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**MODELS OF INFORMATION AGGREGATION PERTAINING
TO COMBAT IDENTIFICATION: A REVIEW OF THE LITERATURE**

**MODÈLE DU REGROUPEMENT DE L'INFORMATION CONCERNANT
L'IDENTIFICATION AU COMBAT : UNE ANALYSE DOCUMENTAIRE.**

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Abstract

This report reviews research literature pertaining to models of human information aggregation in order to apply them, when possible, to combat identification (CID) decisions made by individuals in a land force context. In particular, the review examined social science, science and military literature to identify principles and theories associated with how human decision makers weigh and integrate information. The review identified a variety of heuristics and cognitive biases associated with these processes, along with formal and informal models of combining qualitative and quantitative information. The report presents current conceptualizations of combat identification and places it within the context of cue-based decision making under the intuitive decision framework. By framing this complex decision we were able to evaluate the applicability of the methods of aggregation to the CID task.

Résumé

Le présent rapport examine la documentation de recherche portant sur les modèles de regroupement de l'information humain afin de les appliquer, lorsque cela est possible, aux décisions en matière d'identification au combat (IDCbT) prises par des personnes dans un contexte des forces terrestres. Plus particulièrement, on a examiné les publications des sciences sociales, scientifiques et militaires pour cerner les principes et les théories liés à la manière dont les décideurs évaluent et intègrent l'information. L'examen a permis de relever des connaissances heuristiques et des préconceptions cognitives liées à ces processus, ainsi que des modèles officiels et informels pour combiner de l'information qualitative et quantitative. Le rapport présente les conceptualisations actuelles de l'identification au combat et situe cette dernière dans le contexte de la prise de décisions fondées sur des indices selon le cadre de décisions intuitives. En exprimant cette décision complexe, nous avons pu évaluer l'applicabilité des méthodes de regroupement à la tâche d'IDCbT.

Executive Summary

This report reviews the results of a keyword search of the research literature associated with models, theories and principles of human information aggregation and cue-based decision making as they relate to combat identifications made by individuals in a land force context. The goals of this review were to:

- Perform searches of scientific and military literature databases;
- Obtain relevant literature pertaining to formal models of information aggregation, human information aggregation research, and psychological models of human cue-based decision-making;
- Draft a report documenting models of information aggregation, summarizing major principles and theories of human information aggregation and developing a categorization scheme in which to evaluate the applicability of models of information aggregation to human decision making.

The search resulted in approximately 65 primary articles from science, social science (Economics, Political Science, Organizational Behaviour, and Psychology) and military databases. These articles were reviewed to acquire major themes and principles associated with the weighing and combining of information.

The report contains a review of the following themes and concepts:

- Conceptualization of combat identification
- Decision making frameworks
- Models of information aggregation
 - Reasons for aggregating information
 - Methods of information integration
 - Cue weighing strategies
 - Information presentation effects

By categorizing the methods of information aggregation based on their associated decision making frameworks, we were able to determine which models may be most applicable to combat identification. In particular, we identified several heuristics and cognitive biases as being specifically relevant to the tasks of weighing and integrating information. This review highlights these methods to improve understanding of the aggregation process.

Sommaire

Le présent rapport examine les résultats d'une recherche par mots clés effectuée dans les études liées aux modèles, aux théories et aux principes du regroupement de l'information humain et de la prise de décisions fondée sur les indices en ce qui a trait à l'identification au combat effectuée par des personnes dans un contexte des forces terrestres. Les objectifs du présent examen sont les suivants :

- Effectuer des recherches dans les bases de données de publications scientifiques et militaires;
- Obtenir des publications pertinentes relativement aux modèles officiels de regroupement de l'information, à la recherche sur le regroupement de l'information humain et aux modèles psychologiques de prise de décisions fondée sur les indices;
- Rédiger un rapport qui décrit les modèles de regroupement de l'information, dans lequel on résume les principes et théories essentiels du regroupement de l'information humain et présente un schéma de classification qui permet d'évaluer l'applicabilité des modèles de regroupement de l'information à la prise de décisions chez l'humain.

La recherche a relevé environ 65 articles principaux des bases de données des sciences, des sciences sociales (économie, science politique, comportement organisationnel et psychologie) et militaires. Ces articles ont été examinés pour cerner les principaux thèmes et principes liés à l'analyse et au regroupement de l'information.

Le rapport comprend un examen des thèmes et concepts suivants :

- Conceptualisation de l'identification au combat
- Cadres de prise de décisions
- Modèles du regroupement de l'information
 - Raisons pour regrouper l'information
 - Méthodes pour regrouper l'information
 - Stratégies d'analyse des indices
 - Effets de la présentation de l'information

En classant les méthodes de regroupement de l'information selon leurs cadres de prises de décisions connexes, nous avons été en mesure de déterminer les modèles qui s'appliquent le mieux à l'identification au combat. Nous avons notamment relevé plusieurs connaissances heuristiques et préconceptions cognitives particulièrement adaptées aux tâches d'analyse et de regroupement de l'information. Cet examen met en valeur ces méthodes afin d'améliorer la compréhension du processus de regroupement.

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1 Introduction

1.1 Scope and Objectives

“..the human mind still retains the role of merging, pattern recognition and deciding...As ID techniques become more numerous and sophisticated, the burden on human merging and deciding is becoming excessive...” (U.S. Defense Science Board, 1996)

This report documents the results of a survey of scientific literature pertaining to theories and models of human information aggregation. The purpose of this review is to better understand how decision-makers weigh and integrate information from a variety of sources in the course of making a decision. The review focuses on the aggregation process as opposed to the information-gathering phase or the final step of choosing a course of action. However, the principles and theories associated with the models are reviewed in the context of cue-based decision-making, therefore requiring a summary of the different decision making frameworks. This literature review is restricted to *human* information aggregation models because of the goal to evaluate how individuals (e.g., commander, dismounted soldier) might combine information from multiple sources when making a combat identification (CID) in a land force context. Computational models, often referred to as data fusion algorithms, therefore, are beyond the scope of this review. Literature from psychology, social sciences, and military databases are examined to identify a comprehensive set of models of information aggregation.

The specific objectives of the report are:

- To perform searches of scientific and military literature databases;
- Obtain relevant literature pertaining to formal models of information aggregation, human information aggregation research, and psychological models of human cue-based decision-making;
- Draft a report documenting models of information aggregation, summarizing major principles and theories of human information aggregation and developing a categorization scheme in which to evaluate the applicability of models of information aggregation to human decision making.

1.2 Outline of Report

This report begins with a detailed description of the search methodology used to acquire the articles for review. Then, the literature review commences in Section 3 with a conceptualisation of combat identification, followed by background information related to the different decision making frameworks (Section 4). Section 5 details the purposes of integrating multiple pieces of information, provides a review of the different models of human information aggregation, and discusses weighting strategies and issues related to the methods of information presentation. The review concludes in Section 6 with a categorization of the most likely methods of information aggregation utilized during the combat identification decision.

1.3 Contract

This work was performed under contract W7711-067996/001/TOR. The Scientific Authority (SA) for this work was Dr. David Bryant.

2 Method

2.1 Keywords

We developed a set of keywords for the literature search based on our experiences with the two areas of interest for this review: 1) models, principles and theories related to information aggregation, and 2) psychological models of human cue-based decision-making. In addition, search terms for combat identification were formed to locate literature to assist in framing this review.

The keywords were dividing into several categories (see Table 1), including a general category used to narrow the search when searches returned a large number of records.

Table 1. Categories and Associated Keywords

Category	Keyword	Related Keywords
Models of information aggregation	Information aggregat*	Information integration, information fusion, decision making, decision bias, heuristic, uncertainty, probability, weighting, evidence integration, cue integration, multiple-cue judgment
Cue-based decision-making	Recognition prim*	Recognition primed decision making, RPD, RPDM, cue-based, mental simulation, situation assessment, situation awareness, pattern matching
	Naturalistic decision making	NDM, intuitive decision making, intuition, uncertainty, dynamic decision making, time pressure, satisficing, Lens model
General		Combat identification, combat ID, CID, situation assessment, threat assessment, defence, defense, military, army, decision making, information, knowledge, judgment

Searches revealed several key authors (



Table 2) involved in research relevant to the categories of interest. For example, researchers in the area of information aggregation were identified through the proceedings from Wallsten's (2004) "workshop on information aggregation in decision making". When necessary to find more specific information, these names were used to enhance the search.

Table 2. Key Researchers in the Areas Defined by the Literature Review

Models of Information Aggregation:
David V. Budescu, University of Illinois
Ronald R. Yager, Machine Intelligence Institute, Iona College, New York
Ilan Yaniv, Hebrew University, Israel
Decision Making Heuristics and Biases:
Amos Tversky, Stanford University and Daniel Kahneman, Princeton University
Gerd Gigerenzer and Daniel G. Goldstein, Max Planck Institute for Human Development
Cue-based decision-Making:
Gary Klein, Klein Associates Inc., Ohio
Raanan Lipshitz, Haifa University, Israel
Eduardo Salas, University of Central Florida

2.2 Databases

Searches for relevant literature were conducted of the following databases and sources:

- PsycINFO
- PsycARTICLES
- Scientific and Technical Information Network (STINET)
- Canada Institute for Scientific and Technical Information (CISTI)
- National Technical Information Services (NTIS)
- Institute of Electrical and Electronics Engineers (IEEE) Xplore
- Human Factors and Ergonomics Society (HFES)
- PubMed
- Defence Research & Development Canada (DRDC) Defence Research Reports
- World Wide Web (WWW), Google Scholar

PsycINFO is a department of the American Psychological Association (APA) that offers products to aid researchers in locating psychological literature. Paid membership with the APA is required for use of this database online at www.apa.org/psycinfo. The database is based on Psychological Abstracts and contains non-evaluative summaries of literature in psychology and related fields (e.g., human factors, education, business and social studies). The database contains over one million electronically stored bibliographic references including journal articles, dissertations, reports and book chapters.

PsycARTICLES is a database of full-text articles from journals published by the APA, APA Educational Publishing Foundation, Canadian Psychological Association and Hogrefe Publishing Group. An APA membership is required for use of this database located online at www.apa.org/psycarticles/.

STINET is a publicly-available database (stinet.dtic.mil) which provides access to citations of documents such as: unclassified unlimited documents that have been entered into DTIC's Technical Reports Collection (e.g., dissertations from the Naval Postgraduate School), the Air University Library Index to Military Periodicals, Staff College Automated Military Periodical Index, DoD Index to Specifications and Standards, and Research and Development Descriptive Summaries. The full-text electronic versions of many of these articles are also available from this database.

CISTI is the library for the National Research Council of Canada and a world source for information in science, technology, engineering and medicine. The database is searchable on-line at cat.cisti.nrc.ca. Articles can be ordered from CISTI for a fee.

NTIS is an agency for the U.S. Department of Commerce's Technology Administration. It is the official source for government sponsored U.S. and worldwide scientific, technical, engineering and business related information. The 400,000 article database can be searched for free at the www.ntis.gov. Articles can be purchased from NTIS at costs depending on the length of the article.

IEEE Xplore is the database for articles published by the Institute of Electrical and Electronics Engineers. It is searchable online at ieeexplore.ieee.org. Simple searches and abstracts are available to the general public free of charge from while more complex searches and full-text versions of articles are available only for a fee.

HFES is a database of articles published by the Human Factors and Ergonomics Society including Human Factors, Ergonomics in Design, and the HFES conference proceedings. Searches are available for free, while most articles and contents of the proceedings are available only for a fee. This database is located online at www.hfes.org/Web/.

PubMed is a publicly available, free service of the U.S. National Library of Medicine that includes over 16 million citations from MEDLINE and other life science journals for search of biomedical articles back to the 1950s. PubMed includes links to full text articles that can be purchased directly from the journal source. Pubmed can be accessed online at www.pubmed.gov.

DRDC Defence Research Reports is a database of scientific and technical research produced over the past 6- years by and for the Defence Research & Development Canada. It is available online at pubs.drdc-rddc.gc.ca/pubdocs/pcow1_e.html.

The World Wide Web was searched using search engines such as Google Scholar (scholar.google.com) and Google (www.google.ca).

2.3 Search Strategy and Selection of Articles

Initial searches were performed using each primary keyword individually. If the search resulted in too many records or irrelevant titles, the related keywords were used. Search terms from the primary column were combined with terms in the related keyword column, or terms from within the related keyword column were combined together whenever the searches resulted in too many records. Upon examination of the literature, some additional keywords were identified and used when further information was desired (e.g., names of specific heuristics or information aggregation theories, author's names).

STINET proved to be the most effective database for locating papers related to Combat Identification. NTIS and CISTI consisted primarily of a smaller subset of repeated titles found within the STINET database. Google Scholar located the greatest number of articles directly related to models of information aggregation, particularly in the fields of Economics and Political

Science. IEEE Xplore also revealed papers related to information aggregation. However, these records focused mainly on data fusion, which is beyond the scope of this review because of our focus on the human decision maker. PsycINFO, PsycARTICLES, PubMed, and HFES were particularly useful for finding papers related to cue-based decision making (naturalistic decision making). Articles providing military application of this form of decision making were found using STINET. General decision-making literature was located through Google Scholar as well as PsycINFO and PsycARTICLES.

2.4 Review of Articles

Approximately 150 relevant titles were obtained during the keyword searches. Review of the abstracts reduced this number to about 100. After reviewing nearly 30 articles in detail, the themes of the review became more apparent allowing for more specific searches and selection of papers. Articles were subdivided into primary and secondary references. Articles were defined as primary if their content was particularly relevant to a specific topic covered by this review (e.g., method of information aggregation, naturalistic decision making in a military context). Each of the 64 primary references were cited at least once in the body of this review. Secondary references had some relevance to the themes of this review but were not referenced within the literature review either due to minimal applicability to combat identification, the human decision maker, or because of repetition in topics.

3 Conceptualization of Combat Identification

In order to add context to this review of human information aggregation literature, we begin with a discussion of combat identification. We will then assess how a combat identification judgment might fit within the greater decision-making literature. This will assist us in later evaluating the likely use of analytic or intuitive approaches to combining information in the battlefield.

In a land force context, LAV III commanders, and mounted and dismounted soldiers must be able to form a rapid identification of detected entities (e.g., friendly, neutral, hostile) in the shared battle-space, in order for appropriate actions to be taken (e.g., ignore, shoot, hide) in a timely manner. This process is referred to as combat identification (CID).

CID is necessary in a variety of circumstances. For example, a CF (Canadian Forces) unit may need to enter an Afghan village to locate a suspected Taliban leader. Within this environment they will encounter many different people, some of whom will be neutral (e.g., farmers, children), others who are considered friends (e.g., coalition forces), and in addition, there may be hostile individuals. As each person is encountered in the village, soldiers must rapidly judge which category they are most likely to fit. To make this judgment, cues taken from the person (e.g., appearance, presence of a weapon, actions) and the context (e.g., person is located in a known enemy home) must all be considered, while at the same time combining it with previous knowledge and expectations. In this example, identification goes a step further requiring a judgment on whether an individual is the specific person being sought. In another example, a LAV III may be manoeuvring through an open area of terrain when movement is sighted in the distance. If it is another vehicle, Identification Friend or Foe (IFF) technology may be used to interrogate transponders found on friendly vehicles, which will give an identification response. However, this technology is not always available or 100% effective (Haspert, 2000). If the entity is a person or group of people, Budd light technology (i.e. pulsed infra-red beacons) and reflective gear may be useful in assisting with identification (i.e. determining if they are Blue forces or not). However, enemies may use similar gear in order to cause deception. Therefore, when possible, and when enough time is deemed available, other cues must be utilized. For example, the commander may receive communication from the gunner who is able to offer enhanced visual information about the entity (e.g., insignia, type of weaponry) or radio contact may be made with other units within the area who are closer to the source.

As is apparent with the above examples, the ability to effectively combine information is critical to CID. Not only must data-driven information (e.g., visual cues, sensors and communication) be aggregated, but it must also be combined with cognitively driven elements of information (e.g., expectations, beliefs, knowledge from previous experiences). In addition, there may be multiple cues from a single source (e.g., different visual cues), or multiple sources providing single cues or judgments (e.g., IFF states friend or unknown, Budd light is present or absent). Historically, vision was the primary information source used to identify a detected entity. However, with present weaponry easily reaching distances greater than that of the line of sight, external sensors and information sources must be relied upon (Haspert, 2000). The complexity of the battlefield where suicide bombers use deception to blend in with crowds and guns may be mistaken for hoes or rakes held by farmers, requirements for greater use of communication and a continuously updated situational awareness have arose. The difficulty with creating an ID sensor that is 100% accurate at

all times, in all situations (various weather conditions, terrain and time of day) causes the need to use numerous cues. Failure to utilize this information appropriately can result in a misidentification, which can be very costly, resulting in fratricide (identifying a friend as hostile), neutricide (identifying a neutral entity as hostile) or suicide (identifying a hostile target as a friend) (Karsh, Walrath, Swoboda, & Pillalamarri, 1995).

Several models have been developed to explain the information flow and decision processes of combat identification.

3.1 Models of Combat Identification

Before describing the models of combat identification, it is necessary to define some CID-related terms that might otherwise be confused, since we have observed that they are not used consistently in the literature. The terms “detection”, “identification”, “classification” and “recognition” have unique meanings in a military context, and will therefore be treated as such in this review. In the army, DCRI (Detect, Classify, Recognize and Identify) tasks are considered separate processes (Self, 2005):

- *Detect.* A vehicle, person or structure of possible military interest is noticed. The military observer takes action to search for further information.
- *Classify.* The object is distinguished by class, such as wheeled or tracked vehicle, animal or human.
- *Recognize.* The object is distinguished by category, such as tank or personnel carrier in the tracked vehicle class. If the object is human, elements of the person, such as lack or presence of equipment, head-gear, or posture are used to determine if the person is of military interest.
- *Identify.* The object is distinguished by model (e.g., 4 door sedan if a vehicle) and the force allegiance (friend, foe, etc) is determined (but not confirmed). If the object is human, elements of the person, such as clothing, equipment, posture and/or gender are used to determine if the person is armed or potentially combatant.

Thus, each successive term implies greater refinement in the level of detail extracted from the target under consideration.

Feature identification has been proposed as an additional stage related to the discrimination of vehicles based on their make and model, or between different types of weapons and uniforms used by people (Self, 2005). For our purposes, the words “identification”, “identity” and “identify” will be used to refer to the determination of the allegiance of the detected entity (i.e. friend, neutral, enemy in accordance with formal NATO doctrine of “standard identification”). Whenever it appears that reviewed literature intends to portray the meaning of one of the above terms, but is using another word, it will be changed for consistency.

According to the U.S. Defense Science Board (1996), the CID process starts after receiving information about a detected entity from both direct (organic to the soldier) and indirect (external, off-board) sources. Each source of information is associated with a probability that describes the likelihood of it providing the correct identity of the entity. For example, Geiselman and Samet (1980) have recommended use of certainty levels for intelligence briefings whenever possible. Humans and/or computers fuse the information together to result in a statistical indication of the likely identity of the entity (U.S. Defense Science Board, 1996). Given this identity and its

certainty level, decision makers utilize the Rules of Engagement (ROE) to determine an appropriate action. This model highlights the use of probabilities or certainty levels when weighing information and when choosing an action. For example, in the earlier example regarding the search for a Taliban leader, the cue that someone is found in a known enemy home may be more important than the presence of a weapon, due to the prevalence of arms amongst this culture. One limitation to this article was that it failed to describe *how* soldiers might carry out the process of weighing and combining information.

Allegretti (2000) offers an expanded model of CID that describes three components involved: target identification (TI), situational awareness (SA), and specific tactics, techniques and procedures (TTP). TI involves making distinctions at different levels of resolution for the detection, classification, recognition, identification and feature identification (referred to as characterization in Allegretti's paper) of the entity. SA, on the other hand, is described as the knowledge of one's own location and the location of others. It is necessary to note that this definition of SA differs from the more commonly cited three-level model of SA described by Endsley (1995), as will be discussed shortly. Allegretti (2000) suggests that position location displays will be used to assist in forming an accurate SA. TTPs are tools and rules available to maximize the use of different resources (e.g., sensors). The model described by Allegretti (2000) suggests that TTP (as well as available military intelligence) influences both SA and TI, which together interact through an information exchange to facilitate a combat identification. Although this model provides more detail about the components of CID, it is still inadequate to describe how CID decision makers use information.

Dean, Vincent, Mistry, Hynd, and Syms (2005) of the U.K. Defence Science Technology Laboratory are authors of a draft paper we have identified as containing the most comprehensive model of CID processes. Dean et al. (2005) describe the information flow from the entity to the CID decision maker (Figure 1). They also provide a conceptual model called the Integrative Combat Identification Entity Relationship (INCIDER) to describe how a CID is made. Once an entity is detected, information about the entity is acquired from multiple sources. A fusion process then aggregates the available information, which is further combined with memory and other reports related to the battlefield situation. Similar to the model described by Allegretti (2000), the aggregated information about the identity of the entity is combined with situational awareness during the decision process. Contrary to the definition of SA used by Allegretti (2000), Dean et al. (2005) use Endsley's (1995) classic three-level model of SA, which is as follows:

- Level 1 SA – Perception of cues and elements related to the current situation.
- Level 2 SA – Comprehension of the current situation by integrating and interpreting the perceived information.
- Level 3 SA – Projection of understanding of current events into the near future.

Once situational awareness is achieved and the information has been integrated, answers are determined for the following categories of decisions:

- Detection – Is the entity really a target?
- Classification – What class or type of target is it?
- Identification – Is it friendly, neutral or hostile?
- Action – What action is required (destroy, report or avoid)?

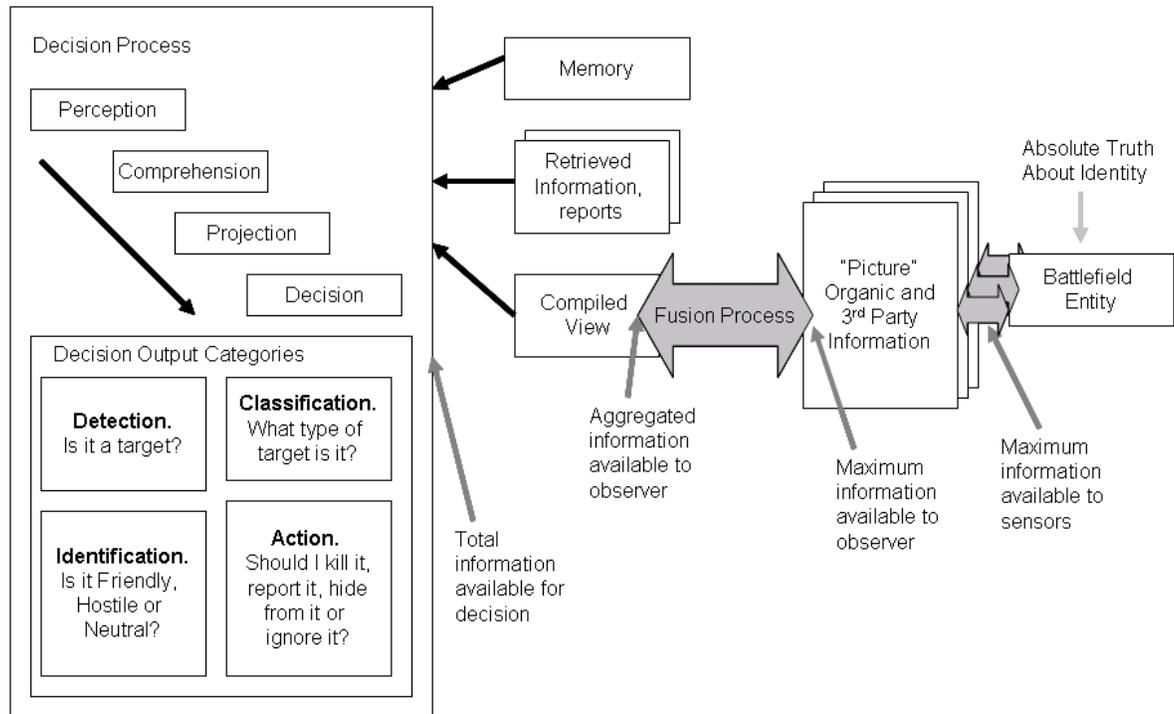


Figure 1. Information flow during a combat identification (recreation of Dean et al., 2005, p, 22)

The INCIDER model (Figure 2) developed by Dean et al. (2005) expands on the concept of information flow to show the relationship between different factors and the decision making process. It shows that once an entity is detected, information acquired through sensors and situation awareness is fused to result in an identification associated with a level of certainty (confidence). A decision is made regarding the acceptability of this confidence level. In other words, the decision maker decides whether a necessary threshold has been met in order to proceed. If it is deemed unacceptable, the process is repeated to acquire more information by moving closer to the entity or using additional sensors. The tentative judgment is fed back into the decision engine to act as history and expectations that will influence future iterations. Once the level of certainty of the judgment is acceptable (i.e. the threshold is met), the identification is made and the process continues to further decision-making stages (i.e. choice of a course of action). Similar to the model described by the U.S. Defense Science Board (1996), Dean et al. (2005) focus on the need to reach a certain level of confidence in the identification before proceeding with a course of action. This level will change as the distance between entities decreases making the decision more urgent (Dean et al., 2005). In contrast to the other models, Dean et al. (2005) suggest three potential ways in which information and the confidence (probabilities) associated with it might be aggregated. These models of information aggregation include Dempster-Shafer theory, Bayes' Theorem and Fuzzy Logic, with particular support towards use of Dempster-Shafer theory. Despite this inclusion, only Bayes' Theorem will be discussed in this review because Fuzzy Logic and Dempster-Shafer theory are data fusion models requiring use of complex algorithms, and are therefore beyond the scope of this review (the interested reader is referred to Dean et al., 2005 for more information or to the following references in the secondary reference list: Choi, 1999 (Fuzzy Logic); Clemen & Winkler, in press (Bayes Theorem); Sentz & Ferson, 2002 (Dempster-Shafer)).

Bayes' Theorem is also used for data fusion, but research has suggested that people may be able to utilize this method in some circumstances (Budescu & Yu, 2006; Sedlmeier and Gigerenzer, 2001). This will be discussed further in Section 5: Models of Information Aggregation.

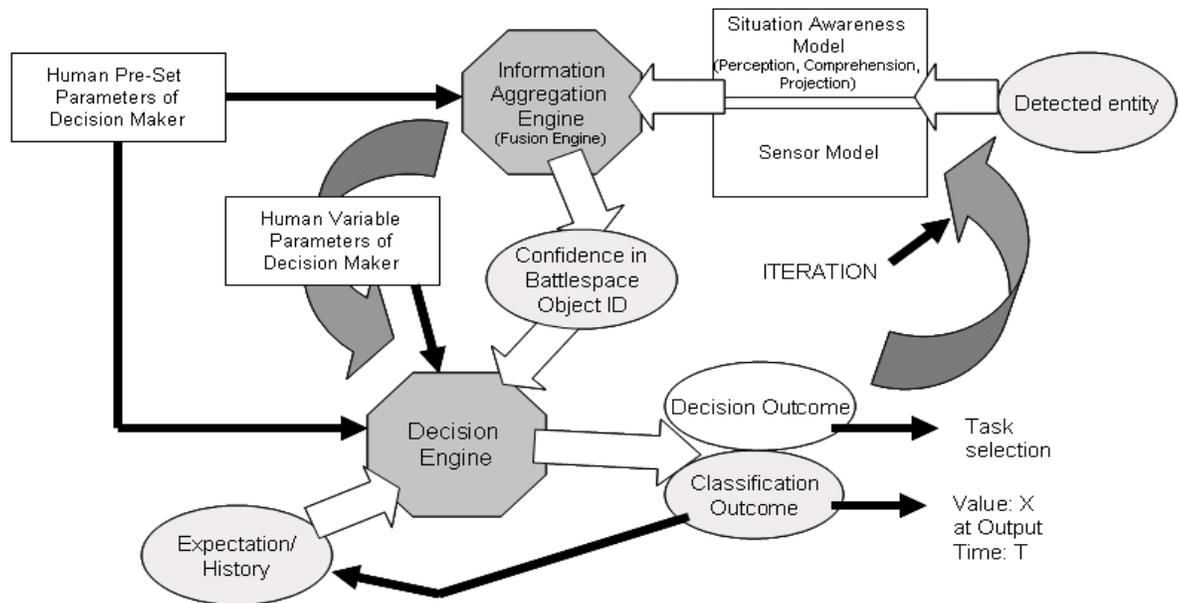


Figure 2. INCIDER Model (recreation of Dean et al., 2005, p. 43).

These models of CID provide a framework for understanding the way information is used during a combat identification. Information must be acquired, it needs to be combined, and then a decision must be made about whether more information is needed, or whether a judgment can be formed. This type of judgment is similar to many everyday decisions. For example, multiple pieces of information are often used when choosing to eat at a specific restaurant, such as opinions from friends, public restaurant reviews, knowledge about ones' personal budget and the cost of eating at the restaurant. People may also combine estimates from different people or sources of information about the seasonal temperature in a given location so that choices can be made about what to pack for a holiday. Each of these pieces of information may be weighted differently when making these judgments. Despite the similarities, CID has two crucial differences from such everyday decisions, first is the environment where it takes place, and second, is the seriousness of the consequences of making an error. Some of the factors affecting CID decisions described by Dean et al. (2005) are outlined in the next section.

3.2 Factors affecting combat identification

Unlike most everyday decisions, CID decisions are made in uncertain environments where timing is critical. To be effective, the CF needs to execute their OODA loop (Observe, Orient, Decide and Act) faster than the enemy can. They need to have a better understanding of the situation so that they can identify enemies faster and more accurately allowing them to take action quicker (Azuma, Daily & Furmanski, 2006). To do this, information must be obtained and combined effectively.

A variety of situational factors can affect the information available to CID decision makers. For example, the terrain difficulty, time of day (day or night), and weather conditions can affect the ease with which people acquire information about the detected entity (Dean et al., 2005). Even the relief, or shape of the ground can affect decision makers' line-of-sight causing difficulty in forming an ID. Communication ability can also enhance or degrade CID. If messages are transmitted too slowly or contain errors, CID decision makers may lose valuable information, resulting in uncertainty (Dean et al., 2005).

Dean et al. (2005) identified two categories of human parameters that affect CID: human pre-set parameters and human variable parameters. Human pre-set parameters of the decision maker include personality, beliefs (culture), experience, trust and preferences. These factors can influence the formation of situational awareness, how information is aggregated and how decisions are formed. Human variable parameters, which can also influence the effectiveness of forming a decision, consist of factors that arise because of the intensity of the situation such as fear, stress and fatigue (Dean et al., 2005).

A factor that affects how information is considered and used for forming judgments related to CID is the level of command. According to Dean et al. (2005) there are five levels of command:

- Grand Strategic (e.g., chiefs of state, political influences);
- Military Strategic (force deployment);
- Operational (commander, training);
- Tactical (land, air, waterspace management, C2 arrangements, planning phases);
- Close Tactical (those directly involved in combat).

Each level of command has different pieces of information that make up the battlefield scenario. Errors made by those at higher levels of command ultimately affect those at the lower levels. At the close tactical level, a single commander may need to make the CID decision by rapidly aggregating information. In contrast, those at the grand strategic level may be involved in debate and discussion over the funding towards training, which will affect the information received by individual soldiers. Although this review will focus primarily on individual decision makers in the close tactical level of command, some of the models of information aggregation will be useful for understanding the processes used by those at higher levels.

This section has highlighted the complexity associated with combat identification, and has emphasized the importance of successful information aggregation. To further our understanding of this task, we will now review the decision-making literature with a focus on cue-based decision-making.

4 Decision Making Frameworks

The need to use multiple cues (information) to form a judgment, in this case about the identity of a battlefield entity, is referred to in general terms as cue-based decision-making. There are several branches of decision-making literature that must be described in order to understand where this term fits. Primary among these are analytic decision theory and intuitive decision theory.

4.1 Analytic Decision Theory

Analytic decision theory, also called normative, rational or classical decision making, focuses on the selection of the optimal course of action (COA) from all possible alternatives derived from all available information. This theory basically views decision making as a statistical problem and therefore makes extensive use of computations. Analytic theory is referred to as prescriptive because it explains how decision makers *should* make decisions. Klein and MacGregor (1988, p. 14) summarize normative decision analysis as involving seven processes:

- 1) Enumerate all possible COAs;
- 2) Identify the possible outcomes associated with each COA;
- 3) Place values on each outcome;
- 4) For each COA, assess the probability that the associated outcome would be experienced;
- 5) Multiply each outcome by its associated probability to obtain an expected value or utility;
- 6) Sum the expected values for each COA; and
- 7) Choose the course of action having the largest expected value (i.e. greatest benefit).

This can clearly be a cognitively demanding process requiring both time and effort. Klein (1997) has suggested that this kind of decision-making only occurs when the decision maker is a novice, there is ample time, the decision maker must justify their choice to others, the best option must be determined, or when the task involves computational complexity. Therefore, in an operational context, it is likely that this kind of decision-making is restricted to those at high levels of command who are involved in the development of the rules of engagement, training methods, plans and policies, rather than those involved in time-pressured CID.

4.2 Intuitive Decision Theory

The second category of decision theory, intuitive decision-making, is referred to as descriptive because it purports to describe what people *actually* do when making a decision. It is made up of two main subclasses: Behavioural Decision Theory (BDT) and Naturalistic Decision Making (NDM). These subclasses focus on satisficing, therefore achieving an adequate decision, rather than an optimal one, in a real-life environment.

4.2.1 Behavioural Decision Theory (BDT)

BDT, also referred to as bounded rationality, was developed after analytic decision theories failed to recognize that people are bound by their cognitive abilities, causing them to stray from normative decision strategies (Einhorn & Hogarth, 1981; Gigerenzer, 2004). In real-life situations, people often use heuristics and cognitive biases because they do not have the opportunity to systematically process the information due to cognitive limitations. For example, heuristics may be used to reduce the amount of information available for making a judgment in order to avoid cognitive overload, particularly when under pressure (Einhorn & Hogarth, 1981; Bazerman, 2001). Theories of bounded rationality often refer to such heuristics and biases as weaknesses because they detract from the optimal decision (Lipshitz, Klein, Orasanu, & Salas, 2001b). However, in some circumstances, heuristics offer solutions indistinguishable from normative strategies, but with decreased effort and time (Gigerenzer, 2004). Tversky and Kahneman are well known for their classification of heuristics and biases used by people when they are under pressure or making judgments in uncertain situations (e.g., Tversky & Kahneman, 1982a,b,c). In addition, Gigerenzer has developed the Adaptive Toolbox to describe the variety of fast and frugal heuristics people use to adapt to their situation (e.g., Gigerenzer, 2004). Relevant heuristics and biases will be described when discussing the different models of information aggregation (Section 5). This form of decision-making has greater relevance for decision makers forming a combat identification because it focuses on real-life with an emphasis on rapid decision making.

4.2.2 Naturalistic Decision Making (NDM)

NDM was first described in the late 1980's following the development of BDT. Its focus is on understanding how experience affects decision-making in dynamic, uncertain, ill-defined, high stress, time-pressured environments (Lipshitz, Klein, Orasanu, & Salas, 2001a). This narrow scope has made it ideal for examining specific groups of people such as military commanders, fireground commanders, pilots and emergency room physicians (e.g., Bonifay, 2000; Lipshitz, Sender, Omodei, McClellan, & Wearing, in press; Falzer, 2004, O'Hare & Wiggins, 2004). NDM research suggests that in real-life situations, people rarely make use of all available information and do not take time to generate or evaluate all possible alternatives. Instead, decision makers rely on a fast and frugal use of cues from the environment and previous experiences to develop an adequate course of action. It is this decision making approach that can be considered synonymous with cue-based decision-making, one of the focuses of this review.

Lipshitz et al. (2001a) present five essential characteristics of NDM:

- 1) *Proficient decision makers.* Decision makers are experts in the domain being studied.
- 2) *Situation-action matching rules.* Decision makers match situations to a COA instead of generating and comparing all possible choices. Matching may be an analytic process, but more likely involves intuitive pattern matching.
- 3) *Context-bound informal modelling.* Recognizing patterns and cues requires context specific expert knowledge.
- 4) *Process orientation.* NDM focuses on the cognitive processes of expert decision makers, not on predicting the options they will choose.
- 5) *Empirical-based prescription.* Determining what decision makers *should* do (prescription) is derived based on observations and reports of expert performance, not on the normative (optimal) rules.

These characteristics have been utilized in several different models of NDM. Two of these models will be discussed here for their relevance to cue-based decision-making, including the Lens Model and Recognition-Primed Decision (RPD) Model.

4.2.2.1 Lens Model

The Brunswikian Lens Model (Figure 3) is a model of cue integration and belief formation (Horrey & Klein, 2001). A belief can lead to three outputs, including the choice of an action (e.g., choose to initiate weapons due to the belief that the entity is hostile), allocation of resources (e.g., seek more information from a second look, from superiors or technology to resolve uncertainty about the identity) and assessment of the degree of confidence in the diagnosis. The Lens Model addresses cue-based decision making by using linear models that deal with how people subjectively weigh information. Particularly, it describes the relationship between what people perceive about cues in the environment to the true value of the cues. Klein and MacGregor (1988) describe this model as a way to distinguish between:

“an object that is represented by a collection of cues, and the psychological representation of that object in terms of a judgmental policy based on those cues. Like an optical lens, the environment is portrayed in terms of a set of information components with predictive importance expressed in terms of validity coefficients.” (p. 11)

In other words, in a CID context, a person in the environment is made up of a series of cues (e.g., helmet, weapon, etc) that have different levels of predictive power (certainty) for determining the person’s identity. The decision maker has a “policy” for using those cues developed through training and experience. The Lens Model is used to evaluate whether that policy lines up with the true meaning of those cues. It can be used for assessing individual judgment formation in specific situations (Bisantz, Gay, Phipps, Walker, Kirlik, & Fisk, 1997). The closer people can match (calibrate) their subjective weightings of the cues to the objective weightings, the better their overall situational awareness will be, which will ultimately affect the accuracy of their judgment (Wickens et al., 1999). This weighing process will be discussed further in Section 5.4.

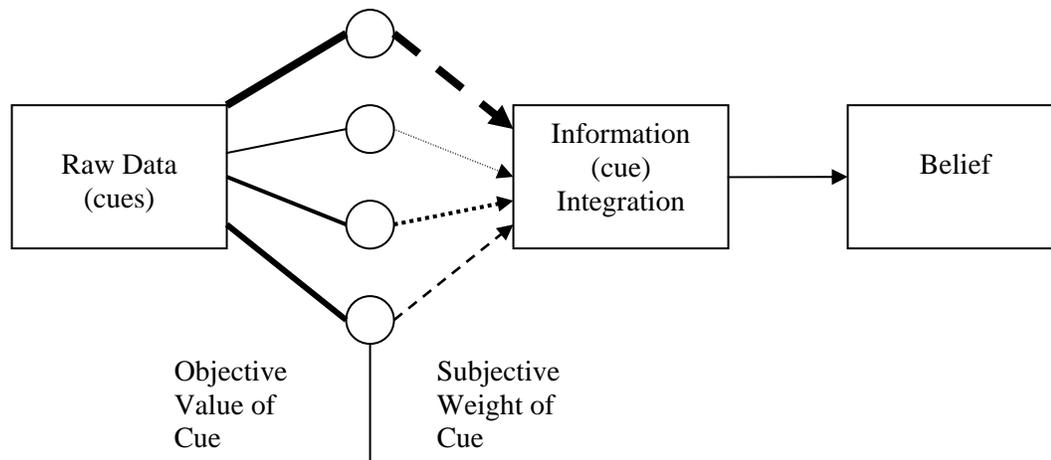


Figure 3. Model of cue integration and belief formation based on the Brunswikian Lens Model (recreation of Kirlik, 1995 as presented in Horrey and Wickens, 2001, p. 4).

Horrey and Wickens (2001) used the Lens Model in two experiments to determine how automation should be used for CID. The experiments involved battlefield simulations where participants had to use large amounts of information presented on map displays in a time pressured situation. Participants had to assess the threat level of enemy units located on the display based on evidence from multiple cues, such as unit type, size, and separation distance from own unit, and terrain difficulty. Each cue had high reliability (confirmed information), medium or low (unconfirmed) reliability. In experiment 1, for some of the trials, a cueing aid highlighted enemy units expected to be most relevant during a threat assessment task. Therefore, the automation was designed to assist participants in gathering relevant information. Participants, assuming the position of a battlefield commander, had to determine whether there was a greater threat to the east or west of their unit (located in the centre of the map) and allocate resources accordingly. This required mental integration of the information.

Prior to the experiment, a linear model was determined to weigh each piece of information based on questionnaire results from independent subject matter experts (SME). This was done to determine the objective value of each cue. In this example, the resulting equation was: $IV_{unit} = X_{type}(90 + 4X_{size} - 5X_{dist} - 14X_{diff}) * R$ such that threat level (or information value, IV_{unit}) of the detected unit increased as the size of the unit increased, separation distance decreased and terrain difficulty decreased. This equation was used to determine the optimal allocation of defensive resources, which was compared to the actual performance so that error scores could be calculated. Horrey and Wickens (2001) found that trials where enemy units were automatically cued resulted in closer to optimal resource allocation, and faster response times, than in trials without the automation. This result suggests that people benefit from a system that assists with gathering appropriate information. A memory probe test was used to determine how deeply people processed (weighed) different information, which found that unit size was the most important predictor for how participants determined the threat level.

In experiment 2, an automatic diagnostic aid was used to assist participants in aggregating the information, by suggesting which of the east or west side should receive a greater allocation of resources. Results revealed superior performance compared to the absence of automation (Horrey & Wickens, 2001). In fact, performance was also superior to use of the information gathering aid in experiment one. Therefore, participants received additional benefits when the information aggregation was performed for them. One disadvantage to this automation was that participants failed to process the cues as deeply when the information aggregate was already available to them, as revealed through memory probes. This suggests that during an automation failure, people might not be as effective at recognizing the problem. This experiment could not confirm this possibility because of using only one trial where the automation was unreliable.

These experiments were described to show that the Lens Model offers a way to evaluate performance and determine how people weigh cues during judgment formation.

4.2.2.2 Recognition-Primed Decision (RPD) Model

RPD is more directly related to the characteristics of NDM, and provides a relevant way to consider CID decision makers. Klein (1997) states that domain-specific experts making a decision in a high stress field setting where a reasonable, but not necessarily optimal solution is required are likely to use Recognition-Primed Decision making strategies. Unlike other decision making theories that rely upon making a choice between options, RPD involves assessing a situation and judging it as familiar to previously experienced events which are associated with an action (Klein, 1997). The classic RPD example is provided by interviews from fireground commanders who were found to identify a course of action by sizing up the situation and then recognizing appropriate actions to take (Klein, Calderwood, & Clinton-Cirocco, 1986 as cited in Klein, 1997). Fireground commanders reported imagining the outcome by using mental simulation to decide if the COA was appropriate. If the simulation revealed problems and there was sufficient time, another COA was considered (Klein, 1997). Therefore, decision makers using an RPD strategy evaluate options serially, instead of concurrently as in normative decision making (Klein & Calderwood, 1996).

There are three variations of the RPD model (Figure 4 on next page). The first and simplest of the three describes cases when an experienced decision maker assesses the situation and then uses existing prototypes to identify a single COA (Klein & MacGregor, 1998). A prototype or category may be a mental representation of a pairing between a situation and an action. It is sometimes described as a schema, script or exemplar, which is developed over time with experience (Perrin et al., 2001). This variation involves sizing up the situation, forming expectancies about what will happen next, determining which cues are most relevant, recognizing the goals reasonable to pursue and recognizing a reaction to apply in the situation so that it can be implemented (Klein, 1997). The second variation occurs when the situation is not clear due to uncertainty. Decision makers use feature matching where they identify relevant aspects of the situation to assist with categorizing it, and story building where they use mental simulation to determine the events that may have led to the observed situation (Klein, 1997). The final variation is the most complex. It occurs in cases similar to that described by the fireground commanders and involves evaluation of a COA without comparing it to other alternatives. This occurs by mentally simulating the outcome to determine whether it will work out as expected. If the COA is deemed inappropriate, a new COA will be evaluated.

Overall, RPD is made up of several components including situation assessment, pattern matching and mental simulation. Situation assessment, the process of “sizing-up” a situation, is the most

relevant for our purposes because it is in essence a model of information aggregation. Klein and Calderwood (1996) identify four types of information relevant to situation assessment in an RPD context:

- 1) *Plausible goals*. These are goals that the decision maker wants to achieve in the given context.
- 2) *Critical cues and causal factors*. Experts prioritise cues so that they do not focus their attention where it is not needed. In contrast, novices, who are excluded from the RPD model, may be overloaded by the variety of cues available in the environment. Experts have learned that specific cues have causal implications for the situation.
- 3) *Expectancies*. These are ideas about what is likely to happen in a given situation, which will be useful when determining the time course of events. Inexperienced decision makers will not have developed expectancies to the same degree as experienced decision makers, and will not be able to evaluate their situation assessment by comparing it to their expectancies.
- 4) *Typical actions*. Situations familiar to a decision maker should elicit a set of typical actions useful for a response.

These types of information can be described in terms of a CID decision. A plausible goal would be the desire to identify the detected entity. Experts evaluate only the most relevant cues, which will be influenced by their expectations about the situation. Once an understanding is reached about the situation, typical actions to respond to the entity will be elicited. As the various cues and expectancies are aggregated, a coherent situation assessment forms, which will impact overall situational awareness and all subsequent decisions and performance (Horrey & Wickens, 2001).

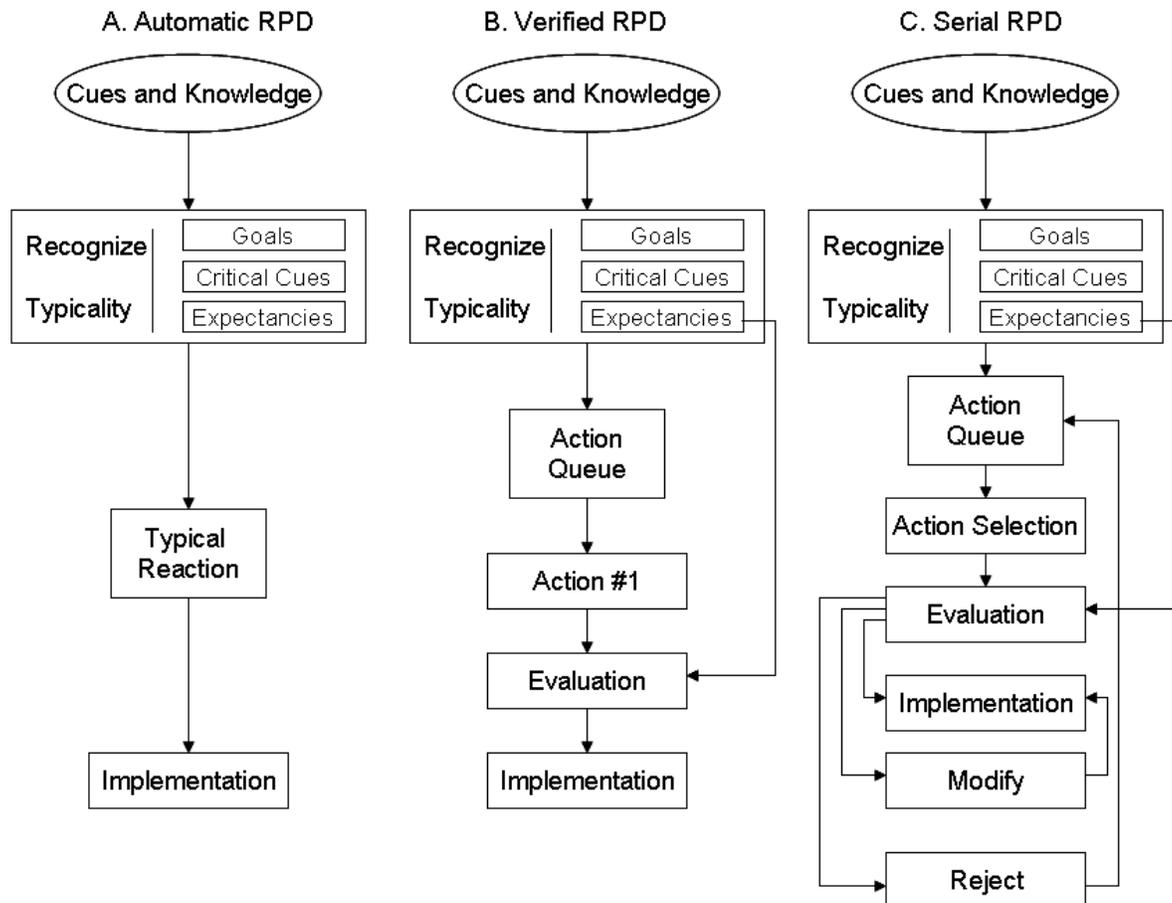


Figure 4. Models of RPD (recreation from Klein & MacGregor, 1998, p. 18).

Pattern matching and mental simulation, in contrast, are involved in the latter stages of the decision process specific to selection of a COA. O’Hare and Wiggins (2004) studied pattern matching abilities of pilots to determine how they used previous experience (i.e. knowledge of similar cases) to match actions to emergency situations. Pilots were able to match previous cases and scenarios found in their long-term memory (LTM) to their assessment of the current situation (i.e. their information aggregate) in order to identify a COA. Therefore, pilots compared and matched previous situations with an aggregate of the current case. This process suggests that people must form an aggregate sufficiently coherent that it can be related to features of past examples. Therefore, although RPD does not explicitly discuss models of information aggregation, it is apparent that the situation assessment results in a combination of cues. One potential problem that can arise with pattern matching is a false positive. This occurs when people assume a situation is similar enough to a previously experienced one that they utilize the associated action, when in reality the situation required a completely new solution. This is referred to as scenario fulfilment and was tragically observed when the USS Vincennes shot down Iran Flight-655 in 1988 partially because of false expectations based on the similarity of the situation to the Iraqi fighter jet attack on the USS Stark the previous year (Craig, Morales, & Oliver, 2004). A way to avoid this pattern-matching problem may be by building ones’ repertoire of experiences so that there are more

examples available for appropriate matching. Bonifay (2000) has suggested using simulations to train in as many scenarios as possible.

Interestingly, an interview between T. Lamoureux of Humansystems® and two members of the 1-PPCLI (First Battalion of the Princess Patricia's Canadian Light Infantry) who had recently returned from Afghanistan, revealed the use of RPD strategies during CID activities (Interview, Feb. 9, 2007, Edmonton, Alberta). The soldiers repeatedly stated that they had to “feel the situation” in order to identify whether someone was an enemy, neutral or friend. One main cue associated with “friend” was the presence of a helmet. Enemies were identified as people holding a gun without attempting to hide it. Assessing the situation was considered critical to the task. For example, the interviewees reported noticing when certain locations (e.g., market) were busy or not. When a typically crowded location was not crowded, this absence of people provided a cue that something was about to happen, causing them to be on high alert for anything out of the ordinary. The soldiers also explained that CID decisions are made rapidly requiring use of their rules of engagement. They noted that there was not time to discuss the situation with those at higher levels of command. However, communication was common between people when time allowed. For example, when travelling as a group of LAVs, there were occasions where a number of LAV commanders contacted each other regarding the identity of a detected entity. The limited details regarding specific cues used to classify people suggest that the aggregation process or situation assessment may be highly automatic in those with experience.

4.3 Summary

In summary, the decision-making literature is made up of analytic and intuitive processes that vary in their goals (optimal vs. satisficing) and in the effort required to reach them (time consuming vs. rapid). Combat identification is most strongly related to the NDM models, which focus on subjective weighting of cues and situation assessment necessary for cue-based decision making. This framework will be helpful in evaluating the usefulness of the models and principles associated with information aggregation.

5 Models of Information Aggregation

As has already been observed in our review of CID and the decision-making frameworks, information aggregation is an important aspect of decision-making. It involves both weighing and combining information (cues) that is selected for relevance to the decision in a preceding process of information gathering (Einhorn & Hogarth, 1981). The information aggregation stage, the focus of this review, involves combining quantitative and/or qualitative information into a single output (e.g., estimate, probability, belief, or hypothesis) used to make a judgment. In the literature, studies involve the aggregation of quantitative estimates, probabilities, opinions, binary choices, or qualitative descriptions. The research identified is often specific to the aggregation of information from different sources (e.g., vision, communication, different sensors). However, it is expected that this research should extrapolate to multiple cues that come from the same source (e.g., different visual cues).

The study of information aggregation is particularly important given the limitations associated with human information aggregation abilities (Westen & Weinberger, 2004; Horrey & Wickens, 2001). Westen and Weinberger (2004) suggest that people are poor at integrating information because they rarely receive feedback regarding their cue-weighting accuracy, therefore limiting their ability to refine the weights that they use. In contrast, it has been suggested that people are fairly good at identifying relevant cues during the information-gathering phase (Horrey & Wickens, 2001; see Gruppen, Wolf & Billi, 1991 for an example where people are poor at the information gathering phase). People also perform adequately at coding the directional relationship between cues and the judgment (e.g., a person wearing coalition insignia provides a positive weight towards the judgement of “friendly”) (Westen & Weinberger, 2004; Dawes, 1982).

The difficulty associated with information aggregation has made it a target for development of automatic support systems (Horrey & Wickens, 2001). Despite the difficulties with this process, it is a necessary one, not only from the perspective of the practicality in designing a 100% accurate identification sensor as discussed in Section 3, but also due to statistical reasons which will be discussed next.

5.1 Reasons for using multiple information sources during decision making

“Information pertinent to individual decisions never exists in concentrated form, but solely as the dispersed bits of incomplete and frequently contradictory knowledge which all the separate individuals possess” (Hayek, 1945, p. 519 as cited in Piketty, 1999).

It has long been recognized, particularly in the social sciences (i.e. Economics, Political Science, Organizational Behaviour), that aggregating information from multiple sources can lead to the most informed decision (Yaniv, 2004; Budescu & Yu, 2006, Feddersen, & Pesendorfer, 1999, Wit, 1998). As stated in the above quote by Hayek (1945), information often only exists dispersed across individuals (or information sources). This may be because people have different experiences and knowledge, which influences their interpretation of events and evidence (Feddersen, & Pesendorfer, 1999). For example, a soldier may have visited a particular village in the past therefore acquiring knowledge about its organizational structure. Upon returning with a soldier inexperienced with this village, he will be able to offer insight into the neutrality of certain

individuals. To make best use of the private information held by different individuals, it is necessary to poll them for their opinion. In ideal situations, individuals provide genuine responses based solely on their private information (Feddersen, & Pesendorfer, 1999). A loose analogy related to this use of dispersed information is Condorcet's Jury Theorem. This theory was developed in the 1700's specific to collective decision making. It states that when responses are genuine, the more people who vote, the more informed the judgment will be. Although this theory is not specific to individual decision making, and deals with aggregating opinions rather than aggregating 'facts' (which may include the opinions of others, but may equally include immutable information about the environment), the ideas espoused by Condorcet's Jury Theorem are analogous to the case of an individual decision maker using and aggregating different sources of information to make a decision. For example, this concept is present when doctors use multiple tests to diagnose a patient. Patients are subjected to numerous tests because there is no single source capable of providing all relevant information needed to make a judgment. For the remainder of this report, we treat the aggregation of opinions as analogous to the aggregation of multiple information sources. The reader should note that we did not find any discussion in the literature of the equivalency of these different aspects.

Budescu (2006) as cited in Budescu and Yu (2006) has identified four reasons for considering multiple sources when forming a judgment:

- 1) To maximize the amount of information for a decision;
- 2) To reduce the effect of extreme sources;
- 3) To reduce the effect of unreliable and inaccurate information; and
- 4) To make the decision process more inclusive and ecologically representative.

Therefore, not only are multiple sources used in order to acquire as much private information as possible, but it is also done to reduce the effect of error and extreme information, which may be caused by biases or in a CID context, by a malfunctioning sensor. If only one source is used, then there is the possibility of making an incorrect judgment because of choosing to rely upon an inaccurate piece of information.

In addition, increasing the number of sources (e.g., visual cues from the decision maker and sensor cues) statistically improves the level of confidence in a judgment (Budescu, Rantilla, Yu & Karelitz, 2003; Yaniv, 2004). This is important because most judgments require that a predetermined level of certainty be reached before forming a final judgment (Dean et al., 2005; Todd & Gigerenzer, 2001). Confidence is improved because the amount of random error is reduced as the number of sources increase. A single quantitative estimate, such as the average seasonal temperature in Toronto, provided by an individual or a measurement device, will contain random error due to fluctuations in the source's performance and bias caused by tendencies to make over or underestimates. However, assuming that individual sources have minimal biases, the random error will be reduced when estimates are acquired and averaged across sources, causing the aggregated estimate to converge towards the true value (Einhorn, Hogarth & Klempner, 1977 as cited in Yaniv, 2004). Realizing this statistical truth will enhance confidence in the final aggregate, therefore improving the certainty of the judgment.

In order to achieve the benefits associated with using multiple sources, it is necessary that the sources be at least partially independent. This is true of the opinions of advisors and of cues acquired from the environment. In group decision-making literature, the necessity of independence is rooted in the assumptions of theories, such as Condorcet's Jury Theorem which assumes that individuals have some degree of independence allowing them to provide unique, private

information when making their vote (Feddersen & Pesendorfer, 1999; Yaniv, 2004). In a similar fashion, cues used by an individual decision maker (which could be in the form of a judgment such as an IFF sensor reporting a judgment of friend, or an environmental cue such as the presence of friendly insignia) need a degree of independence so as not to waste the decision makers' effort and time in evaluating redundant cues. According to Yaniv (2004), redundancy occurs as the number of people or sources increases, causing a lack of added value to the aggregate. With regards to aggregating opinions, Yaniv (2004) suggests that only 3 to 6 opinions are required to reap the benefits of counsel because beyond this, the level of dependence increases resulting in "more of the same." In addition, the gain in accuracy may be decreased if advisors are highly biased or if their opinions are highly correlated. The correlation between sources increases because the individuals may have similar backgrounds or may even consult one another (Yaniv, 2004). Sources other than people must also be partially independent to improve judgments. For example, a sensor that is only capable of detecting an object at the same distance as natural vision will be unable to provide additional information about the detected entity. Therefore, it will not benefit the identification process and may slow judgment time because of the effort to gather and integrate the redundant information.

5.2 Review of the information aggregation literature

Initial investigation of the literature revealed that formal models using the terminology "information aggregation" were primarily located in the Social Sciences (i.e. Economics, Political Science, Organizational Behaviour) and Computer Science disciplines. The search was expanded to include heuristics and psychological principles related to the concept of combining information to achieve a more comprehensive understanding of this process. Across this literature there was minimal application to military operations (with the exception of data fusion algorithms in Computer Science which are beyond the scope of this review, and some papers related to certain heuristics). However, the models were able to provide a variety of concepts that may be transferable to CID decision-making tasks.

Several themes became apparent when reviewing the literature:

- There are both analytic and intuitive aggregation methods;
- Research has focused on the aggregation of quantitative information (e.g., forecasts, probabilities, estimates), with less study in the area of combining qualitatively different information (i.e. combining different kinds of information, such as visual cues and numeric information);
- Information to be aggregated may be cues (raw data) or opinions/judgments;
- Information sources may be independent or dependent (redundant);
- The way information is presented (simultaneous or sequential ordering) affects how informative it is and how it is aggregated;
- Group/team decision making differs from individual decisions made based on information from a group (only the latter is of interest for this review);
- Weighing information from self differs from weighing information from others;
- Outlying information is treated differently than consensus information; and
- Trust levels affect information aggregation.

Although this review will not be sectioned by these themes because of their overlapping principles, their concepts will become more clearly understood throughout the course of this discussion. The review will begin with a summary of formal models of information aggregation and models of judgment related to this process. Following will be details specific to the process of weighing information, and finally factors related to the presentation of the information.

5.3 Integrating information

Two main categories of research related to information aggregation were identified during the search: aggregation of qualitatively different information and aggregation of quantitative information. Each of these categories offers theories and principles regarding how people may combine information when making decisions. The following sections will review these principles, providing CID related examples whenever possible. It is necessary to note that the methods described will include aggregation of opinions or estimates from others and the integration of environmental cues. Although the latter is most directly related to CID, there may be situations where decision makers will seek counsel when making an ID or will use a source that provides a judgment (e.g., IFF sensor reports a judgment of friend) instead of a raw cue (e.g., presence of a helmet), making the former a valuable contribution to this report.

5.3.1 Aggregating qualitatively different information

The literature is limited with respect to research on the aggregation of different types of information (e.g., visual cues, information from sensors, etc). However, two principles were identified which offer insight into how integration might take place, including linear models and the majority rule.

5.3.1.1 Linear models and multiple-cue judgment

Linear modelling describes decision making as an additive approach where cues (information) are assigned weights and are then added or subtracted based on their directional relationships to the judgment. Qualitative cues are thought to be represented in binary format (0 = gun absent, 1 = gun present) so that the linear equation can be calculated. Linear models may be compensatory or non-compensatory. Compensatory models, in which a high value on one cue can compensate for a low value on another, require that every cue be assessed, weighted and combined to form a judgment, whereas non-compensatory models do not require that every cue be used or integrated (Rothrock & Kirlik, 2004). In a compensatory model, no single cue can determine the outcome because a subset of cues can compensate for the value of the most highly weighted cue. Non-compensatory models are defined by the absence of any sub-set of cues that can out-weigh or compensate for the highest weighted cue. Compensatory linear models are part of analytic decision theory, whereas non-compensatory models are more associated with BDT.

The Lens Model, discussed in Section 4, uses compensatory linear modelling to examine belief and hypothesis formation. It is a method used for comparing subjective weightings of cues to the objective (true or expert determined) weightings. This model uses a proper linear model to show how the world (criterion) is really represented by cues and an improper linear model to show how people actually integrate information. The discrepancy between these models is used to determine how people make errors in their judgments (Horrey & Wickens, 2001). A proper linear model is an analytic method of describing the integration of information such that the weighing of information (predictor variables) forms an optimal relationship between the prediction (judgment) and criterion

(standard or true judgment). An improper linear model is non-optimal because people rely on intuitive methods to weigh cues or may randomly generate weightings, or assign all cues equal weightings (Dawes, 1982). Interestingly, these often crude improper linear models have been successful at predicting close to optimal judgments (Dawes, 1982).

Linear models are used in a formal research area called multiple-cue judgment. This research, introduced in the 1950s, evaluates how people use multiple binary or continuous cues to form a judgment (Juslin, Olsson, & Olsson, in press). It is typically rooted in analytic theory, using statistical methods to create optimal, compensatory linear-additive models. A classic multiple-cue judgment task requires participants to determine whether an insect is toxic based on learned rules about the insect's leg length and colouring. Often, the cues are binary (e.g., long or short legs, spots or no spots). Two models, cue-abstraction and exemplar memory, have been developed to explain how information aggregation is performed to make a judgment.

The cue-abstraction model, an example of analytic decision theory, is used to explain how people learn the rules governing the relationship between the cues and criterion. During training, it is assumed that people mentally integrate these rules, which are later probed when exposed to certain cues in the environment. Therefore, the cues are connected to the criterion in memory, providing the direction of the relationship and the cue weight (Juslin et al., in press). The final judgment (or aggregate), if binary (e.g., toxic, not toxic), is based on the sum of the binary cues multiplied by their weight. If the final judgment is to be continuous (e.g., the bug is toxic if the poison concentration is greater than 55 ppm), then the running total of the criterion estimate is updated with each additional cue. Therefore, this model suggests that people integrate information based on learned rules that relate cues (e.g., gun/no gun, helmet/no helmet) to the criterion (e.g., friend or enemy).

The exemplar memory model, found in categorization literature, is not concerned with assigning weights to cues, but instead relies on feature matching between an observed object and those found in memory. This model suggests that people retrieve specific memory traces of objects from different categories (called exemplars) to assist them in making judgments. For example, people may be trained by memorizing different images of insects that are categorized as toxic or not toxic. When they next see an insect, its features will be used to retrieve memories of insects with the same features. The probability that the insect will be categorized as toxic equals the "ratio between the summed similarity of the judgment probe to the toxic exemplars, and the summed similarity of all exemplars" (Juslin et al., in press, p. 3). This model is very similar to the pattern matching strategy described in Recognition-Primed Decision Making. In both models, experience is required to possess an exemplar of a similar object or a schema, script or prototype for a similar situation. RPD offers additional methods such as mental simulation to fit the observed entity or situation with a previously experienced scenario.

Both the cue-abstraction and exemplar memory models may be useful for CID. In certain circumstances, exemplar-based training may be effective. For example, it is possible that people would benefit from training on how to categorize weapons based on whether they are used by friends or enemies. Karsh et al. (1995) trained participants to recognize friends and enemies by using cue-cards showing various angles of different kinds of military vehicles. Participants were able to effectively discriminate the vehicles in terms of identity in a computerized task after 20 minutes of training. Rule-based learning, as described with the cue-abstraction model may also be applicable in some situations if rules can be created to describe the relationship between cues and identity. However, the continuously changing battlefield experienced by today's military limits the ability to create such rules that may have been possible in the past (e.g., all enemies wear a specific uniform).

5.3.1.2 Majority Rule

Voting is a model of information aggregation useful for binary decision making. As already discussed, it is useful for acquiring private information held by individuals. Condorcet’s Jury theorem states that choosing to use the majority vote as the final decision is the most efficient method of aggregating information from across a group of people as the number of voters increases towards infinity (Piketty, 1999; Wit, 1998). This theorem has several limiting assumptions, including: the decision must be a categorical binary judgment (e.g., friend or foe), the individuals or sources of information are independent, each person has an accuracy level of greater than 50 percent, and they are voting sincerely, therefore only voting for a judgment if they have private information specific to that option (Piketty, 1999; Feddersen & Pesendorfer, 1999). Only with large enough electorates or samples does this theory prevail when these assumptions are violated (Piketty, 1999). Although voting may be considered the formation of a collective decision, therefore being related to group decision making, it is in fact directly related to individual decision making. It is often the case where a group of people will vote or provide their opinion resulting in a collective decision, which is then considered by the individual decision maker as one piece of information amongst others. For example, in everyday life, a decision maker might poll several friends to determine whether a specific restaurant is a good place to eat. The majority vote may result in a “yes.” However, the decision maker may use this as one piece of information that is weighted along with formal restaurant reviews. It is not known how often soldiers have an opportunity or a need to take a “vote” regarding the identification of someone that they encounter in a battlefield scenario. It is possible that the fast pace of such a situation might prevent this method of aggregation. However, fireground commanders, who deal with similar high-pressured situations have reported requesting information from as many people as possible in order to gain a better awareness of the situation (Lipshitz et al., in press). Whether this information was a vote on the proper action to take remains to be determined.

5.3.2 Aggregating quantitative information

The majority of information aggregation models identified are specific to quantitative information. Although CID decision makers must combine qualitatively different information, Dean et al. (2005) suggests that each information source is associated with a probability or quantity that needs to be aggregated to determine the confidence one should have in the proposed identity.

Three main categories of models became apparent when reviewing the literature. We categorized them as follows:

Information Aggregation Category	Examples
Reasoning Rules	Bayes’ Rule
Measures of Centrality	Averaging (mean) Weighted average Median
Choosing Strategies	Take-the-best heuristic

5.3.2.1 Reasoning Rules – Bayes Rule (Theorem)

Bayes' rule uses conditional probability theory to determine the optimal way to update prior beliefs in the presence of new information, therefore updating prior probabilities (Budescu & Yu, 2006). It assumes that the probability of an event (i.e. the degree of belief) is dependent upon the presence of other events and the causal links between them (Van Gosliga & Jansen, 2003).

Bayes' theorem is calculated as follows:

$$p(h | e) \times p(e) = p(e | h) \times p(h)$$

- $p(h | e)$ is the posterior probability, which is the probability of hypothesis or belief “ h ” after considering the effect of evidence (i.e. information, cue) “ e ”.
- $p(e)$ is the probability of observing “ e ”.
- $p(e | h)$ is the likelihood, which provides the probability of circumstantial evidence “ e ” assuming “ h ” is true.
- $p(h)$ is the prior probability of “ h ” without observing evidence “ e ”.

In the presence of additional evidence (e_2), the calculation becomes:

$$p(h | e_1, e_2) = \frac{p(h | e_2) \times p(e_1 | h, e_2)}{p(e_1 | e_2)}$$

Bayes' theorem is designed to deal with binary information (e.g., presence or absence of friendly insignia) and binary hypotheses (e.g., identity is friend or enemy). This rule is highly utilized to explain and evaluate Economic theories, and is used in Computer Science as a data fusion algorithm. Bayes' rule is a normative approach, which implies that it describes what people should do, not necessarily what they do.

There is conflict in the literature regarding whether people are capable of using this rule. A typical finding, according to Budescu & Yu (2006) is that people rely too heavily on prior information and do not adequately update their assessment with respect to new information, therefore failing to use Bayes' rule. However, Sedlmeier and Gigerenzer (2001), on the other hand, have been able to teach people to use Bayesian reasoning within two hours of training, provided that they use frequencies instead of probabilities during the task. They suggest that the difficulty associated with Bayes' Theorem may be due to human limitations related to manipulating probabilities.

Budescu and Yu (2006) have explored whether people are more likely to use a Bayesian approach or an averaging model to aggregate information. They used a medical scenario where participants had to distinguish between two diseases based on a subset of six diagnostic tests. Participants made a diagnosis and provided a confidence level associated with their judgment. Three participants were selected to be advisors and their information was given to other participants who used their predictions to form their own judgments about the diagnosis. The advisors had different levels of independence depending on whether they used a partial overlap of the same diagnostic tests or used completely different tests when making their judgments. Budescu and Yu (2006) tested whether participants made use of a naïve Bayesian approach whereby they assumed a conditional independence between advisors (information sources), therefore treating advisors' predictions as perfectly reliable and calibrated, or whether they used an averaging method. Briefly, averaging weighs each piece of information as the inverse of the total number of pieces of information therefore reducing the effect of each advisor. A naïve Bayesian approach, on the other

hand, causes the contribution of each new piece of information to be added to the others without an adjustment for the total amount of information. It therefore predicts an extremeness effect in contrast to the averaging compromise effect (Budescu & Yu, 2006). Results showed that averaging models (especially a weighted average) were superior to the naïve Bayesian model. In fact, even when participants knew that advisors were independent (i.e. used different diagnostic tests), which is a condition of Bayes' rule, the naïve Bayesian model fit less well than averaging models. Participants were not optimally sensitive to inter-cue correlations or the level of inter-judge information overlap. Results did, however, indicate that people are able to use a naïve Bayesian approach in certain circumstances, particularly when the sources of information are in close agreement. When advisors provide similar diagnoses, especially when the judgments are more extreme, people are more likely to have a higher level of confidence in the judgment, and therefore are comfortable putting full weight on each estimate. However, when the advisors provided different diagnoses, people had a lower level of confidence and instead used an averaging method. Therefore, according to Budescu and Yu (2006), the method of aggregation implemented depends upon the perception of the disagreement between different sources of information.

5.3.2.2 Measures of Centrality

5.3.2.2.1 Averaging

The averaging model is a conservative approach for aggregating quantitative estimates. It involves adding together the estimates and dividing them by the total number of information sources. This is also termed a compromise principle because each piece of information receives less weighting as the number of sources increases. The averaging method is a form of linear model using equal weights (Budescu & Yu, 2006). Budescu and Yu (2006) have shown that this method is used particularly when the different sources of information are perceived to have a large discrepancy, causing a low level of confidence in the sources. By using an averaging method, the discrepancy can be minimized.

Despite the simplicity of averaging, it may not be as intuitive as it sounds. Larrick and Soll (2006) performed four experiments to determine that people do not intuitively believe that averaging individual estimates from various sources will result in a more accurate estimate. Instead, the majority of people tested held a false theory that averaging the estimates would result in performance only equal to that of the average individual. Statistically this is not true.

“When combining uncertain quantity estimates, the discrepancy between the average estimate and the truth can be no greater than the average discrepancy of the component estimates.” (Larrick & Soll, 2006, p. 2).

For example, if in reality a detected entity is 1000 meters away and one source estimates it to be 1200 meters away, while another estimates it at 1010 meters, then the average estimate is 1105 meters. This average estimate is 105 meters off from the 1000 meter distance. However, the average discrepancy of the component estimates ($1200-1000 = 200$, and $1010-1000 = 10$) is 105. Therefore, the average estimate is always equal or less than the average discrepancy. Had each of the sources been trusted equally and only the most discrepant one used, then the discrepancy could have been much larger. Therefore, using the average estimate will result in a more accurate estimate.

In contrast to the findings of Larrick and Soll (2006), Budescu, Rantilla, Yu and Karelitz (2003) found that people do use an averaging strategy. In their study, 69% of participants identified the averaging strategy as their method of information aggregation, suggesting an introspective sensitivity to this method.

Interestingly, one factor affecting whether people are likely to use the averaging integration model is their culture. Individualistic cultures, such as the United States and Canada, are more likely to view averaging as causing a loss of information (i.e. watering down) when an expert is included amongst the information sources than are collectivist cultures (Larrick & Soll, 2006).

5.3.2.2.2 Weighted Average

Budescu, Rantilla, Yu and Karelitz (2003) found that when people aggregate the probabilistic opinions from advisors who use asymmetric numbers of cues (e.g., test results, visual symptoms, etc., when forming a medical diagnosis) to form a judgment, they alter their weighting of the information based on both the number of cues used by the advisors, and the known accuracy levels of the advisors. Using medical and business scenarios, Budescu et al. (2003) found that when the decision makers (participants) were provided with information from 3 advisors who had varying degrees of asymmetry (i.e. the advisors used different numbers of cues and had different levels of accuracy) across trials, the participants were more confident in their aggregate when the advisors had partially redundant information as well as when the information was distributed across advisors unequally. Therefore, some level of redundancy in cues used by the advisors was necessary, but the advisors should not use all of the same cues so that they have some unique information (Budescu et al., 2003; Yaniv, 2004).

5.3.2.2.3 Median Value

When people have no previous experience with specific information sources they are likely to take the median estimate, therefore eliminating outlying opinions to accept the consensus value. Harries, Yaniv and Harvey (2004) performed a study where participants imagined they were in a foreign country receiving estimates about the distance and age of a nearby city from four other people. These estimates were said to be based on individuals' personal knowledge about the location. One of the estimates was four standard deviations from the mean response. The participants used these estimates to make a decision about the distance and age of the city. Harries et al. (2004) determined the fit of the estimates and found that people eliminated the extreme estimate by intuitively using the median value. The ease of determining the median was suggested as a primary reason why people might gravitate towards this model, in addition to a desire to produce cognitive consonance (Harries et al., 2004).

5.3.2.3 Choosing Strategy

People often fail to use information aggregation strategies and instead choose a single opinion, estimate or judgment provided by an advisor or information source (Soll & Larrick, 2005, as cited in Larrick & Soll, 2006). Participants may seek to use the estimate of what they perceive to be the most accurate advisor or source of information, or the advisor that used the most cues when forming a judgment (Budescu et al., 2003). For example, a soldier may judge a vehicle as friendly because of the report of "friend" from an IFF sensor, without utilizing judgments from other sources, or by making use of personal information based on experience and visual cues. In other situations, people may seek to use only their own information instead of that provided by others (Yaniv and Milyavsky, in press), as will be discussed in Section 5.4.3. This strategy is not restricted to quantitative estimates, but can also be applied to qualitatively distinct cues.

A heuristic similar to the choosing strategy is “Take-the-Best” (TTB). This is a fast and frugal heuristic that makes use of only the single most valid cue to make a judgment between two options (Gigerenzer, 2004; Jones, Juslin, Olsson & Winman, in press). The validity of a cue is determined by the ratio of the number of correct predictions made by using a cue, to the number of pairs where the values of a cue differ between objects being discriminated. For example, if a person needs to judge whether a person is a friend or foe, they will acquire a variety of cues. When using the TTB heuristic, the cue previously determined to have the highest validity will be examined first for its value. In a CID context, this cue might be the presence or absence of a helmet. If there is no helmet present, the cue will not provide enough information to adequately discriminate between friend or foe (e.g., the person may be a friend by not wearing the full uniform). Therefore another cue will be examined. If, however, there is a helmet present, this may satisfactorily identify the person as a friend, and the search will end (refer to Bryant, 2007 for an example of TTB applied to an air threat decision task). Therefore, the TTB heuristic has three parts: search by validity, one-reason stopping rule, and one-reason decision-making. By using a stopping rule, people can draw inferences without assessing the details of every cue (Gigerenzer, 2004).

5.4 Weighing information

One of the most important components of the information aggregation process is assigning weights to the information. Wickens et al. (1999) describes a weighting as the amount of attention people give to a specific cue. This weighting can be affected by many factors such as the saliency of the cue, the association of the cue to a correct choice based on previous experience, the trust in the cue, and more. Here we will review general weighting strategies, methods used to handle dissenting information, self-versus-other weightings, and methods of dealing with uncertainty and information overload.

5.4.1 General weighting strategies

Not all information is of equal value and therefore should not be treated as such when forming a judgment. Trust, certainty, relevance and importance of cues all affect how people subjectively weigh cues and sources of information (Yaniv, 2004; Wickens et al., 1999; Horrey & Wickens, 2001).

Trust level and certainty associated with a cue is related to the accuracy of the information source, the expertise of the advisor in the case of opinion aggregation, the confidence reported by the source, and previous performance (Yaniv, 2004). For example, when people repeatedly experience accurate opinions from a particular advisor even when the opinion disagrees with other advisors, they will be more likely to accept this dissenting information, despite the tendency to choose consensus information (Harries et al., 2004). In the case of CID, there are factors that may affect the formation of trust for a given information source, such as the reliability of the sensors (Wickens et al, 1999). IFF sensors can be subject to error (e.g., signal is acquired from a neighbouring vehicle, not the detected entity) which when experienced, will effect the weighting people apply to this information in the future. Individual differences will affect trust levels because not everyone will experience the same errors and mistakes, therefore altering how they each weigh different sources of information. Within Lens Model terminology, this difference is discussed in terms of the calibration between the subjective and objective weighting of the cues (Wickens et al., 1999). Individuals will have different beliefs about the value of each piece of information, which will affect how they allocate their attentional resources to each cue. Wickens et al. (1999) discuss two forms of calibration to describe how people weigh information: Attention (A) Calibration and Trust

(T) Calibration. These calibrations refer to the best way to allocate attention and trust to the cues or to the various hypotheses (alternatives). Whenever these calibrations are violated, there is a Type A (attention) or T (trust) bias. A Type A bias occurs when people allocate their attention between sources in an inappropriate way given the true value of sources or the cost of ignoring a source or hypothesis (importance). The Type T bias occurs when people have an overtrust in a source and therefore respond to a cue that is unreliable, or when they have an undertrust causing them to ignore relevant cues due to a previously experienced false alarm (Wickens et al., 1999).

Relevance and importance of the cue will also affect the weighting. Horrey and Wickens (2001) found that people weighed (and therefore processed) relevant information more heavily than irrelevant information, as revealed during a memory probe test. The importance of a cue can be affected by its salience, such as the size or intensity in a display (Wickens et al., 1999). Automatized cueing in a display can draw attention to appropriate cues eliciting a greater weight (Horrey & Wickens, 2001). Importance is also determined through experience. As discussed by the members of 1-PPCLI, who had returned from Afghanistan, with HSI's T. Lamoureux (Feb. 9, 2007, Edmonton, Alberta), experience with the daily routine of villagers assists with assessing the situation and therefore recognizing when a danger might be present. Without such experience, it would be difficult to complete the OODA loop prior to that of hostile forces. By understanding the culture and environment, importance is assigned to the presence or absence of certain cues. Yager (1993) has proposed weighing information based on the relevance it has to the decision at hand by using a penalty approach. To do this, people would assign a penalty value to every piece of information based on what it would cost if the information were disregarded therefore resulting in a decision that conflicted with the information. Haspert (2000) has suggested incorporating the cost of committing fratricide into the weighing process for CID. This cost will vary depending on the intensity of the situation, therefore affecting the threshold required (certainty level) to make an identification.

Typical weighting strategies suggested in the CID literature are probabilities associated with the likelihood that a piece of information is accurate and will lead to the correct identification, which when aggregated results in an overall confidence in the judgment (Dean et al., 2004). These probabilities therefore may be more focused on the trust aspect of weightings. However, CID decision makers will also need to decide which information to use in the aggregation, which is likely to be related to relevance and importance. Karsh et al. (1995) found that military personnel performing in a tank identification simulation neglected to use all available information sources, despite reasonable accuracy levels. This suggests that they did not view the additional sources as important in contrast to other cues.

5.4.2 Weighing Dissenting Information

In many decision-making situations, information from one source may contrast with that provided by other sources. Decision makers must determine how to handle this conflicting information. One could imagine a CID scenario where the ID returned from a sensor during a vehicle interrogation may claim "friend" and yet all other indications suggest enemy. This could occur if a friendly force was nearby an enemy and therefore its transponder was returning the friendly code. The commanding decision maker must choose whether to accept this contradictory information, consider it with more or less weighting when aggregating all available information or omit it entirely. Although the rules of engagement are generally designed to assist in these kinds of situations, it is important to understand the typical cognitive response to this kind of information. According to Harries, Yaniv and Harvey (2004), people often discount outlier opinions because of a cognitive drive to reach consensus. By trimming information to focus on the majority response

one can avoid creating dramatically obscured aggregated estimates due to an information source providing strategically exaggerated or erroneous information. However, resolving inconsistencies by ignoring them may be a risky practice that can eliminate important information unavailable from other sources. Harries et al. (2004) found that when people are provided with quantitative estimates (e.g., age of or distance to a city) where one of the estimates was four standard deviations away from the others, people chose the median response, therefore disregarding the outlying estimate. Harries et al. (2004) determined that the only way to overcome this default response, therefore causing selection of the outlying information as the estimate of choice, required that people experience repeated feedback (as many as 10 trials) regarding the pairing between a particularly named source and an accurate outlier. Therefore, people can learn to utilize dissenting information, but it takes time and experience.

Military research has also suggested that people dismiss inconsistent information when making a decision. Perrin, Barnett, Walrath, and Grossman (2001) studied how U.S. Navy personnel identified unknown aircraft. Information inconsistent with their judgment was recalled less often than consistent information, suggesting that the inconsistent information was weighted and processed less. It is also possible that the inconsistent information was reinterpreted to fit with a known pattern such as a schema, script or prototype already present in the experienced personnel's cognitive repertoire. The study was unable to discriminate between these possibilities. Another example involving inadequate use of inconsistent information was the USS Vincennes shooting of Iran Flight-655. One factor causing the error was the IFF reading of both COMAIR (commercial airline) and MILAIR (military). The COMAIR report did not fit with the other information (e.g., failure to respond to warnings) and therefore was not weighed properly (Craig, Morales, & Oliver, 2004).

Ultimately, people desire to explain away the differences between sources by using cues about accuracy and credibility (Yaniv, 2004). This is observed in such social arenas as criminal court where a lawyer may attempt to discredit a source of information because it does not fit with the story being developed to achieve a judgment of innocence. In a CID scenario such as the search for a Taliban leader in an Afghan village, a sleeping person found holding a gun will cause conflict when forming a judgment about the identification of the person, because although they may be hostile when awake, this cannot be determined with confidence in the presence of these two cues. CID decision makers will have to rapidly decide whether to ignore the sleeping person or to consider the person hostile despite the possibility that the gun was held during sleep solely for protection against such enemies as the Taliban.

5.4.3 Egocentric Weighing of Information

If we expand upon the above sleeping-with-a-gun scenario so that this person is encountered by a group of three soldiers quietly manoeuvring through an area during a late-night raid, we can present an example of decision making influenced by an egocentric mindset. For example, it is possible that two of the soldiers will identify the person as neutral based on their understanding of the danger associated with this village and the need for self-defence. Although they may signal this opinion to the third soldier, he may still choose to identify the person as hostile because of his interpretation of the scenario. Instead of integrating the opinions of the other soldiers, the third decision maker may be subject to an overconfidence bias causing him to assess his opinion as being more accurate than that of the others.

The overconfidence bias is thought to occur because people can access the information that led to their judgment, whereas the cues used by others are not so easily determined. Yaniv (2004) has reported that people have been found to place 70% weighting on their own opinion and 30% on the

opinions of others. Additionally, Yaniv and Milyavsky (in press) have shown that people give more weight to opinions that are closer to their own than those that are distant. The literature does not specify how distant an opinion must be to be ignored, but does suggest that the opinions or estimates that differ the most from one's own opinion may be subject to this exclusion. Therefore, the greater the distance between advice and one's own opinion, the less likely it will be considered. This is referred to as egocentric trimming. Yaniv and Milyavsky (in press) explain that from an objective or external perspective, opinions from others and self appear equal. However, from an internal or subjective point of view, opinions are not perceived as equal because the decision maker has more evidence available to mind regarding his opinion than he does of the advisor's view. This effect of weighing own information greater than others, particularly when others have dissenting views, is also related to the confirmatory bias related to belief revision (Keren & Teigan, 2004; Westen & Weinberger, 2004). When people have a strong opinion or belief about the state of the world, they are more likely to seek evidence or cues that confirm this belief. Evidence in contrast to their opinion is perceived as an outlier that should be ignored.

Yet another heuristic associated with the egocentric frame of mind, is the Availability Heuristic (Ross & Sicoly, 1982). Tversky and Kahneman (1982b) describe the availability heuristic as causing people to deem something more likely to happen depending on whether it is easy to bring a similar instance to mind. This heuristic is based on the implicit assumption that the availability of examples, as determined by its rate of occurrence, reflect their true likelihood. People may use this heuristic, especially in time-pressured situations, to weigh cues differently depending on how they relate to instances they more easily recall (due to active or passive experience). If the soldier who identifies the sleeping person as an enemy could draw upon instances where people with hostile intent have faked sleeping before attacking then this would cause him to weigh the sleep cue more lightly than others would, and may lead to favouring of his own hostile interpretation. Another possible use of the availability heuristic is related to choosing to use cues most easily brought to mind. For example, the belief that people wearing helmets are friendly because of repeated observation of this "rule", may cause this cue to be weighted more heavily when observed, even if there are other, less common cues suggesting hostile intentions.

Noth and Weber (2003) have studied the effect of overconfidence on use of personal versus others' information. When people make decisions one after the other, therefore having an opportunity to use their private information and that of the people who have made judgments before them, they often fail to aggregate the information in a rational way. Instead, they tend to be overconfident and put more weight on their own information, even when they know that their information is weak in quality. In their study, Noth and Weber (2003) had participants perform a computerized experiment where they were informed of their private information (A or B), the strength of the information (strong or weak), and provided with the information (A or B) of the preceding decision makers (if there were any). Participants chose A or B based on this information. They performed approximately 80 trials receiving feedback in different currency units depending on whether their choice was correct or not. Noth and Weber (2003) tested 2 methods of aggregation, Bayesian Updating (BU), whereby people would follow Bayes' rule when making their choice or Private Information (PI), whereby participants would always use their own information regardless of its strength. If people behaved rationally, they would use Bayes' rule in conjunction with the knowledge of their position in the sequence of information presentation. See Table 3 for a description of how people should respond based on Bayes' rule compared to what was actually observed in this experiment. The results revealed use of a heuristic based on overconfidence in private information.

By asking participants how they had performed the task, the heuristic was named: Modified Counting Heuristic (MCH). MCH works as follows (Noth & Weber, 2003):

- Predict according to own strong signal if in position 1, 2, 3, or 4 of the decision maker sequence.
- Use own strong signal at position 5 and 6 if more than one deviation is observed across preceding decision makers, otherwise, go with the majority response.
- Predict according to own weak signal if at position 1 or 2 and use own signal only if no majority exists and the last two subjects have not predicted the same state. Otherwise, go with the majority response.

The MCH is consistent with the idea of overconfidence, which is influenced by a need to overcompensate for the expected error within public information.

Table 3. Expected and observed judgments in a sequential information presentation scenario.

Position in the sequence of decision makers	Type of private information	Preceding Information	Response According to Bayes' Rule	Actual Response
1	Weak	None	Choose private information	14.2% failed to choose private information
1	Strong	None	Choose private information	3% failed to choose private information
2	Weak	Opposite choice of private information	Choose choice of preceding decision maker	49.3% chose based on private information (overconfidence)
2	Strong	Opposite choice of private information	Choose private information	97% chose based on private information
3	Weak	Opposite choice of private information	Choose choice of immediate predecessor (particularly if both predecessors make same choice)	73.7% chose based on private information (overconfidence)
3	Strong	Opposite choice of private information	Choose private information	14.7% failed to choose their own information (irrational herding/conforming)

One CID study was identified that provided evidence of a potential overconfidence bias. Karsh et al. (1995) found that CID decision maker's in a tank identification simulation relied more on their visual information than on that provided by a decision support system. This study could not confirm the presence of an overconfidence bias because the decision support system was only used in 14.5% of the trials, suggesting that it might have been available too infrequently for it to be considered an important cue.

5.4.4 Applying Weights in the Presence of Information Overload

Although there are many benefits associated with using multiple pieces of information when forming a judgment, too much information can cause difficulties. A large number of cues can put demands on limited resources such as selective and divided attention, and working memory

(Wickens & Carswell, 1995 as cited in Wickens, Pringle & Merlo, 1999). Although there is no clear explanation as to what qualifies as ‘too much’ information, the classic limits of working memory (7 +/-2 units) may be one limiting factor. Time will also be a factor, because most cues will require attention in a serial manner, therefore limiting how much information can be processed. When the task load is too high, people may either fail to aggregate all of the information, or they may provide arbitrary weights to the information to avoid evaluating the cues (Perrin et al., 2001; Horrey & Wickens, 2001). For example, Perrin et al. (2001) increased the number of aircraft, display clutter and number of communications that needed to be monitored by U.S. Navy personnel participating in a threat assessment task and found that participants decreased the amount of information that they processed in the high demand tasks. This was revealed by their decrease in recalled information during a memory probe test (Perrin et al., 2001).

When so much information is present that people are unable to properly weigh it, or the different sources have inconsistent reliabilities, people may utilize the “as if” heuristic. This means that people will weigh all cues “as if” they were the same (Wickens et al., 1999; Horrey & Wickens, 2001). Use of this heuristic can cause excess weight to be placed on cues of low value and less on those of high value. Wickens et al. (1999) suggest avoiding this problem by drawing people’s attention towards important cues by presenting them in a salient format in a visual display. Unfortunately, this method will not always be possible, especially in face-to-face combat identification scenarios.

An additional way people cope with high demand is through pattern matching as described in the RPD model (Horrey & Wickens, 2001). People with domain-specific experience use pattern matching to associate recognized cues with similar situations found in long-term memory (O’Hare & Wiggins, 2004; Klein, 1997). These memories are used to match actions to the situation. Gonzalez (2001) has suggested that pattern matching of RPD is basically the same as BDT’s Representativeness Heuristic.

According to the representativeness heuristic, we judge the likelihood of an uncertain event according to the degree to which the event is similar to the population from which it is derived or the degree to which it reflects the salient features of the process that generates the event (Kahneman & Tversky, 1982). For example, CID would qualify as one of these judgments when determining the degree to which a person resembles a suicide bomber. Klein and MacGregor (1988) describe the representativeness heuristic as a method for evaluating the degree to which a particular entity has features similar to ones’ learned prototype. This heuristic seems to be similar to the exemplar memory model described previously when discussing multiple-cue judgment. However, a bias caused by using the representativeness heuristic is that people fail to consider the probability of A or B present in the situation. It is therefore as if people are using Bayes’ rule without taking into consideration the base-rates (Kahneman & Tversky, 1982). For example, in a location where there is a very low proportion of “friends”, the probability of detecting a friend will be low. However, if the person appears to match the soldier’s mental representation of a friend, even if this information is weak, then they may be biased to make a friend identification, even though they should also consider the actual likelihood of this identity. Therefore, the representativeness heuristic can result in an improper weighing of information such that situational factors, like base rates, are ignored.

An additional heuristic that may influence how CID decision makers weigh information is the Adjustment and Anchoring Heuristic. This heuristic causes people to anchor their estimate to the first or most recent estimate presented by someone else. In this case, people are not behaving egocentrically, but instead are reliant upon others’ judgments, even if they are incorrect (Tversky & Kahneman, 1982a).

5.4.5 Dealing with uncertainty

Situations may also occur when the decision maker will have too little information. This will cause the formation of an insufficiently certain aggregate, which will reduce the possibility of making a good judgment. Overall, there are three main forms of uncertainty that may affect decision making, including (Lipshitz et al., 2001a):

- 1) inadequate understanding of the situation because of insufficiently coherent SA;
- 2) incomplete, ambiguous or unreliable information (lack of information); and
- 3) alternative courses of action are insufficiently differentiated by the aggregated information such that a choice cannot be easily made.

Lipshitz et al. (2001a) describes two tactics used in NDM to improve decision making in the midst of uncertainty: the RAWFS heuristic and Recognition/Meta-Cognition (R/M) model.

The Reducing, Assumption, Weighing, Forestalling and Suppressing (RAWFS) heuristic is used to deal with uncertainty caused by either insufficient situation awareness, a lack of information, or conflicting alternatives (i.e. COAs) by: reducing uncertainty, using assumption-based reasoning, weighing the pros and cons, forestalling and suppressing the uncertainty. Lipshitz and Strauss (1997) as cited in Lipshitz, Sender, Omodei, McClellan, and Wearing (in press) describe these coping strategies as follows:

- *Reduction.* Reduce uncertainty by searching for more information to add to the aggregate. This method is consistent with the reiteration of the cycle of acquiring and aggregating information in the INCIDER model developed by Dean et al. (2005) when the identification has not reached a desired level of confidence.
- *Assumption-based reasoning.* Use previous knowledge and imagination to make sense of the available information.
- *Weighing pros and cons.* Make an approximation of the subjective expected utility of each COA alternative.
- *Forestalling.* Prepare a COA to counter potential negative unforeseen events.
- *Suppressing uncertainty.* Ignore the uncertainty and take a risk by proceeding with the COA.

The reduction and assumption-based reasoning strategies most directly affect information aggregation, while the other strategies focus on choosing amongst alternatives. When the situation does not make sense, people may seek more information, therefore reinitiating the information acquisition phase and then re-aggregating the larger volume of information. However, when there is no extra information available, people may pull on previous knowledge to imagine what the situation might mean, therefore combining the present aggregate with previous knowledge. This may involve shifting the weights associated with each piece of information so that an acceptable decision can be made.

Lipshitz et al. (in press) used a cued-recall methodology based on incidents captured by fire-fighting unit commanders' head-mounted video cameras to study the RAWFS heuristic. The study required that the commanders recall and describe what was going on in their minds during the recorded incidents. These statements were coded to determine the kinds of uncertainty the commanders experienced and how they coped with it. Inadequate situational awareness and uncertainty about the required COA and the cause of the incident were the main sources of

uncertainty. Results indicated that the commanders used Reduction, Assumption-based reasoning and Forestalling to cope with the uncertainty. Reduction was performed by delaying action (i.e. waiting for more information passively), relying on standard operating procedures (e.g., such as ROE for CID decision makers), prioritizing (i.e. attending to the most necessary action known), and actively searching for cues through all senses (e.g., seeking cues from crew members, others on the scene, etc). Commanders had to monitor the situation continuously, updating and disconfirming expectations. Assumption-based reasoning involved proceeding forward with a plan, using mental rehearsal to imagine possible COAs, mental simulation to determine how they would turn out, and using assumptions when forming situational awareness. Forestalling did not involve specific tactics. Assumption-based reasoning was also used on the way to the incident such that fire fighting unit commanders listened to the dispatcher in order to construct a mental model of the situation so that actions that might be required could be anticipated ahead of time. Fire fighter unit commanders relied heavily on standard operating practices to guide their actions. They also relied on other people, such as subordinate fire-fighters, bystanders, the dispatcher and other units at the scene to be sources of information. Therefore, despite the time-pressured situation, information was still gathered across as many sources as possible when performing recognition-primed decision making. Lipshitz et al. (in press) found that the commanders first used reduction to reduce uncertainty followed by assumption-based reasoning strategies and then forestalling, leaving the weighing of pros and cons and suppression as last resort methods.

A second tactic is the Recognition/Meta-Cognition model, which suggests that people use a Story, Test, Evaluate and Plan (STEP) procedure when their recognition or pattern matching fails because of uncertainty. The STEP process includes four parts: construct a Story, Test, Evaluate and Plan (Lipshitz et al., 2001a). Constructing a story involves using whatever fragment of recognition is available through pattern matching to make an assessment of the nature of the situation, including past, present and future events consistent with this understanding. Testing is done to determine the likelihood of the constructed story given the implications and expectations associated with it and how these relate to the information present. When gaps or inconsistencies are observed in the story, the decision maker revises it. The Evaluate phase is described as a “devil’s advocate” approach where the decision maker attempts to justify and explain the assumptions associated with the story as they fit with the information about the present situation. Finally, the Plan phase is similar to Forestalling in RAWFS, whereby the decision maker makes a back-up plan in case the current best response based on the constructed story is wrong. Overall, this method can be thought of as adding information to the aggregate based on a mental simulation of the scenario in order to form a judgment that can match a previously experienced situation. Therefore instead of searching for additional information from the environment, the current cues may be re-weighted to fit with a story representing the situation.

In addition to uncertainty caused by a lack of information, it may also occur when people are presented with inconclusive information. This information may be relevant, but it does not clearly favour a particular belief (i.e. friend or foe). Baranski (2003) examined how experienced Operations Room Officers (OROs) and inexperienced students aggregated conclusive and inconclusive information in a naval threat assessment scenario. Results revealed that inconsistent information was not ignored. Instead, it accentuated the hostility information for OROs, and diluted it for students. Therefore, experts erred on the side of “foe” when inconsistent information was present while inexperienced participants erred on the side of “friendly” (Baranski, 2003). These results suggest that uncertainty will be handled differently depending on the level of experience of the decision maker.

5.5 The presentation of information

The way that information is presented to the decision maker will affect how the information is weighed and aggregated. Information may have a different value depending on whether it is presented simultaneously or sequentially (Banerjee 1992; Ottaviani & Sørensen, 2001), as well as depending on the order in which the information is presented (Perrin et al., 2001).

5.5.1 Sequential Information Presentation

Effects related to the sequential presentation of information have already been touched upon when discussing the overconfidence bias in Section 5.4.3. In that discussion, people performed egocentrically and chose to present their personal opinion in a committee setting even when they should have performed rationally by first updating their belief based on information presented by others. Here, we elaborate on the effects associated with sequential information presentation.

When people are required to present their opinions or judgments sequentially in front of each other, they may hide their information if it does not conform to the preceding opinions. This social factor is called herding behaviour and it results in the loss of relevant information (Banerjee 1992; Ottaviani & Sørensen, 2001). Anti-seniority rules have been used to minimize this phenomenon. For example, hierarchical and judicial systems often require that senior experts speak later in the sequence so that more junior experts can provide their opinions without being subject to their influence (Ottaviani & Sørensen, 2001). Even senior experts can fall trap to herding behaviour when their opinion differs from the previous opinions (Ottaviani & Sørensen, 2001). Experts providing their opinion or signal about the state of the world, as it is often referred to in Economic theory, may pretend to have observed a different signal if they believe presenting the information will cause them to receive a bad reputation (Ottaviani & Sørensen, 2001). In fact, rational decision making theory requires that people conform to previous responses when multiple preceding opinions contrast with their own opinion. This is due to the assumption that contrasting opinions must be based upon private information unavailable to the individual. Therefore, they should aggregate this information with their own by conforming. This rational behaviour leads to the creation of information cascades, where every subsequent speaker, based on observations of others, will make the same choice independent of his private information (Noth & Weber, 2003). This behaviour, although normative according to Bayes' rule (therefore providing optimal integration from a rational perspective), is actually a failure in aggregating previously presented information with one's own information.

The overconfidence bias discussed in Section 5.4.3, is also a failure in aggregation because it causes previous information to be weighed too lightly (Noth and Weber, 2003). This bias leads to a reversal of the information cascade which can cause others who are using herding behaviour to erroneously believe information provided by the biased individual is strong (Noth & Weber, 2003). Despite this possibility, the inclusion of some highly biased people may help a discussion to facilitate acquisition of a maximum amount of information that is otherwise hidden within individuals (Ottaviani & Sørensen, 2001).

It is difficult to extrapolate this kind of rational decision theory into a CID made at a close tactical level of command due to the unlikelihood of a round-table discussion where each person presents their information, as often discussed in this literature. Nonetheless, herding behaviour may still occur in the absence of such a "table discussion". For example, anecdotal evidence shows that subordinate formations implicitly trust the plan provided by the higher command, including information about expected locations of friendly forces, control lines and lines of furthest advance.

This leads to friendly-fire incidents when other units get lost and appear in unexpected locations. The formation radios for additional information from the operations officer who states that no friendlies are in the area, and the formation opens fire on the 'lost' unit. This same situation occurred when a USAF A-10 aircraft opened fire on a British Warrior armoured vehicle, resulting in the death of one soldier. The pilot radioed for confirmation from his controller and, despite his own evidence to the contrary, opened fire. It is therefore necessary to investigate when and why CID decision makers might find themselves accepting the opinion of others at higher ranks despite having conflicting information that could benefit the formation of a judgment.

5.5.2 Simultaneous Information Presentation

Problems with herding behaviour can be eliminated by having people provide their private information to the individual decision maker simultaneously or independently of others. For example, a LAV commander might request the opinion of the gunner regarding the identification of a detected entity independently of the opinion requested of an overhead pilot and the opinion of another LAV commander closer to the entity. This would reduce the likelihood of one of the contacts simply agreeing with the others because of herding behaviour. It would be necessary to determine whether such information cascades could develop in the high-pressured military environment given the intuitive nature of the decision. This literature search did not locate military research specific to this topic.

Another benefit of viewing information simultaneously or with minimal time disparity, is that it allows decision makers to make a better judgment on the disagreement between information sources. As already discussed, this will affect how decision makers combine the information because they will be more aware of dissenting information (Budescu & Yu, 2006).

5.5.3 Information Order Effects

Even when information is presented simultaneously, the human information processor cannot consider all information at exactly the same time because of cognitive limitations (e.g., attention cannot be everywhere at once, Wickens et al., 1999). Therefore, even when information is presented as close as possible in time, it will be subjected to an ordering. This ordering can affect how the information is aggregated, even when the decision maker is an expert. Perrin et al. (2001) performed a study in which sixteen U.S. Navy personnel determined the identity (civil or military) of unidentified aircraft using six kinds of information. Three of the information sources supported each of the two possible identities. On each trial, all of the information was presented, but in different orders. This was done to determine whether participants were using an information order bias or pattern matching when making their judgment. According to Perrin et al. (2001), pattern matching would cause participants to update their understanding of the situation as each new piece of evidence was provided. An information order bias, on the other hand, would cause people to dismiss information not consistent with the judgment formed. Perrin et al. (2001) found support for an information order bias because participants identified the aircraft as civil when the first three pieces of information suggested military and the last three suggested civil. Therefore, participants appeared to be employing a recency effect where the most recent information was utilized for the judgment. This effect is related to memory processes which are biased towards recalling information presented first (primacy) and last (recency) in sequence (Hogarth & Einhorn, 1992 as cited in Wickens et al., 1999). Perrin et al. (2001) suggest that the recency effect is more likely in the presence of a short, complex sequence of evidence instead of a long one. This is because there will be less pressure to alter the judgment hypothesis to fit with the greater amount of information.

5.6 Summary

In summary, the models and theories of information aggregation and the various weighting strategies offer us insight into the complexity involved when combining information. Although much of the literature is outside the realm of military operations, we were able to extrapolate and apply some of the principles to example CID scenarios. Further research will be necessary to determine whether these extrapolations are actually valid in real-life CID contexts. The following and final section of this review will highlight the relationships between CID, intuitive and analytic decision theory and the principles of information aggregation in order to categorize the likely use of these models.

6 Evaluation and Conclusions

As determined by the literature, combat identification is a complex decision-making task requiring successful combination of data-driven and cognitively driven information in a time-pressured environment. CID decision makers must reach a situation-specific level of certainty (threshold) about their identification before accepting it as a final judgment. This certainty is affected by how information is weighed and combined. If, after acquiring and aggregating some information, the threshold of confidence is not met, then more information is sought, the situation awareness is updated, the identification is revised (if necessary), and a new level of confidence is reached (Dean et al., 2005; U.S. Defense Science Board, 1996). If the confidence level is adequate, the decision-making process can continue with the selection and implementation of a COA based on the identification judgment. The necessity of achieving a faster OODA loop than the enemy (by quickly identifying the enemy and executing an action) puts stress on the individual decision maker to gather and combine information rapidly (Bonifay, 2000). The cost of making a misidentification (e.g., fratricide, neutricide or suicide) confounds this situation, creating a need for a speed-accuracy trade-off that will vary depending on the intensity of the situation. For example, as the distance from a LAV and a detected entity decreases, the time pressure will be enhanced, therefore decreasing the threshold required to make an identification (Dean et al., 2005). Although a decreased threshold will result in a greater chance of fratricide, the risk may be necessary to avoid other consequences, such as an unacceptable risk to oneself or comrades.

The dynamic, time-pressured nature of CID and the expertise of its decision makers, make it difficult for this decision to be compatible with the time-consuming process implied by analytic decision theory (ADT). For a soldier in the field, the requirement of the ADT approach to use all available information and to develop and consider all possible alternatives would not be practical. In addition, the speed-accuracy trade off required by CID decision makers under many operational circumstances eliminates the need for an optimal decision. Instead, satisficing is required so that an adequate identification can be made, given the less than adequate time available. If we return to the example scenario of the search for a Taliban leader in an Afghan village, we can recognize the difficulty associated with collecting all available information about every individual encountered before identifying them (i.e. friend, foe). To do this, decision makers would not only assess the appearance and actions of the individual, but would need to determine the relationships between the person and others in the village, the history of the person, etc. This time draining task would surely allow for the escape of the intended target. Instead of performing this demanding process, CID decision makers need to be able to look at a person and quickly categorize them based on their own understanding of the situation, the cues the person presents, and in situations with enough time, possibly use the opinions of others and/or technology.

Unlike ADT, intuitive decision theory offers a better fit to CID decisions because of its focus on cue-based decision making in real-life situations. Aspects from both BDT and NDM are helpful in describing this decision process. For example, the Recognition-Primed Decision Model and the Lens Model of NDM offer insight into how experience fosters rapid decision-making without using demanding mental computations. RPD suggests that people with domain-specific experience assess the situation and then use pattern matching to match cues from the environment with previously experienced scenarios which are associated with a particular action. This action is then mentally simulated to determine its effectiveness in the present situation. The Lens Model, in contrast, describes how experience and proper trust levels will affect the calibration between

subjective weightings of cues and the actual informativeness of the cues. With increased experience, people will more easily allocate attention (weight) to the proper cues, assuming they are not overloaded by the situation. The effect of factors, such as cognitive overload, can be explained with the heuristics and cognitive biases of BDT. By combining the details of BDT with the principles of NDM, CID can be understood at a greater level.

The models and principles of information aggregation can also be classified by their relationship to analytic or intuitive decision making (Table 4). Methods of aggregation that are highly computational, and aim for an optimal integration can be considered as part of the domain of analytic decision theory. Methods that are used more naturally and lead to a reasonable combination of information fit within intuitive decision theory.

Table 4. Categorization of Models and Principles of Information Aggregation Based on Decision Making Theory

	Analytic Decision Theory	Intuitive Decision Theory
Information Integration	Proper Linear Models	Improper Linear Models
	Compensatory Models	Non-compensatory Models
	Cue-abstraction Model	Cue-abstraction Model
		Exemplar Memory Model
	Majority Rule	Majority Rule
	Bayes' Rule	Naïve Bayes' Rule
	Averaging (Larrick and Soll, 2006)	Averaging (Budescu & Yu, 2006)
		Weighted Average
		Median
		Take-The-Best Heuristic
Weighing information		Availability Heuristic
		Representativeness Heuristic
		Adjustment and Anchoring
		Confirmation Bias
		Consensus Trimming
	Herding Behaviour, Information Cascades	Overconfidence Bias, Herding Behaviour
		Egocentric Trimming
		"As If" Heuristic
		Information Order Bias

As can be observed in Table 4, the majority of principles discussed in this review fit under the heading of intuitive decision theory. One reason for this discrepancy is that many of the models associated with analytic or rational decision theory are too difficult for people to perform, even when given sufficient time. Therefore, these methods are often used as data fusion algorithms, which are beyond the scope of this paper. For example, Dempster-Shafer Theory and Fuzzy Logic

are both methods of information integration that should fall within the analytic decision category because of their formation of an optimal aggregate. However, literature could not be found suggesting the natural, unassisted use of these methods by humans.

Several of the methods of information aggregation are included under both analytic and intuitive decision theory. This duplication is caused by conflicting literature regarding the natural use of these methods in time-restricted situations. For example, the *majority rule* is designed to create the optimal integration of information dispersed across individuals, therefore making it an analytic approach (Piketty, 1999). At the same time, it is common for people to seek consensus information in dynamic situations by ignoring conflicting information, and in turn accepting the “majority” response. In other situations, however, dissenting information may be used because of the expertise or previous accuracy of that source, therefore violating the majority rule (Harries et al., 2004). *Cue-abstraction* is also listed under both categories. This is because it involves the governance of cue weightings based on learned rules, which is not always possible in natural settings. There may be some situations where there are well-established rules regarding the relationship between cues and criterion. However, in many cases, especially battlefield scenarios, the cue-criterion relationships change too frequently to form a set of rules.

By assuming that CID decision makers will be subject to the same restrictions and biases associated with intuitive decision theory, we can summarize the applicable methods of weighing and combining information as follows:

- Pattern matching between observed cues and mental schemas or prototypes may assist in understanding the situation.
- Pattern matching between observed cues and memorized exemplars might assist in forming a combat identification.
- The identification threshold (confidence level) will be lowered if it is easy to recall an instance of enemy contact. For example, if a soldier has a vivid memory of an encounter with an enemy, he may be more likely to accept an enemy identification with a lower level of certainty than to risk this kind of misidentification. This is an example of the *availability heuristic*.
- The identification threshold will be raised if it is difficult to recall an instance of enemy contact. For example, if a soldier has no memory of enemy encounters, he may require more certainty that information is guiding him towards an enemy identification before stopping the cue acquisition phase. This is an example of the *availability heuristic*.
- Weights will be assigned to cues non-optimally based on heuristics and cognitive biases due to the uncertainty and time pressure in the battlefield.
- Soldiers, who have experienced accurate and reliable information from information sources in the past, such as from IFF sensors, will put more weight on this information when forming their judgment.
- Trust levels gained through experience will be ignored when the situation is too cognitively demanding, causing each cue to be weighed equally.
- Soldiers may ignore the opinions of others in favour of their own beliefs about the identity of an entity because of an *overconfidence bias*. They may also seek to prove their judgment by ignoring conflicting information because of a *confirmatory bias*.

- Only a single cue may be used to form a judgment if the decision maker views it as adequate for distinguishing between two options (e.g., friend vs. unknown; enemy vs. not an enemy). This is an example of using the *Take-the-Best* Heuristic.
- If cues suggest different identifications, the most recently presented information may be used to form the judgment because of an *information order bias*.
- If an information source is known to use multiple cues to form a judgment, this source will receive a greater weighting when forming ones' own judgment. This is an example of the *weighted average strategy*.
- If an information source provides a numeric estimate, such as blue force position coordinates, the soldier will anchor their estimate of this position based on this information, even when they know it is erroneous. This is an example of the *Adjustment and Anchoring Heuristic*.
- In a situation where time permits communication of opinions about the identity of an entity, the majority "vote" may be accepted, unless dissenting judgments are made by a consistently accurate, but outlying source.
- In a situation where time permits communication of opinions about the identity of an entity, the soldier may accept the opinion of superiors despite possessing conflicting information. This is an example of *herding behaviour*.

Studies, such as battle simulations will be necessary to determine the validity of these methods of information aggregation as they apply to CID. It should also be noted that in order to make a successful combat identification, decision makers must not only accurately weigh and combine information, but they need to first utilize their experience to gather the appropriate information, and following the aggregation they must have an efficient strategy for identifying and making use of a course of action. Information aggregation is only one part of this complex process.

7 Conclusion

In conclusion, this report has reviewed the literature for models of human information aggregation in order to relate it to combat identification decisions made by individuals in a land force context. Although the literature related to models of information aggregation was limited by its primary application to economics, political science and organization behaviour, we were able to extrapolate a variety of principles to facilitate understanding of the processes involved in the weighing and combining of information during the formation of a belief or judgment. The review found that the characteristics of combat identification fit it to the intuitive decision making framework. By determining the methods of aggregation associated with this framework we were able to form a list of principles, heuristics and biases that may affect CID decision makers.

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10 Acronyms

A Bias	Attention Bias
A Calibration	Attention Calibration
ADT	Analytic Decision Theory
BDT	Behavioural Decision Theory
CID	Combat Identification
COA	Course of Action
COMAIR	Commercial Airline
ID	Identification
IFF	Identification Friend or Foe
INCIDER	Integrative Combat Identification Entity Relationship
IV	Information Value
LTM	Long Term Memory
MILAIR	Military Aircraft
NDM	Naturalistic Decision Making
ORO	Operations Room Operator
PPCLI	Princess Patricia's Canadian Light Infantry
ROE	Rules of Engagement
RPD	Recognition-Primed Decision
SA	Situational Awareness
T Bias	Trust Bias
T Calibration	Trust Calibration
TI	Target Identification
TTB	Take-the-Best
TTP	Tactics, Techniques and Procedures

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(U) This report reviews research literature pertaining to models of human information aggregation in order to apply them, when possible, to combat identification (CID) decisions made by individuals in a land force context. In particular, the review examined social science, science and military literature to identify principles and theories associated with how human decision makers weigh and integrate information. The review identified a variety of heuristics and cognitive biases associated with these processes, along with formal and informal models of combining qualitative and quantitative information. The report presents current conceptualizations of combat identification and places it within the context of cue-based decision making under the intuitive decision framework. By framing this complex decision we were able to evaluate the applicability of the methods of aggregation to the CID task.

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(U) information aggregation; combat identification; judgment; decision making; models

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