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TECHNOLOGY AND DECISION MAKING

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ABSTRACT

This paper argues that in the present context of exploding information and knowledge technologies the human in the loop risks becoming the weak link in the decision making process unless appropriate steps are taken to develop the advanced tools necessary to process and present the information in such a way that the commander can assimilate it. Otherwise, technology, instead of reducing the friction and the fog of war, could actually increase them, and the commanders, unable to take full advantage of the technology, will ignore it, use it as mere crutches or worst, will get lost in the maze of an inefficient decision process.

After a brief review of the history of Information Technology, and of how it possibly prompted a Revolution in Military Affairs, it is demonstrated that while tremendous progress has been achieved on the technology side, the integration of the this technology into actual systems has been much less successful, because, firstly, in many instances the designers did not take the opportunity to reengineer the processes to take full advantage of the new capabilities provided by the technology, and secondly and more importantly, the human user was not considered in the design process. This situation led to the rejection of numerous IT systems in the recent years. Therefore, an increase emphasis must be put on understanding the interaction between the human users and his technological tools, as well as the nature of the aids that commanders will actually require, such as artificial intelligence applied to sensors fusion and decision support

systems. This must be considered an essential investment for the Canadian Forces if they want to remain technologically relevant on the battlefield in the coming decades.

LIST OF ACRONYMS

AI:	Artificial Intelligence
CoA:	Course of Action
DSS:	Decision Support Systems
IT:	Information Technology
MSDF:	Multiple Sensor Data Fusion
RMA:	Revolution in Military Affairs
R&D	Research and Development
SA:	Situational Awareness

Introduction

This paper argues that in the present context of exploding information and knowledge technologies, the human in the loop risks becoming the weak link in the decision making process unless appropriate steps are taken to develop the advanced tools to process and present the information in such a way that the commander can assimilate it. Otherwise, technology, instead of reducing the friction and the fog of war, could actually become an additional burden. Potential research avenues for the Canadian Defence R&D community are presented to fill the knowledge gap in developing the required tools.

The end of the 20th century was marked by what seemed to be an explosion in the world of science and technology, in particular in the so-called Information Technologies (IT). This was, in fact, the continuation of a trend that started at the end of the 18th century, when the "domestication" of electricity allowed the invention of the telegraph and the telephone. As science, technology and engineering developed during the industrial era, we saw an exponential trend in the increase of both the rate of innovation and the rate of penetration of technologies in our society. The year the telephone was invented, telegraph communication still counted its performances in thousands of words[1]. While telephone took 45 years to reach 10 million homes (in the US)[2], radio and television took respectively 40 and 15years to each reach 50 million homes[3]. At the beginning of the new millennium, the developed world is linked through a network of

[1] Htt:www.cwhistory.com, "Cable and Wireless: A history"
[2] http:www.geog.buffalo.edu, Flammger D. M. , "A History of Telephone"

satellites, fibre optics and other communication equipment and infrastructure. Yet, for the "communication hungry" military, there is still a bandwidth deficit:

> *Lack of bandwidth is an ever-present problem and so managing its usage is critical. More sensors of higher resolution, sometimes being multi-spectral, can generate the need for huge bandwidths. The transmission of map data, the use of video conferencing, and the updating of databases compound the problem. As the tempo of battle increases, the need to reduce delays in the transmission of messages and other information becomes increasingly important.*[4]

Since the first electronic computer ENIAC entered service in 1946, the development of computers has also seen an exponential growth. While the computing capabilities grew at a steady but relatively slow pace during the third quarter of the 20th century, the last quarter saw a dramatic increase, three orders of magnitude, in microprocessor capabilities, going from 1 million operations per second to 1 billion operations per second between 1975 and 2000.[5]

Combining computer technology with advanced telecommunications, the Internet took only 5 years to reach 150 million homes. Today, a growing number of people have access to an unprecedented wealth of information.

The effect of combining these technologies is having a profound effect on the industrialized societies, to the point that it now widely accepted that we are at a turning point between the Industrial Age and an Information Age. This effect is so pervasive and powerful that people now have the opportunity to change radically the way they are doing

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[3] Faubert Denis, " Technology and its Relation to Peace Operations", PowerPoint presentation, Oct. 2000
[4] Brook Peter and Thorp Tim, "C3I in the new defence and commercial environments", Journal of Defence Science Vol 3, No 1., p. 8
[5] http://www.intel.com/research/silicon/mooreslaw.htm

things. This so-called Information Age is bringing about a series of revolutions such as the Revolution in Business Affairs and the Revolution in Military Affairs (RMA).

The pace of innovation is not about to slow down: if anything, it will probably continue to accelerate for the foreseeable future. This is hardly surprising when we consider that approximately half of the physicists of all times are still alive and that the world R&D budgets are constantly increasing, despite generalized cuts in defence R&D.

Trying to forecast the future is always risky. But if the actual trend continues, thanks to new emerging technology such as nanotechnology and optronics, the most optimistic forecasters expect, that by 2030, desk computers will have the processing capability of a human brain, and by 2060, that of the whole human population of planet Earth[6]. (See fig 1.) By 2010, holographic teleconferencing should be technically achievable[7], and night vision goggles the size of a regular pair of glasses might be a reality[8].

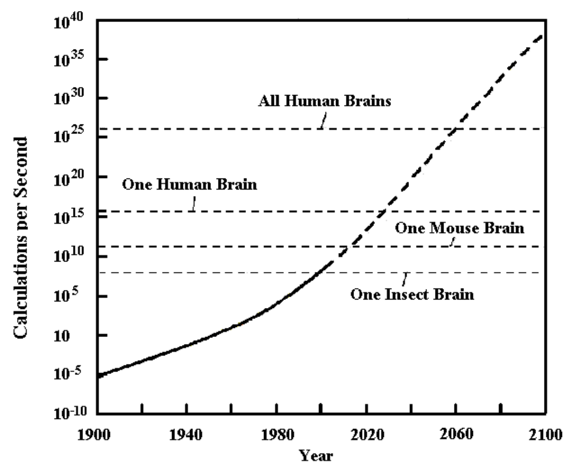

Figure 1. Forecast of Evolution of Microprocessing

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[6] Laurie Grace, as quoted by Marsh Howard (Col), "Science and Technology: Precursor to Force Structures", DMRC, Nov 2001, PowerPoint presentation.

[7] Stancia Lucio (Italian Minister for Science and Technology), Technologies: Bridging the Gap, Ulisse, Feb. 2002, p. 23

[8] Phong L. N., "MEMS Transducers for Direct Thermal Viewers", May 2001

There is however, another side to the coin. The human brain is often already overwhelmed by the amount of information that is available, and communication channels also suffer from "traffic jams". While we can expect that technology will alleviate to a certain point the communication bandwidth problems[9] (an increase of up 10^{6} in the transmission rates is possible during the next 20 years[10]), there is little hope in the foreseeable future that we can do the same thing for the human brain, at least in a direct fashion. This can present dire consequences for the military commanders, especially in combat. The battlefield has become a six-dimension "relativistic universe' (space, time, information and technology), in which the uninterrupted acceleration of the technology creates an infinite increase of the mass of information, while time seems to be compressed toward zero.

Unless proper steps are taken to improve the interaction of the human with these systems, he will remain an external observer and not a part of this acceleration, and as the speed of the technology increases, he will be less and less capable to react on the same time scale.

THE RMA AND TECHNOLOGY

In the military community, the possible emergence of a breakthrough in the conduct of warfare, the so called Revolution in Military Affairs, began to make its way in

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[9] Michael O'Hanlon, "Technological Change and the Future of Warfare", Brooking Institution Press, 2000, p. 52

[10] Marsh Howard (Col), "Science and Technology: Precursor to Force Structures", DMRC, Nov 2001, PowerPoint presentation.

the US armed forces after the Gulf War in 1991[11] [12], based on the success of the high tech weaponry and command and control systems of the US Forces. Marshal Ogarkov of the Soviet Union, who described a revolution in military technology in the early 1980's, has foreseen this so called revolution much earlier[13]. By 1997, the RMA concept was receiving wide acceptance in official US policy documents such as the Pentagon's Quadrennial Defense Review and the National Defense Panel. This does not mean, however, that there is a consensus on the emergence of an RMA, or on its nature. In fact, there are several different views on the RMA. For example, O'Hanlon[14] identifies six different RMA schools, from a vary prudent approach acknowledging the influence of IT on the military, to a global revolution involving the whole spectrum of technology from weapons effect to robotic systems.

In its Strategy for 2020[15], the Department of National Defence of Canada adopted Frank Watanabe's[16] definition of the RMA: "a major change in the nature of warfare brought about by the innovative application of new technologies which, combined with dramatic changes in military doctrine and operational and organizational concepts fundamentally alters the character and conduct of military operations". Strategy 2020 also

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[11] Michael O'Hanlon, "Technological Change and the Future of Warfare", Brooking Institution Press, 2000, p.7

[12] Arquilla and Ronfelt, "In Athena's Camp: Preparing for conflict in the Information Age", Rand, 1997, p. 1

[13] Ogarkov Nicola V (Marshall)., "Always in Readiness for the Defence of the Fatherland", Voyenizdat, 1982

[14] Michael O'Hanlon, "Technological Change and the Future of Warfare", Brooking Institution Press, 2000, p. 11-16.

[15] "Shaping the Future of the Canadian Forces: A Strategy for 2020", Department of National Defence (Canada), June 1999

[16] Frank Watanabe, "Understanding the RMA" Armed Forces Journal International, August 1995, p. 6

identifies space, remote sensing, telecommunication and information management as priority R&D domains.

While these various schools and definitions of the RMA differ in their respective scope, they all have in common a reliance on the synergy that advances in communication and computers can bring to information management. However, while it is now largely accepted that a combination of breakthroughs in technologies such as computer, communication and sensors has initiated a new age of information (some say a revolution), it is also obvious that the possibilities and the consequences of these breakthroughs have not yet been fully mastered, by any sector of our society, including the military. For example, one of the emerging warfare concepts of the RMA, Information Warfare, "is *probably the least understood and most ill defined …*"[17]. Revolutions are by definition not only periods of rapid changes, but also of uncertainties, chaos and challenges to established orders. While the onset of a revolution is normally highly visible because of its disruptive effects, its final outcome is hard to predict, especially at the very beginning. The RMA "*is going on right now, all around us, but …we haven't yet recognized a new world*"[18].

Since this so called revolution is fuelled by technology, it would be useful to look at the normal evolution of a technology to its maturity, to try to understand where we are

[17] Keith Thomas, "The Revolution in Military Affairs: Warfare in the Information Age", Australian Defence Studies Center, 1997, p.88
[18] Ibid, p. 24

today, before considering where the scarce DND R&D dollars should be spent. Gillis proposes the following life cycle for technologies evolution[19]:

> <u>Conjecture:</u> The very beginning of the quest for knowledge, vision without knowledge, when you know what you'd like to accomplish, but have no idea if it is even possible.
>
> <u>Speculation:</u> Knowledgeable conjuncture, when you have learned enough to know what you do know, and know what you don't toward solving the problem.
>
> <u>Science:</u> Science understood, when you know what is theoretically possible. You now know if something can be done and what it will involve
>
> <u>Technology:</u> Science applied, the level when you can begin to engineer and build working devices to apply those laws of nature to answer your goal.
>
> <u>Application:</u> Mature technology, the final state when the technology is good enough to be put to common use.

The S-Curves in Figure 2. both illustrate the evolution of a technology, and compare mature and emerging technologies in terms of R&D investment payoff. For any given technology, there is a period of speculation

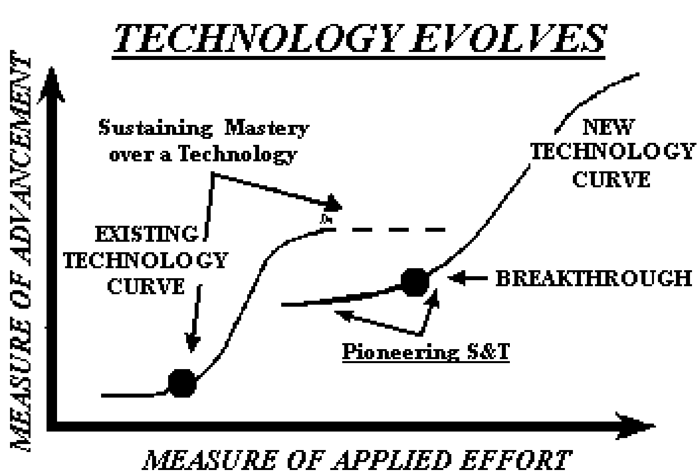

Figure 2. Evolution of technologies

[19] http://www.grc.nasa.gov/www/PAO/html/warp/inspinv.htm, Gillis Marc G., NASA Glenn Research Center

and trial and error with little progress until a break-through is reached. "*A break-through is when the performance limits of an existing device or method are exceeded by a new, different device or method. The key word is different and the breakthrough event is when the new method demonstrates its viability to exceed the limits of its predecessor*".[20] After this point, if there is a viable market for the technology, it becomes widely established and profits ensure that it will be developed to its maturity. When the curve approaches its upper end and flattens out, it is high time for the R&D community to start looking for the next breakthrough.

While technologies related to computers, communications and sensors taken as individual efforts are still evolving at a fast pace, they are well past the breakthrough point. There is a strong demand from the civilian market, and therefore, the civilian R&D in these fields is well funded, as demonstrated by the rapid introduction of new computers, cellular phones, pagers, Palm-pilots etc. However, when all these technologies are taken together in the context of the information age and its associated revolutions, it is far from obvious that we have reached a breakthrough point in <u>information systems</u>. Some even reject outright that we have reached an information age and accept at best an "Age of Information Technology". In business and management for example, Dilenschneider[21] claims that we do not really suffer from an information overload, but from a communication and data overload, many of which are poorly organized, irrelevant and plainly useless. Portable computers, cell-phones and their associated e-mails, electronic agendas and voice mails have become a burden more than a

[20] Foster Richard N., "Innovation: The Attacker's Advantage" Summit Books, March 1986

relief in many instances because the tools have become the focus of our attention instead of the message. The fact that, for example, in 1995-1996, of the 175 000 corporate information systems developed, the vast majority have been total (40%) or partial (33%) failures and that only 27% have been total successes is proof enough that a different approach is needed before we reach the true Information Age[22]. A similar situation prevails in the military community where it is recognized that while the commanders of the higher-echelon units often fail to obtain the information they need, the problem resides more in the absence of a proper and timely organisation and transmission of this information than in its availability[23].

WHAT IS MISSING?

Most of the IT system failures stem from the fact that they have been acquired like consumer goods, with no or little consideration given to their impact on the organizations. The most common approach is to acquire new equipment to carry out the same tasks without reviewing the existing processes. In that regard, the military are no different from the civilian world and most of the assumptions applying to IT introduction in businesses apply to them as well: *"The military, like most of the business world, remains in a stage of installing pieces of the new technology to make specific operations more effective"*.[24]

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[21] Dilenschneider Robert L., "The coming age of content and critical thinking: Age of Information Technology", Vital Speeches of the Day, Jan 15, 2001, p. 2
[22] Vézina Guy, Private communication
[23] Kahan James, Worley Robert, Stasz Cathleen, "Understanding Commander's Information Needs", Rand Arroyo Center, 2000, p. 1
[24] Arquilla and Ronfelt, "In Athena's Camp: Preparing for conflict in the Information Age", Rand, 1997, p. 42

Cooper[25] identifies three fundamental errors in limiting the RMA to its technical dimension:

1) The belief in fruitless silver bullets (US Army TRADOC Battlefield Visualization Concept paper[26] and to a lesser extent Australia's DSTO views on C3I systems[27] are good examples of almost strictly technology oriented approach that expect a silver bullet solution),
2) It takes attention from critical issues such as purpose, strategy, doctrine, operational innovation and organizational adaptation that are essential to success of RMA, and
3) The first two errors lead to non-strategic investments of scarce resources.

Obviously, a different approach must be taken in the implementation of IT on the battlefield, one that will take into account the human component of the system. IT systems fail to meet expectations because designers and clients fail to recognize that IT systems are not just a collection of electronic equipment, and that in these systems, the client is more than a user, he/she is <u>part of the system</u>. Noting that failures in the business world result from the reluctance of managers to adopt rigorous system engineering approach, Markam and Salmon[28] propose a socio-technical approach, which by

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[25] Cooper R. Jeffrey, "Another View of the Revolution in Military Affairs"{, US Army War College, April 1994, p. 39-40

[26] TRADOC Pam 525-70, 1 October 1995

[27] DSTO-GD-0075, "A proposed model of interoperability and a common operating environment for C3I information systems.

[28] Markham Geoff and Salmon Rod, "Information Technology and the Battlefield", DERA Land Systems, Journal of Defence Science Vol 3 No 1, p. 57.

introducing the human in the equation, will allow the armed forces of the future to adapt their doctrine and practices to successfully exploit the opportunities of new technologies.

> *If the (IT) system is optimised at the expense of the human system, the result will be non optimal. ... The benefits of business systems must be measured by taking into account their operation in context; narrow measures such as technical performance or increased departmental efficiency are unlikely to capture the overall impact of cost and benefits on the organisation.*

The need for a new approach in the use of IT has also begun to permeate the Canadian Forces and the Canadian Defence R&D community. For example, CDR Okros[29] foresees the need for *"fundamental alteration of the command structure with consequences for the number ranks, levels of authority and critical combat skills"*. At RDDC Valcartier (formerly DREV), Breton, Rousseau and Price[30] propose a triad approach between the human, the task and the technology, that establishes relationships between the user's subject matter experts who define the task, the system designers (technologists) and the human factor specialists.

In that model, the task subject matter experts and the human factor specialists identify deficiencies along their common axis to define requirements aimed at the system designers. The task subject matter exerts and the system designers do the same exercise toward the human factor specialists. The system designers

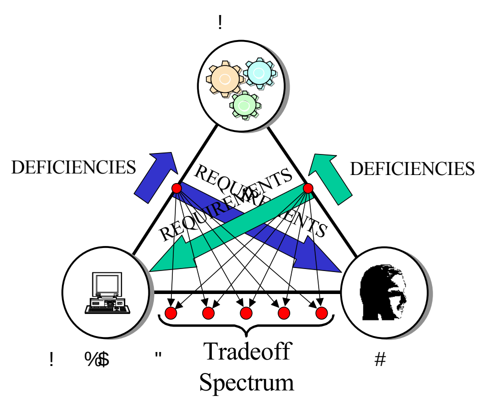

Figure 3 – The Triad Concept

[29] Okros A. (Cdr), "Into the 21st Century: Strategic HR Issues", Defence Management Committee Discussion Paper, p. 7.

and the human factor specialist are then in a position to come up with an acceptable compromise to meet the requirements of the task (assuming that the scientific knowledge and the technology are available). This approach is in line with Orasanu's and Connoly's[31] contention that "*decision performance is a joint function of two factors: (1) the features of the task, and (b) the subject's knowledge and experience*".

Information on the Battlefield

According to Kahan, Worley and Stasz[32], a commander uses information to obtain "*a dynamic image of the battlefield that will lead him to understand what action needs to be taken*". This image is the commander's mental model of the battlefield. Sharing this image with his subordinates helps the commander in establishing "*a common intent to achieve coordinated action*" (this is the definition of Command and Control proposed by Pigeau[33]). This mental image is more often referred to as the Situational Awareness (SA) and comprises three hierarchical levels of complexities (the so-called Endsley model)[34]. The first level deals with the acquisition and integration of all the data and information that applies to the current situation. This information can originate from all sources, including sensors, databases and intelligence. The second level involves the creation of a top-sight view of the situation, "*a central understanding of the big picture that enhances*

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30 Stéphane Paradis, Richard Breton and Jean Roy, "Data Fusion in Support of Dynamic Human Decision Making", Fusion 99

31 Klein et al., "Decision Making in Action: Models and Methods" Ablex Publishing Corporation, 1993, p. 7

32 Kahan James P., Worley Robert D. and Stasz Cathleen, "Understanding Commander' Information Needs, Rand Arroyo Center, 2000, p. viii.

33 Pigeau, R., "The human in command", Defence Science & Technology, Issues #2, January 1998

the management of complexities"[35]. The third level involves the ability of the commander to project the situation into the future, in relation with the desired end state and taking into account the enemy's perspective. These three levels parallel the first two elements of the OODA (observe, orient, decide, act) loop with which most military officers should be more familiar. There is also an obvious relationship with the cognitive hierarchy shown in figure 4.

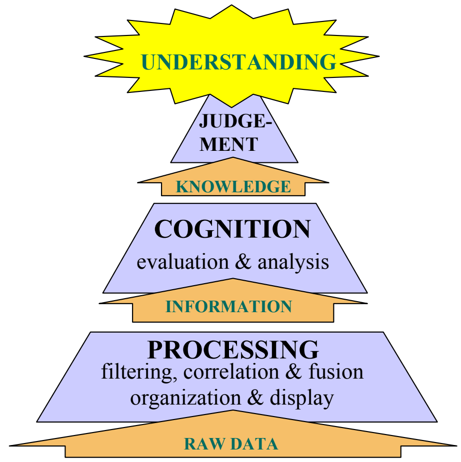

Figure 4: The Cognitive Hierarchy

> ***Data*** *are the raw material of C2 and originate from feedback of actions in the battlespace. They include signals from any kind of sensor, whether organic or non-organic, or communicated between any kinds of nodes in a system. Data are provided meaning through the act of processing. Processing involves aligning, organizing, formatting, collating, filtering, plotting and display, and any other similar conditioning function.* ***Information*** *is the name we assign to data placed in context, indexed and organized.* ***Knowledge*** *is information that has been evaluated and analysed as to reliability, relevance and importance. Knowledge is information understood and explained and it is where we begin to develop situation awareness, by integrating together various sets of information and interpreting what they could possibly mean. Understanding means that we have gained situational awareness, and we can apply the knowledge to effectively implement a plan or action to achieve a desired goal*[36]**.**

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[34] Lerch Xavier F. and Harter Donald E., "Cognitive Support for Real-Time Dynamic Decision Making", Information Systems Research, Vol. 12, No. 1, March 2001, p. 66.

[35] Faubert Denis, " Technology and its Relation to Peace Operations", PowerPoint presentation, Pearson Peace Keeping Center, Oct. 2000

[36] Bossé Eloi and Bertrand Serge, "R&D Perspectives on Data Fusion and Decision Support Technologies for Naval Operations", Proceedings of Eurofusion99: International conference on Data Fusion, Stratford-upon-Avon, UK, 5-7 October 1999, p. 2.

No matter which model is applied, the decision cycle is never linear, as all elements of the cycle happen in a continuous and simultaneous manner: "… *most decisions are elements of a larger endeavour that is directed towards achieving some desired end state of affairs, with each decision providing a small step in the appropriate direction."*[37] The same cycle applies to all level of command. However, the density of information is normally inversely proportional to the level of command (execution/operational to strategic) while the value added of the processed information is proportional.[38]

In the first level of the Endsley model, the key words are <u>all the information that applies to the situation</u>. However, as mentioned in the introduction, the proliferation of data and information sources threatens the commander with information overload:

> *"First, all this data may exceed the human information processing capabilities. The human has only limited attentional and memory resources, and only a small fraction of all the data available can thus be processed (i.e., perceived and understood). For instance, many situations require that a lot of different pieces of information be considered simultaneously, exceeding the human short-term memory resources. Second, it is not all of the data and information available in the environment that is relevant and useful for reaching an optimal decision. In fact, in some situations, most of the data can be seen as distracters and noise for the decision maker, and may thus reduce his/her level of* (SA). *The decision maker must detect and use only a specific fraction of this information to enhance his/her* (SA) and (decision making) *processes.*[39]

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[37] Klein et al., "Decision Making in Action": Models and Methods" Ablex Publishing Corporation, 1993, p. 25

[38] Labbé J. C. and Levesque C. (Maj), " Relationship between Information and Decision Characteristics and the Land Forces Organizational Structure", DREV R-9823, Dec 1998, p. 2

[39] Roy Jean, Breton Richard and Paradis Stéphane, "Human-computer interface for the study of information fusion concepts in situation analysis and command decision support systems", SPIE Proceedings, Vol. 4380, Signal Processing, Sensor Fusion, and Target Recognition, Orlando, 16-18 April 2001, p. 2-3.

Decision Support Systems (DSS)

Technology, properly applied to DSS, offers the possibility of alleviating the commander's informational burden by bridging the gap between the demand of his/her task and human limitations. Literature presents several characteristics of a "good" DSS. Here are a few of these characteristics:

1. First, it must be user-friendly: *"... the time associated with using the DSS is an important factor in whether and how much the DSS is used in time-constrained environments"*[40].

2. According to Chu and Spires[41] *"... people primarily use three mechanisms to cope with time constrainst, which are thought to form a hierarchy of responses to time pressure: (1) acceleration, (2) filtration, and (3) process change".* Therefore, DSS should be able to adjust to the commander's decision mode. Examples of parameters to be considered are the speed of presentation, the media used to present the information and the selection and the level of information presented.

3. It must present the information in the "language" of the users: *"Busy people prefer to have information displayed to them in familiar forms. For example, a commander requires information to be displayed in operational terms,*

[40] Chu P. C. and Spires Eric E., "Does time constraint on Users Negate the Efficacy of Decision Support Systems?", Organizational Behavior and Human Decision Processes, Vol. 85, No. 2, p.229
[41] Chu P. C. and Spires Eric E., "Does time constraint on Users Negate the Efficacy of Decision Support Systems?", Organizational Behavior and Human Decision Processes, Vol. 85, No. 2, p.229-230

not technical terms …"[42]. The performance of decision makers improves if the information is presented in meaningful content rather in symbolic abstract form[43]

4. Since humans can only process a small fraction of the information, and that often only a portion of this information is required to make a decision, it is important for the DSS to have the ability to choose this critical fraction for presentation to the decision maker[44].

5. Different commanders have different experience, expertise and styles of leadership, and may therefore require different types of support. The DSS must adapt to the commanders: *"… different commanders have varying information needs; to deny the needs of the non-conformist commander may be to disable the creative thinker just when he is most needed."*[45]. "*Decision training and aiding should be targeted at strengthening the decision maker's preferred approach to a problem rather than replace it altogether.*"[46] Otherwise, DSS would be simply rejected by the user.

6. Research demonstrates that time constraints reduces confidence in decisions[47]. DSS should therefore aim at enhancing decision maker's confidence.

7. It must allow the regular flow of information directed to the commander by his/her "establishment" (information push), it must allow the search and

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[42] Davenport Daniel M., "Toward an understanding of the Cognitive Aspect of Data Fusion", Raytheon Systems Company, [redacted]
[43] [redacted] Making in Action: Models and Methods" Ablex Publishing [redacted] Robert, Stasz Cathleen, "Understanding Commander's Infor[redacted] Rand Arroyo Center, 2000, p. 4.
[45]

retrieval of information from a variety of media (information pull) and it must provide an alarm mode to alert the commander of any unexpected event that could affect his/her image of the situation[48].

This does not pretend to be an exhaustive list of characteristics, but it is nevertheless a tall order. A lot needs to be done, especially to take into account the human part of the information systems. Up to this day, "*The largest portion of the design of* (DSS) *is devoted to technical aspects of the systems; behavioural aspects are often overlooked; as a result, the* (Decision Aid) *may be ineffective"*.[49]

Data Fusion

According to Klein[50], decision makers under time constraints and stress spend much effort in situation assessment before sequentially evaluating single options until the first satisfactory one is found (not necessarily the optimal). This approach, based on the decision maker's knowledge and experience, is referred to as recognition-primed decision, as opposed to an analytical approach. Enhancing SA shall therefore be a priority of any DSS, especially in combat situation where the consequences of error are often definitive. The application of Artificial Intelligence (AI) to the emerging field of data fusion offers the opportunity to improve SA through the processing of data from multiple

[48] Kahan James, Worley Robert, Stasz Cathleen, "Understanding Commander's Information Needs", Rand Arroyo Center, 2000, p. 36-46.
[49] Reneau J Hal and Blanthorne Cindy, "Effects of information sequence and irrelevant distractor information when using a computer-based decision aid", Decision Sciences, Atlanta, Winter 2001
[50] Klein et al., "Decision Making in Action: Models and Methods" Ablex Publishing Corporation, 1993, p. 6

sources into actual information more usable by the commander and resolves the first level of Endsley's complexity levels. Moreover, if data processing can be done locally at the platform level, an economy of bandwidth could be achieved.

a. <u>Multiple Sensor Data Fusion (MSDF)</u>

The objective of MSDF is to convert various numerical data that often cannot be interpreted directly by the human (multi-spectral imaging, for example) into meaningful information. MSDF can process these data into various levels of abstraction of increasing value and significance. Different models and architectures of MSDF have been proposed. Zuidgeest's[51] concept, a four level-hierarchy approach, resulting in the creation and maintenance of a "world model", is representative of the typical MSDF concepts presented in the literature. In his concept:

1) The sensor level is the least abstract level of the world model. It is a low level report of a phenomenon that provides the sensor characteristics (location, type, time, etc) and some object measurements or features (range, velocity modulation etc).
2) The object level consists of hypotheses expressing the belief that a set of sensor reports is concerning the same object. It is at this level that objects are created, updated or deleted in the world model.

[51] Zuidgeest Rene G., "Multisensor Data Fusion and the Use of Artificial Intelligence", National Aerospace Laboratory, Amsterdam, The Netherlands, p. 76.

3) The military level assigns an identity and capabilities to the object (a tank or a destroyer).

4) The unit level brings the information at the tactical level and attempts to identify higher level coherent units from the military level and the tactical behaviour of objects or lower level units.

These systems could eventually be designed to qualify the information in terms of completeness, certainty and exactitude. However, research in this field is still in its infancy and most of the work so far has been dealing with the first levels of complexities. It is interesting to note that most of the research in MSDF is carried out in the military context[52]. This is hardly a surprise. While many other sectors of activity also have to make decisions under time constraints (such as the air traffic controllers) or use output from several sensors and sources, the military are probably in a unique situation in their need to use so many different sources of data and information under severe time constraint, often in life threatening situations.

b. <u>Non-sensor Data Fusion</u>

Another aspect of the data fusion not yet addressed is the fusion of data or information originating from non-technical sources. These non-sensor data (such as Humint) are an essential part of the commander's information environment. Non-sensor data are not the result of a physical measurement, but the output of a human brain, as speech or in written form. As such, they need a different type of processing before they can be integrated into a computer-based data fusion system that could process them along with sensor data. However, this field is even less evolved than MSDF. According to Davenport[53], *"... the state of the art in natural language processing is stone age compared to the state of the art in signal processing. At least in term of result. ... if any real progress is to be made in data fusion of non-sensor data, the source of that data needs to be understood."* Hal and Llinas[54] also support this view and define in broad terms the research challenge in this domain: *"The main challenge in this area is the need to establish a viable knowledge base of rules, frames, scripts or other methods to represent knowledge that support situation assessment or threat assessment. Unfortunately, there exist only very primitive cognitive models for how humans accomplish these functions."* This aspect of data fusion is highly dependent on cognitive science, and is viewed by many as a very optimistic goal.

Artificial Intelligence (AI) to Assess Decisions

While from a purely analytical point of view, it might seem preferable to identify and analyse several courses of action (CoA) before reaching an optimal decision, in the reality of the dynamic, complex and uncertain environment that the military commander is facing, decisions are made under high time pressure and stressful conditions. The

[52] Zuidgeest Rene G., "Multisensor Data Fusion and the Use of Artificial Intelligence", National Aerospace Laboratory, Amsterdam, The Netherlands, p. 74
[53] Davenport Daniel M., "Toward an understanding of the Cognitive Aspect of Data Fusion", Raytheon Systems Company, Dec 1998, p. 2

recognition-primed decision mode is dominant, and in most instances, there is little time if any for assessing the chosen CoA.

At the higher level of the Endsley model (the ability to project in the future), AI could also be used to help the decision maker evaluate a situation's evolution as well as the strengths and weaknesses of a selected CoA. For example, Zuidgeest[55] proposes a Knowledge-Based-System (KBS) for situational and threat assessment as part of a DSS. Bélanger[56] proposes a multi-disciplinary approach using AI, cognitive science and human factors to design a CoA critiquing system to support the human decision making process. Such systems would help overcome the degradation of human cognitive capacity (loss of reasoning, judgement and memory retrieval) encountered by humans under severe stress[57] and consequently would increase the confidence level in one's decision.

Human-DSS Interface

How the information is to be presented to the decision maker is perhaps the most complex and least understood of all the problems in DSS. Yet it is a crucial part of the process by which the commander creates his/her image of the situation. The presentation interface must take into account the human sensory limitations (usually auditory and

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[54] Hall D. L. and Llinas J., "An introduction to Multisensor Data Fusion", proceeding of the IEE, Vol 85, No. 1, Jan 1997

[55] Zuidgeest Rene G., "Multisensor Data Fusion and the Use of Artificial Intelligence", National Aerospace Laboratory, Amsterdam, The Netherlands, p. 80

[56] Bélanger M., "CoA Critiquing System for the Improvement of the Military Estimate Process", DREV, May 2001

[57] Chu P. C. and Spires Eric E., "Does time constraint on Users Negate the Efficacy of Decision Support Systems?", Organizational Behavior and Human Decision Processes, Vol. 85, No. 2, p. 229

visual, but one could imagine other means such as tactile devices), and present him/her in a timely manner with a complete and accurate vision of the battlefield environment[58].

> *… the bandwidth between humans and their machines is limited---the source being the form of human input/output we are restricted to and the natural speed of processing we perform at. Neither of these obeys Moore's law. Most of the significance of the sensor data that we collect will be lost if it is not interpreted for the human user beforehand. Improvements in speed only make this gap wider*[59].

Cognitive Science/Human Factors in Decision Making[60]

Cognitive science and its applications to decision making have been around since at least the end of the 18th century. However, its progress has been much slower in understanding the "human brain laws" than the physical sciences were in understanding nature's laws and applying them.

Until recently, the traditional approach to decision making theory has been mainly analytical, normative and rationalist, and assumed *a priori* that human decision making was flawed and therefore tried to design systems to correct these flaws. On the other hand, designers of computer-based DSS were using their own engineering language and were trying to force it upon the decision makers, creating a sort of mysticism around the whole process. These attitudes (that Rouse and Valusek qualify as arrogant) made the resulting DSS more difficult to accept for the users.

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[58] Roy Jean, Breton Richard and Paradis Stéphane, "Human-computer interface for the study of information fusion concepts in situation analysis and command decision support systems", SPIE Proceedings, Vol. 4380, Signal Processing, Sensor Fusion, and Target Recognition, Orlando, 16-18 April 2001, Par. 5.
[59] Davenport Daniel M., "Toward an understanding of the Cognitive Aspect of Data Fusion", Raytheon Systems Company, Dec 1998, p. 1

In fact, recent research has demonstrated that, because of the nature of the problems encountered in real life (dynamic and continually changing conditions, real-time reaction to these changes, ill-defined goals and ill-structured tasks, and knowledgeable people), people trained in traditional decision making theories seldom use them in real life. Instead, especially under stress and time constraints, they use their knowledge and experience as a reference to the situation at hand and devise an acceptable course of action accordingly. This is referred to as "Recognition Primed Decision", as previously discussed.

A new school of thought in decision making (Naturalistic Decision Making) suggests that instead of forcing normative decision making processes onto people, it is preferable to develop decision aids that support the natural decision processes, and exploit more effectively the decision makers' knowledge and capabilities. This approach, coupled with appropriate training, appears particularly well suited for the military environment.

Conclusion

During the last decade, we have witnessed tremendous developments in the field of information technology, spurred by rapid advances in computer and telecommunication technologies. While there is not yet a consensus on the fact that we

[60] Klein et al., "Decision Making in Action: Models and Methods" Ablex Publishing Corporation, 1993

are seeing a societal revolution that will bring us from the industrial age to the information age, everyone agrees that information technology already has and will continue to have a profound effect on every sector of our society, including the military. However, until very recently, most of the attention was directed towards the development and acquisition of hardware, with little or no attention paid to how the human was coping with the ensuing deluge of poorly organized information and communication. The consequence for the decision makers relying on this information is that they are often denied access to it, despite the fact that it is most of the time available. The problem is compounded by the state of development in the study of human factors, in particular, cognitive science. In that field, the realisation that analytical concepts developed in isolation in the laboratory cannot be forced upon decision makers, and that decision-making models used in DSS must comply with the way decision makers naturally work, not the opposite, is relatively new and poorly developed. The attitude of the users, civilians and military, has been to consider IT systems as consumer goods, forgetting that in such systems, the end user is more than a client, he/she is an integral part of the system. Failure rate in implementing IT systems is ample proof of this situation.

In the field of computer and telecommunication R&D, the lead is already with the civilian sector (and has been for a while), and it is highly unlikely that the balance will shift towards the military sector in the foreseeable future. Therefore, the defence R&D efforts in that field should be limited to keeping a technology watch and to use and leverage the civilian R&D when appropriate. The bulk of our R&D effort should rather be directed towards domains that will help us in the efficient use of that technology, with the emphasis being put where the military have distinct needs. Decision Support Systems represents one of these very distinct opportunities where wise R&D investments can make a significant difference and help avoid costly failures. In particular, artificial intelligence applied to data fusion (sensors and non-sensors) and expert systems, human-machine interface applied to display technology, and cognitive science applied to decision making, offer the possibility to enhance the decision making ability of the commanders.

Finally, the ultimate condition for success is that the military users be considered (and consider themselves) as partners in this research and as an integral part of the process.

> "*A hiatus exists between the inventors who know what they could invent, if they only knew what was wanted, and the soldiers who know, or ought to know, what they want and would ask for it if they only knew how much science could do for them*". **Winston Churchill**

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