributes such as ECA-probability and time criticality. The second part is to deploy own forces in order to maximize effectiveness.

The decision-making model uses conceptual blending theory (CBT) [13] to model Boyd’s OODA mental process [12] to develop ECAs and OCAs for maritime interdiction. The CBT is implemented using the first generation NPS CMAS Library [14]. The threat assessment model is based on the Surface Warfare Threat Assessment strategy [15]. Probability estimate of event (PEoE) [10] is used to indicate the significant of an ECA. A combination of several PEoE for several ECAs of the same shipping-contact is used to represent the mental picture of a decision-maker on a tactical situation, which is similar to the process of inductive reasoning [16]. The linear assignment uses Munkras algorithm [17] to optimally assign interdiction resources to suspicious shipping-contacts. Simkit [18] is used to provide a simulated composite situational picture for the decision-making process.

2.1 Conceptual Blending Theory (CBT)

Conceptual Blending Theory [13] suggests how humans process and rationalize information through a set of mental operations. The theory explains the process of assigning meanings to incoming information from sensory input, integrating them, and eventually learning and gaining knowledge. Conceptual blending is a set of operations for integrating mental spaces to form new mental spaces. Blending has been proposed as a fundamental high-speed background process in the brain (of which we are normally unaware) that combines knowledge from perception and experience to construct meaning and new knowledge. Mental spaces are small conceptual packets interconnected in working memory, and are constructed continuously and seemingly without effort by the brain. Within the

mental spaces are elements of knowledge that are structured by long term schematic frames called organizing frames, which shape or govern the elements in the mental spaces. Mental spaces are modified as thoughts and discourses unfold; they appear to set the stage for our conscious mental activity. An example of the simple integration network is described in Figure 1.

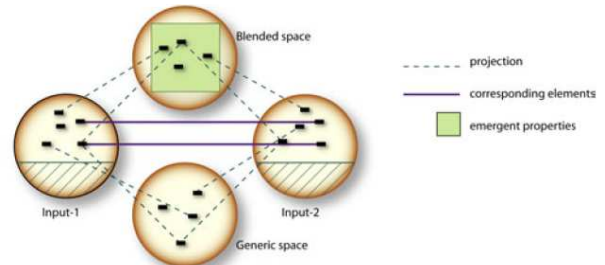


Figure 1. A simple integration network. (Extracted from ref [25])

2.2 Software Blending

Professor Hiles [14, 19] has demonstrated software blending in Project IAGO using multi-agent coordination techniques motivated by the properties of biological cells. The software blending is implemented using three key bio-inspired operators called Membrane, Connector and Ticket (Figure 2). The membrane is the common environment in which all related mental spaces such as generic spaces, input spaces and blended spaces exist. Connectors, which resemble the receptor mechanisms that support signaling and communications in biological cells [20], are used to connect one space to another. Tickets contain the procedural information that describes how knowledge elements will be processed upon establishment of connection among the connectors. Each ticket contains several frames with each frame having individual receptor either extended or retracted. The sequence of operations of corresponding tickets will be executed when two connectors match. The connections formed are persistence and scale free, which can then be used to build the blending network.

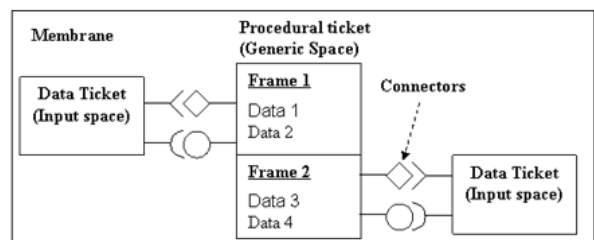


Figure 2. Membrane, Connector and Ticket

2.3 Boyd's OODA Loop Theory

Boyd's OODA (Observation-Orientation-Decision-Action) loop is a theory of knowledge formation [12]. The OODA loop describes how humans construct mental models of their environment through immediate observation and orientation, which is under the influence of experience, culture, history, genetics, etc. These mental models are then used to decide on course-of-action. The outcomes of the decision are known through subsequent observation. Observation is the information collection about the enemy and the environment. Orientation is the analysis of the information collected. Decision is the selection of course-of-action from the alternatives. Action is the implementation of the course-of-action selected.

2.4 Threat Assessment

Liebhaber and Feher [15] have investigated the threat assessment process used by experienced surface warfare personnel. Data were collected from experienced watch standers and used to develop a surface threat assessment algorithm as part of a decision support system (DSS). The DSS can be used to support the cognitive process of surface warfare personnel operating in highly complex, fast-paced littoral environments. The first part of the investigation is to categorize the various types of platform into five different threatening levels in littoral or open waters. After which, the following cues are used to either increase or decrease the likelihood of the threat: Speed, heading, Closest-Point-of-Approach, recent maneuvers, distance, cargo, number of vessels, sea lane, Electronics Intelligence, coordinated activity, voice communication, own support in area, destination, weapon envelope, regional intelligence. In this paper, the same threat assessment strategy is used to derive a probability estimate associated with each ECA.

2.5 Bounded Rationality & Inductive Reasoning

Arthur [16] suggested that human beings are not good at deductive logic but rather good in pattern recognition and inductive reasoning: during the reasoning process, several hypotheses will be formed and will either be strengthened, weaken or even replaced, accordingly to input arriving from the environment. In the course of planning process, human beings will attempt to conduct situational reasoning. The reasoning process is usually based on bounded rationality because decisions are usually made with incomplete and conflicting information. This is in line with Tversky and Kahneman study that human being does not usually make rational choice but can easily be biased based on

experience or personal preference [21]. Simon [22] suggested that decision-making is further complicated by psychological processes. Arthur [16] proposed that inductive reasoning approach enables the human beings to deal with complication and ill-defined problem space.

Based on these propositions, several ECA hypotheses can be created for one shipping-contact. These hypotheses will either be strengthened or weakened, according to arriving cues from the external environment. Each cue can be interpreted independently and accordingly to human experience by assigning different weight by which the attack probability (PEoE) is increased or decreased. Each PEoE will be updated autonomously. Each shipping contact will have one PEoE for each possible ECA. A group of PEoE for a single shipping-contact forms a pattern that resembles the mental picture of a human expert. The pattern of related PEoE dynamically models the human inductive reasoning process, even under rapidly changing and novel conditions.

3. Related Works

Scientists at Ohio State University performed a course-of-action simulation analysis for the U.S. Army [23]. They used modeling and simulation (M&S) technologies to assist in the planning and decision-making chain with COA development and COA effectiveness predictions. Genetic algorithms were used to create a large number of COA permutations from subject-matter-expert-defined initial conditions and constraints. The large set of course-of-actions is then reduced to a set of pareto-optimal course-of-actions containing unique COA characteristics. One fundamental difference between the CBT approach and the genetic algorithm (GA) approach is that, the use of conceptual blending theory and software blending mechanism allow fast parallel evolution of the solution space. The experiment and results described in section 6 show that the CBT approach can generate correct and optimal solution within a short time.

Sokolowski [24] has developed the RPDA agent based on Klein's recognition-primed decision (RPD) making concept to model a military decision-maker at the operational level of warfare. The RPD model also emphasizes on the ability to recognize a particular decision situation and to identify an appropriate action based on past experiences. Sokolowski uses the frame data structure that corresponds to a single experience that holds the cues, goals, and actions that describe that experience. In each decision situation, the RPDAgent

searches its table of frames to look for a match. If a match is found, the matching frame, together with its associated cues, goals, and actions will be retrieved. Otherwise, the model will ignore the situation. The objective is to find a decision of actions that will satisfy the goals through a process of negotiation and mental simulation. In the CBT approach, we use several PEOE, generated through inductive reasoning process to represent the mental picture for a situation. In this case, there will always be a mental picture formed even for a novel situation. We have tested in a separate experiment that our decision-making model is able to generate a good solution even for a shipping-contact that provide a novel set of sensory cues that is beyond the experience of an expert.

Ozkan [25] implemented a threat assessment model, using a multi-agent system and conceptual blending theory, to mimic how a human expert assesses the intention of an incoming air threat. The thesis shows that a multi-agent system and conceptual blending theory can be used to introduce cognitive intelligence into a computational model. In another thesis, Tan [26] also implemented threat assessment using CBT for surface warfare based on cues to establish various forms of violations. The violations are used to determine each track's intention through a weighting strategy in terms of "friendly," "neutral," "potentially hostile," or "unknown." This paper extends the work of Ozkan and Tan by using CBT and software blending mechanism to generate ECA and OCA.

4. Modeling Approach

The modeling methodology begins with defining the mental process in which the decision maker undertakes during the decision-making process. The mental process is jointly defined with several experienced naval warfare officers in Naval Postgraduate School. After which, the conceptual blending network will be designed based on the mental process.

4.1 Mental Process

The mental process of observing the composite situational display, deriving ECA hypothesis, evaluating and selecting OCA can be explained based on Boyd's OODA loop theory [12]. During Observation, the operator observes all shipping contacts, high value units (HVU) and interdiction resources displayed on the situational display. The display can be a fusion of radar plot with other sensory sources such as Automatic Shipboard Identification System, Electronics Intelligence, and other spot reports.

Essentially, information types available for further processing are kinematics, descriptive, intelligence and imagery information.

During Orientation, the operator uses information observed to infer hypotheses for all shipping-contacts. In order to identify hostile intention, several shipping-contact ECA hypotheses can be derived for each contact against each possible HVU with different ECA probability. The probability of each ECA is increased or decreased based on Surface Warfare Threat Assessment strategy [15]. The likely situation, which is represented by the contact's ECA probability, can be "recognized" through the interpretation of the cues in the same way an expert interprets the cues to recognize a particular situation. This is similar to the recognition approach proposed by Klein [27]. However, instead of serial recognition approach, multiple agents are used to process multiple serial recognitions in parallel to improve efficiency and to reduce the complexity involved in the second variability in RPD model [27]. Klein explained that serial approach with "satisficing" is more efficient, while a comparative approach would be more difficult although it is desirable as described in classical decision theory [28]. In this experiment, multiple agents can be introduced to process multiple serial-recognition in parallel for eventual comparison. This approach proved to be highly efficient (see Section 6).

The possible attack tactics are derived base on the findings of Rohan [29, 30], Raymond [2, 31] and Bateman et al [3]. Six attack tactics have been identified: (1) Suicide bombing; (2) Short Range Weapon Attack; (3) Boarding; (4) Suicide Attack using ship with huge mass and high inertial energy; (5) Suicide Attack using Ship with flammable cargo; and (6) Missile attack. Neutral Intention is added to account for neutral course-of-action.

Mental simulation is then conducted for each attack hypothesis to simulate into the future to compute counterfactual information about the attack such as possible collision time and space (counterfactual mental spaces play an important role in planning possible outcomes [13]). After the hypotheses have been established, the inferred ECA of the ship can be selected based on the hypothesis that carries the highest probability. The computed ECA probability becomes an attribute of the contact as well as the vulnerability attribute of the HVU through back projection [13]. The contact can now be prioritized according to ECA probability or time criticality.

During Decision, many OCA are generated, one for each interdiction resource-contact pair. An effectiveness value for each OCA will be determined. After which, a linear assignment can be applied to select the optimal set of OCA by using ECA probability as priority and effectiveness as the cost. After the assignment process, the OCA selected is evaluated against the goals derived based on hypothesized ECA. If any of the goals cannot be fulfilled even for an optimal solution, an external agency such as a helicopter can be deployed.

During Action, the OCAs selected are executed. The operator continue to monitor the situation and to amend the plan if situation changes. The changes to the plan can be done by repeating the OODA mental process again.

4.2. Conceptual Blending Network

In observation, one input space is created for each shipping-contact, HVU and interdiction resource to monitor their states in the real world. Each input space is created as Data Ticket in the software blending library. An example of a data ticket for HVU Input Space is described in Figure 3. The elements of knowledge are data that are translated from the real world. The lines with different shapes are connectors that can be extended or retracted in the membrane, depending on the availability of the data.

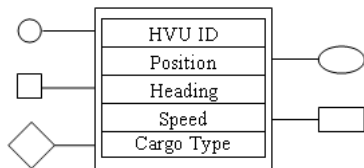


Figure 3. Data Ticket for HVU Input Mental Space. The labels represent elements of knowledge while the lines extending from the elements represent connectors for the elements.

Contact ECA deduction is carried out through the blending network as shown in Figure 4. It is done through the process of composition, completion and elaboration, which are the three conceptual blending processes [13]. During the composition process, the orientation generic space blends the shipping-contact input Space with HVU input space and Tactic input space to create seven unique ECA hypothesis blended spaces for each contact-HUV pair. The contact, HVU and attack tactics are connected through the vital link of predator-prey relationship. Each hypothesis blend represents one possible shipping-contact ECA that reads:

Contact c Attack HVU h using Tactic t.

The process of completion is carried out using Liebhaver and Feher [15] surface warfare threat assessment approach. The baseline of each ECA probability is first set to 0.5, representing that a new ECA has similar chance of being valid or invalid. After which, each ECA hypothesis blended space computes its probability value autonomously based on incoming cues available in the shipping-contact input space. The process of elaboration is carried out by projecting the completed blends into the future to deduce counterfactual information such as time of collision. The time of collision determines the time criticality of this threat. After the blending process is completed, the contact ECA with the highest probability will be chosen as the most probable ECA. The ECA probability, time-to-react as well as the possible target are then back-projected to the shipping-contact input space and become part of the shipping-contact input space attributes for use in the subsequent blending process. Similarly, the ECA probability will be back-projected to the HVU input space to serve as the HVU vulnerability attribute. The shipping-contacts can now be prioritized according to their ECA probability.

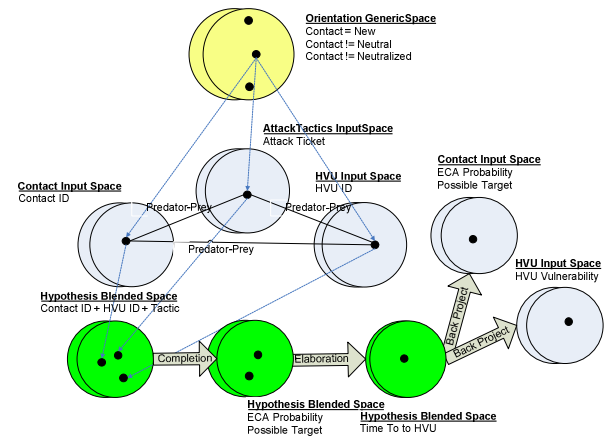


Figure 4. Blending Network for ECA Analysis in Orientation. The yellow node is the generic space that guides the selective projection from the 3 input spaces (grey nodes) through predator-prey vital relationship. The 3 green nodes refer to the same blended space through the 3 processes of composition, completion and elaboration. The Counterfactual informations are back-projected into the shipping-contact and HVU input spaces.

The OCA mental process can be further organized into three sub processes: Goal Generation, OCA generation and OCA selection. After a shipping-contact ECA has been derived, the human operator will determine the Goal for each shipping-contact ECA. The blending network for Goal Generation is shown in Figure 5.

During composition, the generic space guides the selective projection of elements (sensed state) from the shipping-contact input space and goal input space (goal type) and connects the spaces through cause-effect vital link to form the new goal blended space. The goal is determined based on the sensed-state of the shipping-contact. The sensed-state is either determined through real-world information or deduced through the inferred ECA probability from the previous blending process. If the sensed state is “unknown”, an “Investigation” Goal will be assigned with the intention to collect more information on this shipping-contact. If the sensed state is “possible-hostile”, a “Boarding” Goal will be assigned with the intention to board the possible ship with personnel for hostility confirmation. If the sensed state is “hostile”, a “Destroy” Goal will be assigned with the intention to either stop the ship with a weapon or through boarding operation. The completion process derives the time required for the Goal to be fulfilled using the “time of collision” counterfactual information derived in the previous blending process. Note that there is no elaboration process. After the blending process has completed, the blended goal is back-projected into the shipping-contact Input Space.

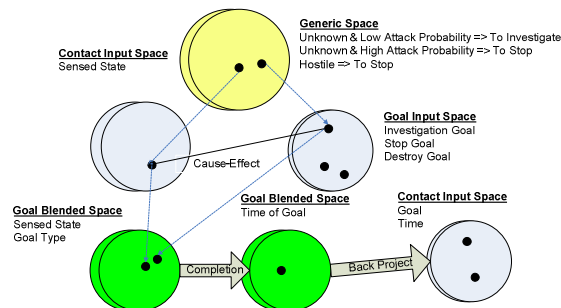


Figure 5. Figure 3 Blending Network for Goal Development in Orientation.

After the Goals have been derived, the next mental process is to derive all possible OCA. In this context, one OCA means the assignment of one interdiction resource to one shipping-contact. If there are m contacts and n resources, there will be $n \times m$ possible OCAs. The blending network for generating OCA is given in Figure 6. The composition process generates an OCA blend for each interdiction resource and shipping-contact pair. The completion process determines if there has been a match in Goal requirement and capability available. For example, if the goal is to stop the ship through boarding operation, an unmanned surface vessel that carries no human-being on board can never fulfill the goal. The elaboration process then computes the time required for the interdiction resource to reach the contact, which forms the effectiveness value. If the mental simulation

concluded that the interdiction-resource is unable to reach the shipping-contact before it reaches its target, the ineffective flag will be set.

The decision on the OCA is carried out through a linear assignment process using Munkras’ algorithm [17] with the effectiveness as the cost. The Contact Input Spaces are sorted according to ECA probability (not including neutral ECA). After which, n number of the highest ECA probability contact are selected for the assignment process while n is the number of available interdiction resources. After which, the initial list of possible OCA is reduced by culling the OCA that are not in the top priority list. The effectiveness in the reduced OCA list is formulated into the cost matrix as input to Munkras’ algorithm. After the assignment process, if none of the interdiction resource is able to reach a particular shipping-contact in time before it reaches its hypothesized target, an emergency flag will be raised.

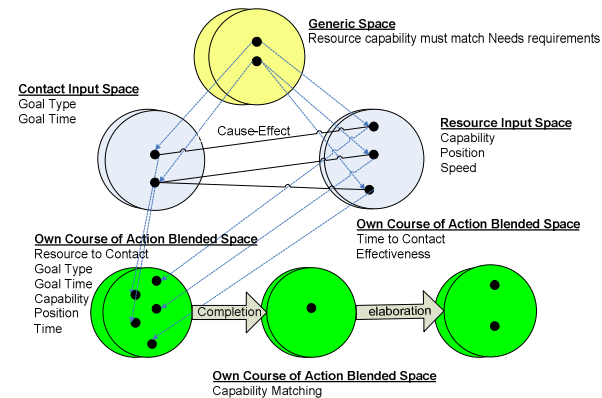


Figure 6. Blending Network for OCA generation

After the assignment process, the OCAs are disseminated out to the interdiction resources for execution. The OODA mental process is repeated immediately in order to allow continual assessment and dynamic reassignment should a higher priority threat appear.

5. Verification and Validation

The verification and validation (VV) strategy is based on the recommendations provided by Sargent [32]. The maritime scenario (Figure 7) used in the VV and experiment contains five HVUs (Grey Square icon), two patrol crafts (Blue Square icon), four unmanned surface patrol vessels (Cyan Square icon), and about 200 neutral ships (yellow Circle icon). Terrorist ships (Yellow Square icon) are launched either from sea lanes or southern islands.

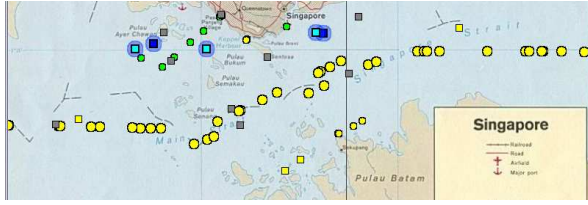


Figure 7. Scenario for Model Testing

The threat assessment experiences were compiled from a group of Naval Surface Warfare Officers in Naval Postgraduate School through a survey to understand how they conduct threat assessment based on a set of cues. Experts may process cues differently. The differences were de-conflicted by taking the median. It is also discovered that experts do not evaluate cue in isolation. Henceforth, certain cues are evaluated together as a singular state. For example, the speed of a boat is usually evaluated in conjunction with closest point of approach (CPA) to determine its threat level. After the experience coding process, the results were presented to them for calibration. The mental spaces are displayed in the form of tables to provide a visual display of mental spaces. Example of HVU Mental Space, Hypothesis Blended Space and OCA Blended Space are shown in Figure 8, 9 and 10 respectively.

Hypothesis	Goal	CourseOfAction	Decision	Terrorist	Setup
Contact(1)		Contact(2)		HVU	
ID	Vulnerability		PossibleThreat		
MobileHighValueUnit 1	0.90000004			Terrorist 1	
HighValueUnit 3	1.0			Terrorist 1	
HighValueUnit 4	1.0			Terrorist 4	
MobileHighValueUnit 4	0.90000015			Terrorist 4	
MobileHighValueUnit 2	0.90000004			Terrorist 1	
HighValueUnit 1	1.0			Terrorist 1	
HighValueUnit 5	1.0			Terrorist 4	
HighValueUnit 2	1.0			Terrorist 1	
MobileHighValueUnit 3	0.90000004			Terrorist 3	

Figure 8. HVU Mental Space

Hypothesis	Goal	CourseOfAction	Decision	Terrorist	Setup	
Contact(1)		Contact(2)		HVU		
Contact	Identity	HighValueUn...	Directivity	Range	Probability	TimeAvailable
BigShip 1	Unknown	HighValueUn...	0.99058163	348.59444	0.3	102.232666
BigShip 2	Unknown	HighValueUn...	0.37138304	169.10492	0.2	49.595005
BigShip 3	Unknown	HighValueUn...	0.8197195	259.59	0.3	76.132416
BigShip 4	Unknown	HighValueUn...	0.82626706	268.3264	0.3	78.694626
BigShip 5	Unknown	HighValueUn...	0.8395746	288.4268	0.3	84.58966
BigShip 6	Unknown	HighValueUn...	0.4917934	155.53885	0.2	45.616356
BigShip 7	Unknown	HighValueUn...	0.60571647	136.24844	0.3	39.95887
BigShip 8	Unknown	HighValueUn...	0.8547085	316.01758	0.3	92.881465

Figure 9. ECA Hypothesis Blended Space

Resource	Contact	Goal	Hypothesis	CourseOfAction	Decision	Terrorist	Setup
PCG 1	Terrorist 1	ToStop	8.047412	true	true	8.047412	
Helo 1	Terrorist 4	ToStop	7.4579253	true	true	7.4579253	
USV 4	Terrorist 2	ToStop	7.2501526	false	true	3.4028235E38	
PCG 2	SmallBoat 7	ToStop	5.5059857	true	true	5.5059857	
USV 1	Terrorist 5	ToStop	43.074146	false	true	3.4028235E38	
USV 3	Terrorist 3	ToStop	26.44944	false	false	3.4028235E38	

Figure 10. OCA Blended Space

The scenario was run with the adaptive display shown in Figure 11. The darker green color icons symbolize inferred neutral while the maroon color represents inferred possible hostile. The mental patterns of all possible ECA were presented to the expert. An example of the patterns that resembles that of a suicide bombing attack and Boarding attack are shown in Figure 12 and 13 respectively. The probabilities of ECAs do not add up to one because they are derived independently. The mental pattern describes that although a set of sensory cues may point to a high chance of suicide bombing, the possibility of short range weapon and boarding attack also exist based on similar attributes such as small and fast boat. The interviewees agreed that the PEOE Pattern describes a possible mean to represent an expert's mental pattern in the situational recognition process.



Figure 11. Situational Awareness Display

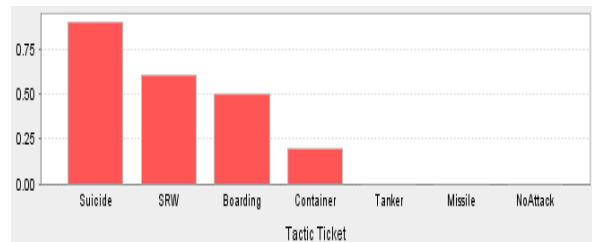


Figure 12. Suicide Bombing Mental Pattern. (Y axis is Probability)

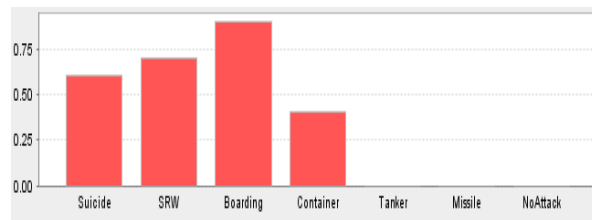


Figure 13. Boarding Attack Mental Pattern. (Y axis is Probability)

Computerized model verification was carried out by verifying the mental spaces through the visual display. Operational and Data validity was carried out through a survey conducted. Some of the techniques used in the VV processes were animation, Degenerate Tests, Extreme Condition Tests, Face Validity, Fixed Values,

Internal Validity, and Turing Tests. The survey results (Table 1) have been positive. Most of the interviewees indicated that the decision-making process resembles the way they make decisions in the littoral surface warfare. Most interviewees agreed that such a model will be beneficial as a decision support tool.

Do you use observation-orientation-decision-action loop theory as your mental process in making decision in a combat environment?	Yes 100%	Not Sure 0%	No 0%
Does the mental picture formed by the computer resemble the mental picture formed by human expert?	Similar 80%	Not Sure 20%	Different 0%
Does the computer produce meaningful attack hypothesis mental picture with the given cues?	Yes 80%	Not Sure 20%	No 0%
How does the computer perform in identifying terrorist activities?	Good 80%	Not Sure 20%	Bad 0%
How does the computer perform in own course-of-action analysis?	Good 80%	Not Sure 20%	Bad 0%
How does the computer perform in deciding own course-of-action?	Good 100%	Not Sure 0%	Bad 0%
Will such a system be useful to assist the human expert in planning for maritime interdiction mission?	Good 100%	Not Sure 0%	Bad 0%
Can you tell the difference if the probability estimate pattern is generated by computer instead of human being?	Good 80%	Not Sure 20%	Bad 0%
Will adaptive display be useful for decision-making?	Yes 100%	Not Sure 0%	No 0%
How does the computer performs in generating adaptive display?	Good 80%	Not Sure 20%	Bad 0%

Table 1: Summary of Survey Results

6. Experimentation

An experiment was designed to test the performance of the model based on comparison of the performance with and without the model as well as computation time. The scenario described in Figure 7 was run in either scripted mode or in decision-making mode. The measures of performance were:

- Percentage of neutral shipping investigated
- Percentage of terrorist neutralized.

In each run, ten terrorists were launched either from southern islands, eastern or western side of the Singapore Strait with the attempt to saturate the maritime interdiction process. The performances for with and without using the decision-making model are

given in Figure 14. The planned profile was able to neutralize most of the terrorists while the scripted profile was only able to neutralize around 60% of the terrorists by chance. The planned profile investigated lesser neutral ships because more emphasis were being placed on high priority threats, which resulted in investigating ships that were usually further apart that required more travelling time. The lesser number of neutral ships being investigated may not imply lower performance, but rather imply a higher efficiency without unnecessary investigation and yet still able to achieve a higher terrorist interception rate.

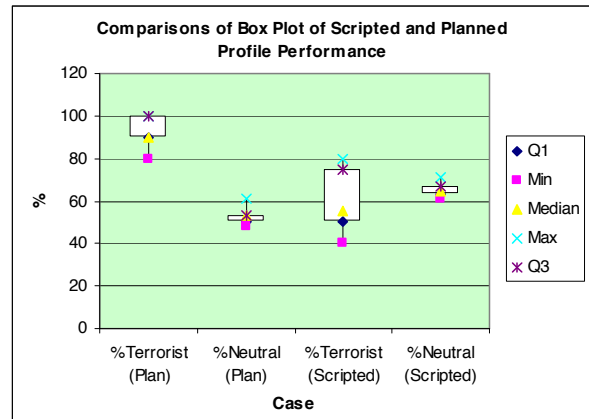


Figure 14. Comparison of Planned profile and Scripted Profile

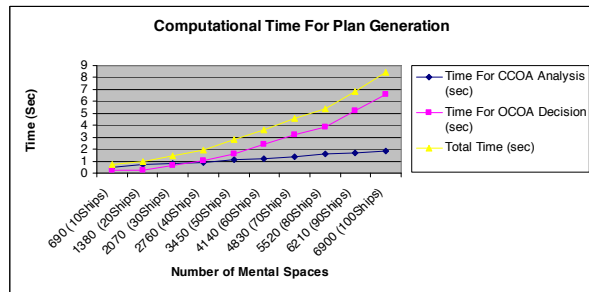


Figure 15. Computation Time

The computational times required to compute the ECA and to make a decision on OCA as a function of number of shipping-contact are given in Figure 15. The timings collected were based on running the software on a Dell Inspiron Notebook computer with 1.67 MHz CPU and 1GB RAM. The time requirement increases almost linearly with the increase of the number of shipping-contact. This is a remarkable performance because an addition of one ship will add 69 mental spaces into the systems. With extrapolation, the time required to compute one plan for one thousand ships in Singapore Strait may take under 2 minutes. Since 60000 ships transit through Singapore Strait yearly [1], the ship time of arrival is approximately 8 minutes. As

can be seen, the running of the plan for every arrival of each ship is feasible even on a low end notebook computer. Therefore, the decision-making software based on CBT and software blending mechanism is able to support near real time decision-making for maritime interdiction.

7. Conclusions

This model demonstrated that it is possible to model Boyd's OODA mental process using CBT to develop OCA for maritime interdiction resources. The CBT have been implemented using the first generation NPS CMAS Library to model the human expert in the process of shipping-contact ECA identification. The threat assessment model has been developed based on a modified Liebhaber and Feher's Surface Warfare Threat Assessment Model because experts interviewed in this study do not process cues in isolation. It has been shown that the threat assessment model resembles the process of a human operator conducting surface threat assessment. It has also been observed that a group of PEOE can be used to model the human mental pattern in the threat evaluation process. Individual PEOE that autonomously process incoming cues locally can produce a global effect that represents the mental pattern of a threat reasoning process. The experimentation has demonstrated that a group of interdiction resources can be better managed with this Model and can allow the interception of terrorist with high success rate without having the need to inspect more ships. The experimentation has also shown that a huge amount of contact ECA and OCA can be generated and evaluated through the CBT process in a timely manner even on a commodity computer.

8. Recommendations and Future Work

Although this concept demonstrator achieved some success in the application of several cross-disciplinary theories in the maritime domain, the factors of consideration are by no means comprehensive if this system is going to be deployed in the real world environment. A more detailed study based on available cues and classification of cues should be conducted. In addition, the process of goals generation and decisions can be further improved by considering logistical factors, area of coverage influence and environmental condition. In addition, the contact ECA analysis can be improved with mental simulation using intelligence agents to represent terrorists' behavior as a function of interdiction resources positioning, environmental and traffic condition before launching an operation. Another enhancement may include learning-agents to

manage the interpretation of the cues in the threat assessment instead of simple application of expert's knowledge. After a prediction, each ECA agent can compare its prediction with the actual results after positive identification so that adjustment can be made to improve the cue interpretation process. This will allow the system to accumulate its own experiences in addition to the expert experience input.

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