Use of Situation Awareness Data by the CDA to Enhance Ground Combat Vehicle Survivability

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Abstract: Situation awareness for ground combat vehicles is being actively developed by the U.S. Army to enable soldiers and commanders to have a better understanding of their environments and hence allow them to fight smarter. The control of hit avoidance assets (sensors and countermeasures) by the Commander's Decision Aid (CDA) can also benefit from situation awareness data, either from offboard reports or onboard systems that support situation awareness. Such data can be used in an automated way to enhance threat typing as well as countermeasure selection, timing and control. Managing the hit avoidance data, by the CDA, can provide additional information to support onboard C4I useful to the maneuver force. This paper addresses the specific ways that the CDA – and vehicle survivability – can benefit from situation awareness data.

1 Background

Improved situation awareness can greatly enhance the warfighting effectiveness of commanders and soldiers. Use of situation awareness data by an integrated defense system on a ground combat vehicle can also provide significant benefits with respect to the vehicle's and crew's survivability. Such data can be used by the Commander's Decision Aid (CDA) in an automated way to enhance threat typing as well as countermeasure selection, timing and control. Managing the hit avoidance data, by the CDA, can provide additional information to support onboard C4I useful to the maneuver force.

The Commander's Decision Aid (CDA) is a processing architecture and logic that provide fusion and resource/response management for integrated defense systems installed on ground combat vehicles. The CDA is designed to work with multiple sensors and multiple countermeasures in cluttered battlefield environments.

The basic things the CDA does are to fuse track data relevant to particular threat events; fuse multiple sensor data as well as stored data to discriminate threats from non-threats and to type the threats (with a confidence factor); prioritize threats in the case of multiple, simultaneous threats; and select and execute the optimum countermeasure response. The CDA also provides threat information (as well as the status of the integrated defense system) to the crew.

The fundamental challenge for the CDA is shown in Figure 1. In general, the CDA must provide rapid and accurate responses in the midst of cluttered battlefield conditions. Modes for each hit avoidance countermeasure (manual, semiautomatic, or automatic control) are selectable by the vehicle commander. In general, it would be expected that countermeasures requiring very rapid response (such as active protection) would be in automatic mode.

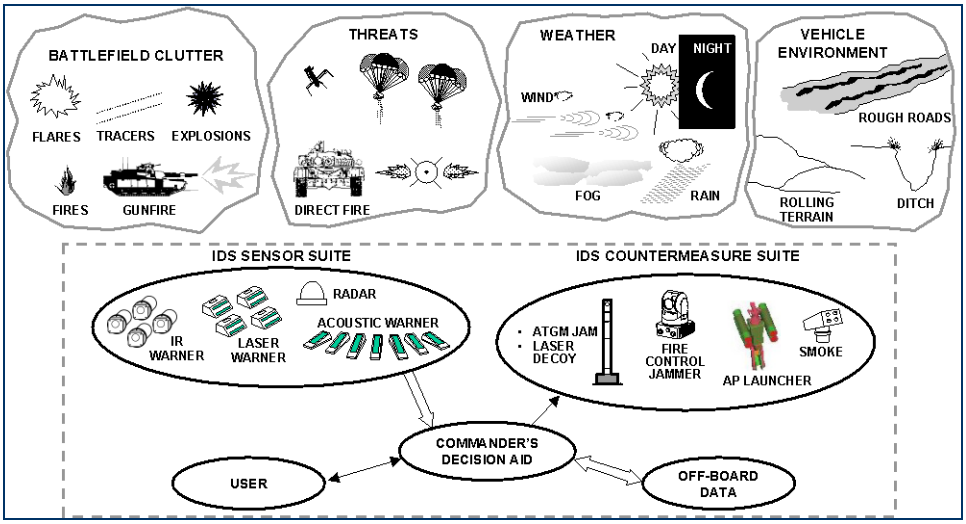

Figure 1. The CDA Problem Space: Multiple Sensors, Multiple Countermeasures and a Cluttered Battlefield

Figure 2 shows the basic architecture for the CDA. The basic functions are track fusion, threat typing, threat prioritization, countermeasure response management, and countermeasure effectiveness assessment.

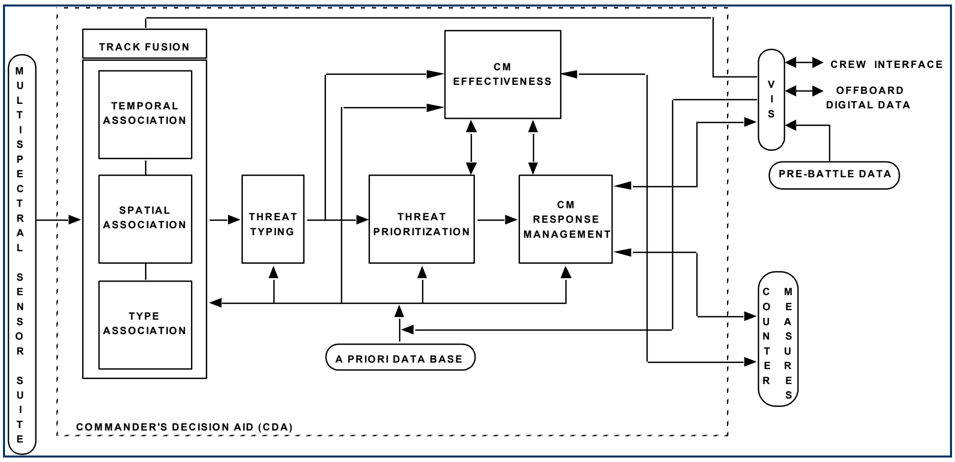

Figure 2. The CDA's Basic Architecture

To help ensure optimal understanding of the local battlefield environment, the CDA architecture has been designed to incorporate sensor data from any source, not just the sensor reports from on-vehicle hit avoidance sensors (that are part of an integrated defense system). These sources may be hit avoidance or situation awareness sensors or additional onboard sensors not specific to hit avoidance or situation awareness such as those designed for fire control.

In addition to being designed for using sensor data from any source, the CDA architecture has been designed to use other data to enhance its decision-making including:

- threat data (e.g., minimum/maximum ATGM deployment ranges)
- theater data (e.g., particular threats to be expected in the theater)
- countermeasure stores data
- terrain data
- pre-battle updates from the vehicle commander (e.g., update of expected threats)
- vehicle INS data (e.g., heading and speed)
- system configuration data (for the integrated defense system).

The initial CDA has been developed under the TARDEC-sponsored Integrated Defense System Program. EI&S performed the work under contract to United Defense. The CDA is currently being used on another ATD.

1.1 How the CDA (and Vehicle Hit Avoidance) can Benefit from Situation Awareness Data

Situation awareness can help the CDA help the vehicle crew by improving the quality and timeliness of the CDA's decision-making including its recommendations to the crew (for maneuver and counterfire and to support such needs as route-planning and hiding). The benefits of CDA use of situation awareness data are over and above the benefits of offboard situation awareness data that get to the crew via FBCB2 and existing embedded C4I capabilities.

Table 1 provides examples of how the CDA's decision-making and the vehicle's survivability can be enhanced by offboard situation awareness data. Basic benefits include controlling encounters (timing and direction), avoiding detection, hit avoidance, and faster and more effective counterfire.

Table 1. How the CDA and Vehicle Hit Avoidance Can Benefit from Offboard Situation Awareness Data

Situation Awareness Report	CDA/Hit Avoidance Benefit
• hostile forces in the area	• intent factor of prioritization boosted: system more expectant
• location and classification/ID of threat combat vehicles	• use of terrain data to assess when line of sight happens → possible recommendations for vehicle movement • improved threat munition typing
• reports of enemy RISTA headed toward own vehicle	• if type known, could bias signature management countermeasures (including communications EMCON)
• reports from UAVs or other RISTA that Hinds are close by	• maneuver (stop/hide/turn) and signature management • support fire control for counterfire
• location reports of other friendly vehicles	• improved ID and YATO/YANTO determination
• indirect fire headed your way (reported by Firefinder)	• recommendation to crew to button up (if hatch interlocks are open) • if timely report indicating precise impact area, recommendation of a maneuver to avoid/mitigate
• NBC attack points and wind direction	• recommendation to button up and switch to filtered air • recommendations for vehicle movement, route planning
• weather	• temperature/humidity → improved passive ranging accuracy → improved prioritization

Onboard hit avoidance sensors can also provide situation awareness data useful to the CDA and its survivability decision-making. These data, managed by the CDA, can provide substantial benefit to the crew and C4I as well. Table 2 provides examples of how hit avoidance sensors as well as other onboard sensors such as BCIS that are not specifically for "hit avoidance" or "situation awareness" can provide very useful information helpful to both purposes.

Table 2. How Onboard Sensors Can Provide Situation Awareness as Well as Hit Avoidance Support

Sensor	Situation Awareness Support Examples	Hit Avoidance Support Examples
hit avoidance		
• IR threat warner	• gunflashes ~ 5 km at 45° (with possible classification: artillery vs. tank gun) • explosions showing an attack in the near distance at 120° (with some possible classification)	• ATGM detection, classification, intent • top-attack detection, classification, intent
• laser warner	• UAV with lidar in the area	• detection of laser rangefinder pulse indicating imminent attack
• acoustic warner	• Hind helicopter at 235° • T-72 tank at 45°	• top-attack threat detection, classification
• MMW warner	• UAV with SAR radar in the area	• ATGM with MMW seeker headed at own vehicle
• radar (cued)	• range, velocity and typing information for weapon platforms	• accurate range and velocity of ATGM → improved prioritization • fire control for active protection
other		
• BCIS	• location of friendlies, unknowns (lat, long)	• location of friendlies, unknowns (lat, long) → supports classification of particular weapon event
• local SA IR sensor	• possible soldiers within 1 km at 193°	• possible threat ground vehicle within 3 km at 68° where no known friendly vehicles are → supports classification of particular weapon event
• wind sensor	• help with NBC cloud predictions	• improve effectiveness of active protection (especially against unguided rounds) • improve effectiveness of smoke use

Finally, the hit avoidance and situation awareness data provided by "hit avoidance" sensors on other vehicles (via the CDA) can also be extremely useful. Table 3 provides examples of how the information from other vehicles' hit avoidance and other sensors can help one's own vehicle's situation awareness.

Table 3. How the Hit Avoidance Sensors and the CDA on Other Vehicles Can Provide Situation Awareness as Well as Hit Avoidance Support to Own Vehicle

Comms Band-width	Sensor	Situation Awareness Support Examples	Hit Avoidance Support Examples
restricted bandwidth	• IR threat warner	• attack by AT-11 at lat/long x, y from direction y at time t	• local hand-held HEAT attacks → active protection deployment
	• laser warner	• attack by laser designated threat at lat/long x, y from direction y at time t	• attack by laser designated threat at lat/long x, y from direction y at time t → intent factor of prioritization boosted: system more expectant
	• acoustic warner	• T-90 detected at lat/long x, y from direction y at time t	• Snipers detected at lat/long x,y from direction y at time t → recommendation to button up if close by
	• MMW warner	• MMW SAR from hostile airborne RISTA asset detected at lat/long x, y in direction y at time t	• MMW top-attack threats detected at lat/long x, y at time t → top-attack detection and classification improved
high bandwidth	• IR threat warner	• accurate line of bearing to AT-4 launch point → (supports computation of range to hostile weapon platform)	• accurate line of bearing to AT-4 launch point → supports computation of range to hostile weapon platform → improves prioritization and counter-fire
	• laser warner	• report of hostile laser rangefinder and accurate line of bearing to its source (helps to locate threat weapon platform)	• localization of lidar top-attack threats → supports active protection fire control
	• acoustic warner	• accurate line of bearing to T-80 (helps to locate threat weapon platform)	• accurate line of bearing to Hind → supports computation of range to hostile weapon platform → improves prioritization and counter-fire
	• MMW warner	• Accurate line of bearing to a weapon platform that uses MMW radar (supports computation of range)	• Localization of MMW top-attack threat → improves prioritization

There are many potential sources of situation awareness reports, both offboard and onboard. Although each data source may issue reports at different rates, there will clearly be many reports when the Army's tactical internet (FBCB2) is fully implemented. Full use of these data from a survivability standpoint will be impossible for the vehicle commander without computerized help. There will be too much data and, besides, the commander will not always be focused on hit avoidance or in general maximizing his defensive posture (as balanced against the mission needs). Nor will he in many cases be able to respond with the correct countermeasure with the speed needed to counter impending threats.

There needs to be a survivability manager (i.e., the CDA) automatically sifting through the data to ensure that the most accurate understanding of the environment relative to the vehicle's survivability is constantly being maintained and acted upon. Improved understanding of the local threat environment helps the CDA make better decisions which in turn improves the survivability of the vehicle.

Sensor fusion of the offboard and onboard situation awareness data with the hit avoidance and other sensor data (as well as vehicle data and stored hit avoidance data) is the principal means by which the CDA gains its understanding of the threat environment. This understanding is essential for correctly and quickly assessing the nature of specific threat events.

The CDA architecture incorporates a Dempster-Shafer threat typing approach to enable the incorporation of sensor class/ID and confidence data from any source. The Dempster-Shafer approach for data fusion allows the accurate capture of information and its uncertainty from different sensors or other sources, each having different levels of abstraction. (The Dempster-Shafer approach is actually a generalization of Bayes reasoning that "combines the Bayesian notion of probabilities with the Boolean notion of sets.")[1] The information can then be combined in a formal way that correctly infers the range of likelihood of a particular threat type given the available evidence. Figure 3 shows how sensor reports can be sequentially combined using Dempster-Shafer reasoning to produce an aggregate class/ID and confidence estimate.

[1] Bogler, Philip L., "Shafer-Dempster Reasoning with Applications to Multisensor Target Identification Systems", IEEE Transactions on Systems, Man, and Cybernetics, Vol. SMC-17, No. 6, November/December 1987.

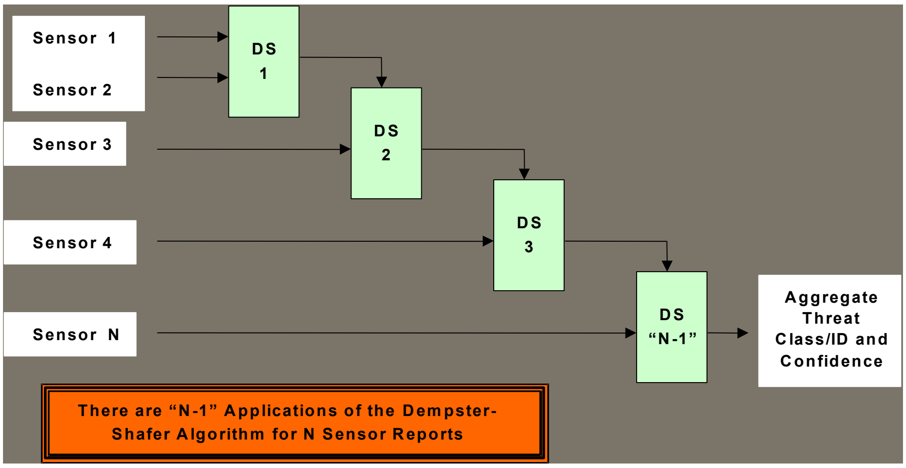

Figure 3. Dempster-Shafer (DS) Cascade Processing is Used to Combine N Sensor Reports

Being able to combine data from sources with different levels of abstraction means that the CDA can, for example, use reports from an IFF sensor (friend/foe) and combine these data with reports from, say, an acoustic sensor (particular weapon platform type; e.g., Hind helicopter).

Figure 4 defines the basics of the Dempster-Shafer approach to capturing the knowledge and uncertainty of information, whatever the source. All the data are normalized such that a belief function for a particular hypothesis for a particular sensor – or the combination of a set of sensor reports – will run from 0 (not true) to 1 (completely true). The "support" is the level of certainty with regard to a particular belief (say, that the threat is an AT-5) based on direct evidence. The "plausibility" is the sum of the support and the potential commitment to the hypothesis given what evidence directly refutes the hypothesis. Figure 5 shows how levels of certainty and uncertainty have clear meaning in the Dempster-Shafer reasoning approach.

Figure 4. Dempster-Shafer Knowledge Representation Captures Explicitly the Confidence We Have In A Set Of Hypotheses

In the figure above, S and P represent Supportability and Plausibility, respectively. The interval [0,S] signifies the "supporting" evidence; while the interval [P,1] signifies the amount of "refuting" evidence. The "belief interval" is shown as the interval [S,P]. The interval [0,P] represents a "plausible" region – either supported by evidence or unknown.

The left-hand component of the interval, the belief(H), or the support(H), is the probability that the hypothesis H is supported based solely upon the evidence examined.

The right-hand component, the plausibility(H), is the maximum amount of belief for H, which is possible in light of other evidence that supports the negation of H (conflicting evidence).

> The belief interval pictorially depicts certain information. The lower bound shows the minimum certainty that the hypothesis is true. The upper bound shows the highest certainty that a hypothesis is true, allowable by the data. A narrow bar shows high certainty in the hypothesis. A wide bar shows ignorance about the hypothesis

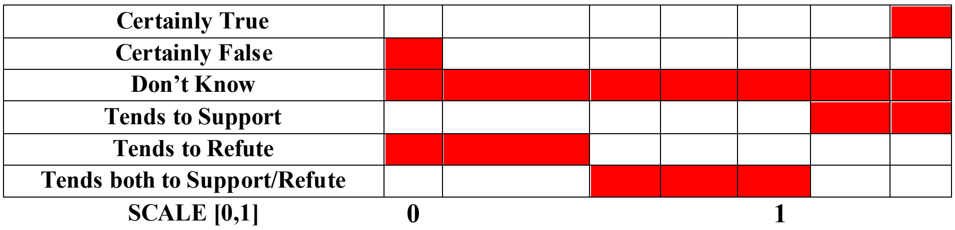

Figure 5. Levels of Certainty and Uncertainty Have Clear Meaning in the Dempster-Shafer Reasoning Approach

Table 4 shows an example of how various sensor reports using onboard and offboard data as well as theater data have been combined to yield the displayed supports and plausibilities for each of several threat propositions. These data are depicted graphically in figure 6. The "belief regions" quickly give a measure of the strength for each of the hypotheses. A shorter belief region is indicative of more certain information, whether supporting or contradicting a hypothesis.

Table 4. Example of Aggregated Report with Support and Plausibility for the Threat Propositions

Propositions	Support	Plausibility
TOW	0.047	0.142
AT-6	0.038	0.076
TOW or AT-6	0.085	0.18
HOT	0.606	0.789
Hellfire	0.126	0.252
HOT or Hellfire	0.82	0.915

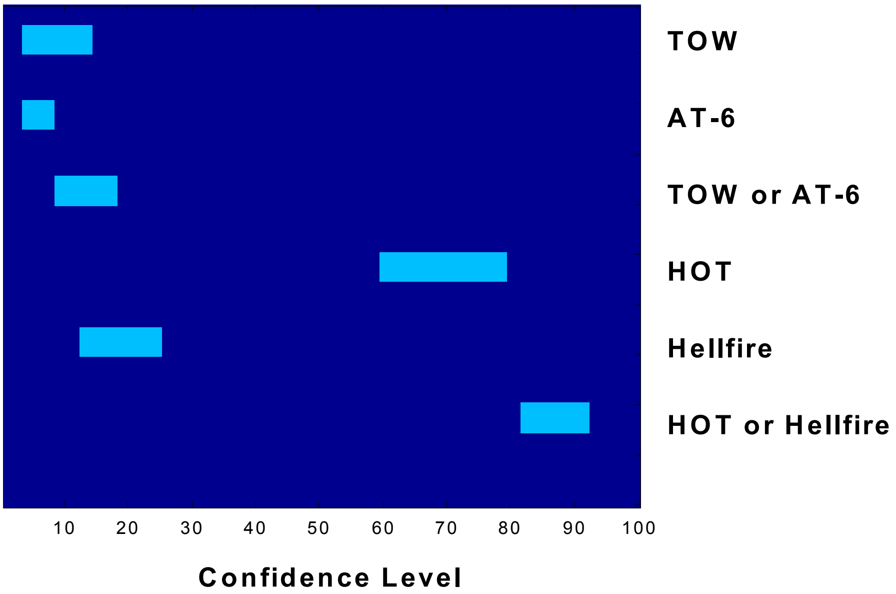

Figure 6. The Dempster-Shafer "Belief Regions" for each Hypothesis Quickly Reveal the Probability and the Level of "Uncertainty"

Issues

There are a number of key issues that must be addressed in dealing with situation awareness data to ensure that the data do in fact improve the quality and timeliness of the CDA's decision-making including its recommendations to the crew. The three principal issues are

- its time-geographic relevance
- the timeliness of receiving the situation awareness data
- how to deal with conflicting information.

There is a time-geographic relevance for data obtained on the battlefield. That three T-72s were located at coordinates x, y at time t will in general have relatively little value at time t plus one hour. The accuracy and relevance of data generally degrades with time. Table 5 indicates how offboard data reported can have greatly varying relevance vis-à-vis time and geographic extent.

Table 5. Space and time (and Level of Detail) Nature of Offboard Reports Varies

Item Reported	Location Time Constant	Area Covered
Division/Brigade	Long	1000s of square meters
Foot Soldier	Longish	~ point
Ground Combat Vehicle	Moderate	~ point
Helicopter	Short	~ point
UAV	Short	~ point
Incoming Artillery Round	Short	10s of square meters
Munition (by Wingman)	Short	10s-100s of square meters
Jet Aircraft	Very short	~ point

A ready means to compensate for the foregoing effect is depicted in Figure 7. Essentially, the belief vectors (or "mass assignment vectors" in Dempster-Shafer jargon) for the various sensor reports are de-weighted using a time function relevant to the particular data type. For the case in the figure, the total time over which the data are relevant is assumed to be 5 minutes. A simple linear function was created to degrade the import of the data over the 5 minute period.

In Figure 7 "m(θ)" is the uncertainty for the given sensor report (in essence, the width of the belief interval). The support for the hypothesis of AT-10 is m(AT-10). The plausibility for the hypothesis of AT-10 is the support plus the uncertainty: m(AT-10) + m(θ).

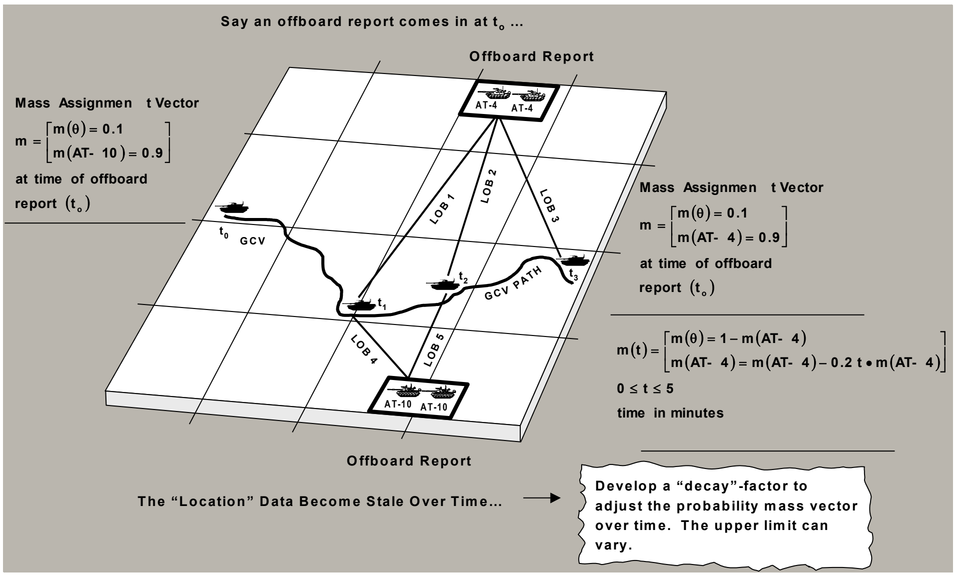

Figure 7. The Time-Geographic Relevance of Data can be Compensated for Readily

The various uses to which offboard data can be put are driven strongly by how timely the data arrives. For example, reports of particular vehicle locations (friendly and threat) received many seconds or minutes after the instance of fixing their location will still have relevance to longer term decision-making (e.g., what threats can be expected to be encountered). On the other hand, the same information will have little relevance to immediate decision-making in the local battlefield (e.g., a gunflash in the immediate local area is detected: is it from a friendly or hostile vehicle?)

Bandwidth-restricted networks such as FBCB2 can therefore still have great utility for longer term decision-making. Use of the BCIS high bandwidth (and short range) communications link, however, offers the potential to allow additional powerful uses of situation awareness data. Such uses would include: precise location of local friendlies at all times; cooperative passive ranging to threat launch points (to support hit avoidance countermeasures and counterfire). Table 3 provides a comparison of restricted/high bandwidth communications capabilities and their implications.

Dealing with conflicting information is also a major issue for incorporating the use of situation awareness data. Given the many different sources of data and the fog of war that will yet remain, there will certainly be instances when data conflicts in particular details or between various levels of detail. An example of this is the following: one source indicates there are no threat vehicles in the local area but another source indicates there are T-80s.

The Dempster-Shafer reasoning approach deals with inconsistencies and conflicts in a methodical way that correctly fuses the information such that accurate inferences can be drawn. To show how Dempster-Shafer can deal with conflicting information, a comparison of two cases will be made.

For the first case, four sensor reports are received that each have the same support (0.7) and uncertainty (0.3) for the same threat type hypothesis. (The plausibility is the support plus the uncertainty, 1.0 in this case.) All reports indicate an TOW, for instance. Table 6 shows the combination of the reports numerically. Figure 8 shows the combination graphically. As expected, given that all reports provide the same generally confirming information, the fused sensor report has grown to a high degree of certainty.

Table 6. Simple Example of the Same Class/ID Information from Four Different Sensors

m(θ) = 0.3	m(TOW) = 0.21	m(θ) = 0.09
m(TOW) = 0.7	m(TOW) = 0.49	m(TOW) = 0.21
	m(TOW) = 0.7	m(θ) = 0.3

m(θ) = 0.3	m(TOW) = 0.273	m(θ) = 0.027
m(TOW) = 0.7	m(TOW) = 0.637	m(TOW) = 0.063
	m(TOW) = 0.91	m(θ) = 0.09

m(θ) = 0.3	m(TOW) = 0.2919	m(θ) = 0.0081
m(TOW) = 0.7	m(TOW) = 0.6811	m(TOW) = 0.0189
	m(TOW) = 0.973	m(θ) = 0.027

Four sensors report TOW threat with confidence 0.7 and uncertainty 0.3. We merge the first two of these reports and then with the third and the fourth.

The "belief region" resulting after each of the three applications of Dempster-Shafer are shown in the next image plot figure, as well as the resulting cumulative "probability" plot for class/ID TOW.

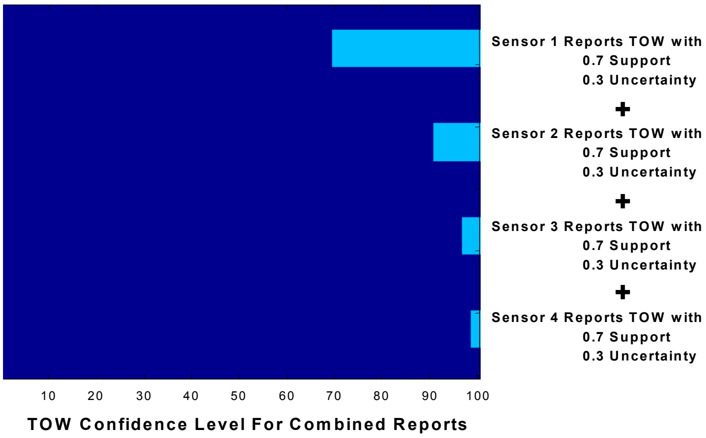

Figure 8. The "Belief Regions" for the Dempster-Shafer Output for a Four-Sensor Example in which All Reports are Equally Confirming

For the second case, four sensor reports are received. The first two have the same support (0.7) and uncertainty (0.3) for the same threat type hypothesis (TOW). The third report has the same support (0.7) and uncertainty (0.3) for a different threat type hypothesis (AT-4). That is, the third report conflicts with the first two by saying the threat is something different from what the first two reports indicate. Then a fourth report is received. This report has the same support (0.7) and uncertainty (0.3), but this time it's for the original threat type hypothesis (that the first two reports supported).

Table 7 shows the combination of the four reports for the second case numerically. Figure 9 shows the same combination graphically. As can be seen from the chart, the Dempster-Shafer processing has correctly eroded the confidence of the combined sensor reports upon receiving the third report. The fourth report then boosts the confidence back up but not as high as in the first case when all the reports were confirming.

Table 7. Re-Looking at the Four-Sensor Example with "Conflict" at Sensor 3 and Then Re-Support by Sensor 4 that Threat is "TOW"

Sensors 1 and 2 say it is "TOW"

m(θ) = 0.3	m(TOW) = 0.21	m(θ) = 0.09
m(TOW) = 0.7	m(TOW) = 0.49	m(TOW) = 0.21
	m(TOW) = 0.7	m(θ) = 0.3

‘Conflict’ that Sensor 3 says it is “AT-4”

m(θ) = 0.3	m(AT-4) = 0.273	m(θ) = 0.027
m(AT-4) = 0.7	k = 0.637	m(TOW) = 0.063
	m(TOW) = 0.91	m(θ) = 0.09

‘Conflict’ that Sensor 4 says it is “TOW” again

m(θ) = 0.3	m(TOW) = 0.226	m(AT-4) = 0.052	m(θ) = 0.022
m(TOW) = 0.7	m(TOW) = 0.526	k = 0.122	m(TOW) = 0.052
	m(TOW) = 0.752	m(AT-4) = 0.174	m(θ) = 0.074

The “belief region” resulting after each of the three applications of Dempster-Shafer are shown in the next image plot figure, as well as the resulting cumulative “probability” plot for class/ID TOW.

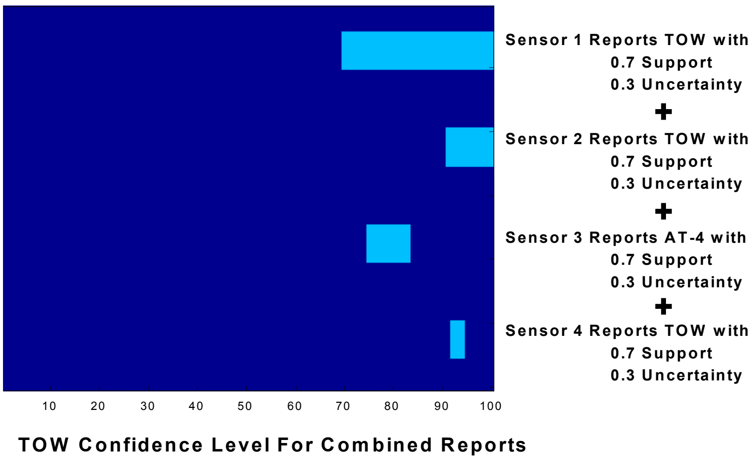

Figure 9. The “Belief Regions” for a Four-Sensor Example with Conflicting Reports

Conclusion

The CDA and hit avoidance can strongly benefit from the use of situation awareness data. The CDA, moreover, can aid the crew and C4I with additional situation awareness data from the onboard hit avoidance sensors and from other vehicles’ hit avoidance sensors provided by their CDAs. Use of Dempster-Shafer reasoning in the CDA’s threat typing greatly facilitates the use of situation awareness data (as well as data from other sources). The approach is robust even for cases of inconsistent or conflicting information.

Acronym List

AP	Active Protection
ATD	Advanced Technology Demonstration
ATGM	Anti-Tank Guided Missile
BCIS	Battlefield Combat Identification System
C4I	Command And Control, Communications, Computers, And Intelligence
CDA	Commander’s Decision Aid
CM	Countermeasure
EMCON	Emissions Control
FBCB2	Force XXI Battle Command, Brigade and Below (It’s the Army’s tactical internet currently being implemented.)
GCV	Ground Combat Vehicle
HEAT	High Explosive, Anti-Tank
ID	Identification
IDS	Integrated Defense System
INS	Inertial Navigation System
IR	Infrared
LOB	Line of Bearing
MMW	Millimeter Wave
NBC	Nuclear, Biological, Chemical
RISTA	Reconnaissance, Intelligence, Surveillance And Target Acquisition
SA	Situation Awareness
SAR	Side-Aperture Radar
TARDEC	Tank and Automotive Research and Development Center
YANTO	You Are Not The One
YATO	You Are The One
UAV	Unmanned Aerial Vehicle
VIS	Vehicle Interface System