Extending the scope of Situation Analysis

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Abstract* – *The use of technology to assist human decision making has been around for quite some time now. In the literature, models of both technological and human aspects of this support can be identified. However, we argue that there is a need for a unified model which synthesizes and extends existing models. In this paper, we give two perspectives on situation analysis: a technological perspective and a human perspective. These two perspectives are merged into a unified situation analysis model for semi-automatic, automatic and manual decision support (SAM)^2. The unified model can be applied to decision support systems with any degree of automation. Moreover, an extension of the proposed model is developed which can be used for discussing important concepts such as common operational picture and common situation awareness.

Keywords: Situation analysis, situation awareness, data fusion, information fusion.

1 Introduction

Technology has since the mid 20th century become a crucial part of our society. Machines are able to handle an increasing number of tasks and advances in technology have provided us with the ability to solve complex tasks more efficiently. However, not all tasks can be solved by machines without interaction with humans. This paper explores some important aspects related to the creation of decision support for the complex task of decision making. It proposes a unified model for integrating manual, automatic and semi-automatic decision support.

Decision making is a complex task which, at a high level of abstraction, is one component of a larger and iterative process. First the relevant information needs to be gathered and analyzed, in order to allow the decision maker to become aware of in what way the different pieces of information relate to each other and influence potential decisions. This part of the larger iterative process is often termed *situation analysis* (SA). The result of the analysis is a kind of *situation awareness* (SAW). One very important aspect of SA is to focus on the relevant information for the decision at hand. The reason for this is tied to the problem of information overload. The decision maker should only need to focus attention to the relevant information. When the decision maker has become *aware* of the current situation and its future implications, the actual decision might be quite straight forward to take. After the decision has been made it results in a number of actions which are intended to change the situation. This completes one iteration of the decision cycle. This iterative process is perhaps better known as the OODA loop (Observe, Orient, Decide and Act) [1]. The OODA loop is a cyclic process that allows for concepts such as SA and SAW to be related to decision making, see Figure 1.

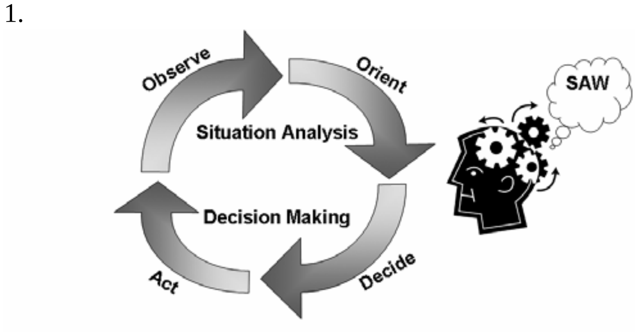

Figure 1: The OODA loop, and its relation to SA and decision making (adapted from [2]). The figure also shows the relation between the process of SA and the state of SAW that it generates in a decision maker. This awareness is vital for the decision making process.

Originally the OODA loop was developed by an American aviator named John Boyd to explain why the Americans where so successful compared to their counterparts during the Korean War. According to Boyd, the key to win a conflict is to establish a relative advantage over one's adversary in both accuracy and speed of the OODA loop – "to get inside the opponent's OODA loop". Since then, the OODA loop has become a standard model for explaining decision making [3]. It has also become the dominant model for command and control [4]. The OODA loop has however received criticism over the years for not capturing the goal-directedness of decision making and for describing only reactive decision making rather than proactive behavior [5]. It has also received criticism for not applying to contexts other than that in which it was conceived (i.e. aviation). Despite this criticism, we believe that it still has some value, since it describes decision making at an abstract level.

One distinguishing feature of today's society is the availability of huge amounts of incomplete and uncertain information. The availability of information does, however, not guarantee that a human can capitalize on it in the decision making process. Proper tools and automatic assistance will often be necessary, especially when under time pressure. For certain tasks, this automated decision support is of such high quality that the actual decision making can be automated too, while for most other tasks, automated systems support human decision making. Examples of the latter kind are systems that analyze situations and anticipated effects of available actions and how these influence decision making. The result from an analysis process, which depending on the task can range from single entity identification to prioritized lists of available actions, is reported to the decision maker to base a decision on. For most complex tasks fully automated SA is not possible with today's technology. In such cases, integration between machine and human analysis is needed.

The literature does not supply a unified model for SA, integrating both technical and human analysis. Nor is SAW fully incorporated into models commonly used for constructing technical systems. The only exception being Kester [6] who discusses the need for Network Adaptive Interactive Hybrid Systems (NAIHS). Kester solution to the problem is to focus on the functional components of the system, not if the functions are carried out by a human or a machine. The view put forward in this paper is to study the problem by acknowledging the difference between humans and machines. In the paper, we put a unified SA model for generating human and machine SAW originally outlined in [7] into a larger context. We call this model $(SAM)^2$ (Situation Analysis Model for Semi-automatic, Automatic and Manual decision support) as it can be applied to automatic and manual SA as well as to analysis integrating both of these, referred to as semi-automatic analysis. This latter type of SA is important since it will allow exploitation of both human and machine strengths.

The outline of this paper is as follows. In section 2, we explore the relation between SA and SAW. In section 3, we exploit the SA processes from a technological perspective on the basis of the JDL model for data fusion. The corresponding human perspective on SA and SAW is described in section 4. In section 5, we present our unified SA model for human and machine SAW. The central issue is to explain how information about individual elements can be fused by a system, human and/or machine, to generate awareness about the situation and how this awareness can influence decision making. In section 6 we discuss an extension of the proposed model to also include multiple users and/or machines. Section 7 concludes the paper and section 8 presents future work.

2 The relation between SA and SAW

It is important to highlight the relation between SA and SAW. While SA is a process, SAW is the result that the SA process generates. Roy [2] expresses this by defining SA as:

> *a process, the examination of a situation, its elements, and their relations, to provide and maintain a product, i.e., a state of SAW, for the decision maker.*

It however remains to be defined what this product, i.e. SAW, is. The most commonly accepted definition of SAW, given by Endsley [8], sheds some light on this:

> *Situation awareness is the perception of the elements in the environments within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future.*

Achieving correct SAW can be vital for making good decisions and according to Endsley [9], SAW is a mental model of the environment. This would indicate that SAW is a property of the mind and not of the machine.

We argue, however, that it also should be considered to be a potential property of a machine. Consider for instance a situation where the decision maker is a fully automatic system which uses the result of SA from perhaps both humans and machines as basis for its decisions. For an outside observer, it would appear as if the machine maintains a state of SAW, provided that the decision making would require this if it was performed by a human.

According to Adams [10], Endsley's definition of SAW is not specific for humans. We argue that machines also can perceive the elements in the environment, comprehend their meaning and project their status in the near future. We are not arguing that the awareness situated in machines is human-like, but we do see a clear connection to Endsley's definition of SAW. Nevertheless, the formalization of the concept SAW, in machines, and its similarities and differences compared to human SAW, is beyond the scope of this paper. Alternatively, the result of the SA processes can be viewed as input to a human decision maker.

3 The technological view of SA

Within the military domain, the standard model for providing an automated support for SA is the JDL model for data fusion (DF), see Figure 2.

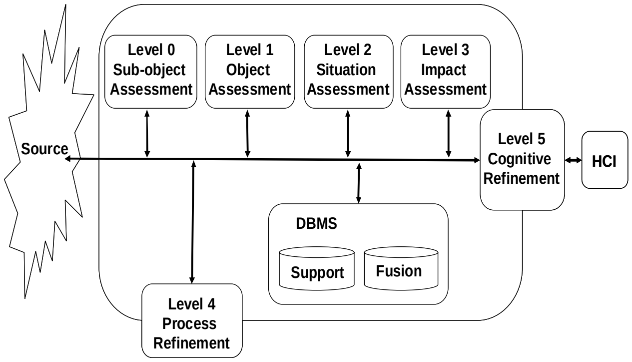

Figure 2: The JDL model (adapted from [11]).

The JDL model separates the DF process into different "levels" as follows:

- **sub-object assessment** (level 0): the process of estimating and predicting signal or feature states.
- **object assessment** (level 1): the process of combining sensor data to obtain reliable and accurate estimate of an entity's attributes, such as position, velocity, and identity.
- **situation assessment** (level 2): the process of identifying entity-to-entity and entity-to-environment relations.
- **impact assessment** (level 3): the process of inferring future effects on situations of planned or predicted actions.
- **process refinement** (level 4): a meta-process concerned with monitoring and optimizing the overall DF process.

Later work by Hall, Hall and Tate [12] and Blasch and Plano [13] include an additional level that addresses cognitive issues and human computer interaction aspects:

- **cognitive refinement** (level 5): key functions within this level include cognitive aids and human computer interaction. Issues like trust, workload, and attention, are of high importance.

As can be noted from the descriptions above, the data fusion process can be expressed in terms of assessment processes at various levels of abstraction[1]. It is important to highlight that the data fusion process is conducted with the purpose to focus on what is interesting, or as Lambert [15] puts it:

Data fusion is the process of utilizing one or more data sources over time to assemble a representation of aspects of interest in an environment.

In the literature, the higher levels (mainly situation and impact assessment) have been termed information fusion, rather than data fusion[2]. The rationale for this is that they use interpreted data as input, i.e., what in Figure 3 is termed SAW. We argue that this is a suitable term, especially when human SA processes are integrated with machine oriented SA processes. It is also, as highlighted earlier, important to acknowledge the difference between these processes and the results they produce, see Figure 3.

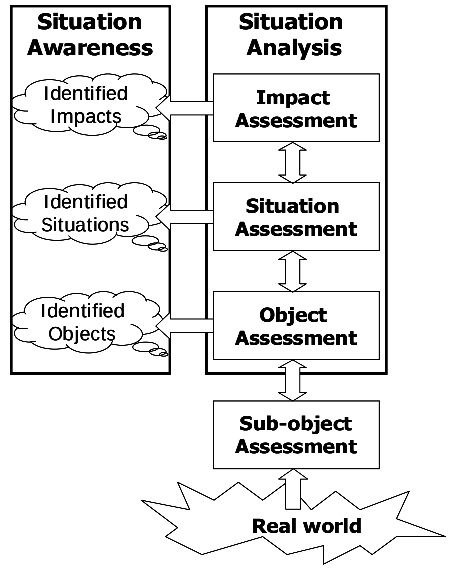

Figure 3: SA and its relation to the JDL model and SAW.

It should be noted that Figure 3 is a simplification of the JDL model since it implies only direct communication between adjacent levels, and does not include process or cognitive refinement. However, its purpose here is to illustrate the relation between assessment processes and their results. It should also be noted that preprocessing at the sub-object level is tightly coupled to the sensory level and regarded as producing results that need further analysis in order to be useful for decision making[3]. In other words, the result at the other levels could produce a state of SAW in a decision maker on their own accord, whereas the sub-object level cannot.

It could also be debated where the border for SA should be drawn. Here Roy's [2] definition, presented earlier, has been used as motivation since it focuses on the levels above the sub-object level. This view naturally ties in with the view that SA produces a result that can, on its own accord, be used as a basis for decision making.

In general terms, the JDL model focuses on the technological aspects of SA. It accounts for functions to assess objects, situations, impacts, and the fusion process itself. For some tasks, the result of this analysis could be sufficient for automated decision making. For most other tasks the JDL model needs to be connected to human aspects of decision making. The inclusion of an additional

[1] In this paper we adopt the view that "assessment" is a process, rather than the result of a process. For an opposing view see Lambert [12].

[2] Other distinctions between data fusion and information fusion exists, see e.g. [14].

[3] Obviously, it is possible to act on these results from the preprocessing. However these actions do not require any further analysis based on a state of SAW, this means that they short-cut the OODA loop. These actions are more similar to reflexes than the result of informed decision making.

level for cognitive refinement that acknowledges human issues, such as trust and workload [12,13], is an important step in this direction. But, as we will see in the following it is not enough. However, before tackling this issue, we will briefly look at human SA.

4 The human view of SA

According to Endsley [9] achieving SAW involves combining, interpreting, storing, and retaining information. In Endsley's model SAW is the result of processing at three distinct levels: *perception*, *comprehension* and *projection.* At the perceptional level, attributes and dynamics of the elements in the environment are perceived. At the comprehension level, multiple pieces of information are integrated and their relevance to the decision maker's goals is determined. At the projection level, future events are predicted.

Hone, Martin, and Ayres [17] complement this view by arguing that at least one process must occur before perception. This process allows connection to the external world. We have here chosen to term this process *sensing*. In addition, we argue for the need for feedback, since awareness at some level might demand input from both lower and higher levels of awareness. We also want to highlight the need for the ability to conduct an impact assessment purely on the output of the object assessment, i.e. the communication between non-adjacent levels.

As well as for machines, it is in human decision making important to separate the process of SA from the results it produces, i.e. SAW, see Figure 4.

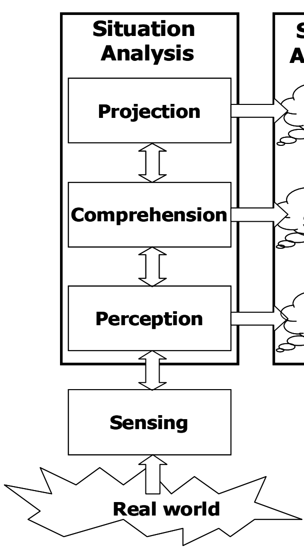

Figure 4: The human perspective on SA and SAW.

Figure 4 depicts our interpretation of Endsley's definition, extended with a level for sensing the environment, feedback between the levels, and a clear separation between the process of SA and the resulting state of mind, i.e. SAW. It should be noted that this figure is a simplification too since it does not acknowledge the possibility of interaction between non-adjacent levels. We will, however, tackle this issue in the next section.

Endsley's model of SAW is a purely cognitive model and does not include any technological aspects. The JDL model, presented earlier, provides a technological view on the DF process. Although the JDL model provides a functional model of the fusion process, it does not model this process from a human perspective. Many complex tasks require synthesis of both human and machine analysis. Consider for instance SA (human or technological) for ground level combat. The assessment might be based on identified objects from automated systems (e.g. ground looking airborne radars) as well as humans (e.g. manually interpreted sensor images).

5 A unified SA model

In the previous sections we have indicated that a unified SA model is warranted. We would go even further and argue that such a model is needed in order to identify the issues necessary to address to create a fully functional system for situation analysis. In this section we argue in more detail for the need of such a unified model and suggest how it can be achieved.

5.1 Manual SA

Humans apply SA in their everyday life to achieve SAW as a basis for making decisions. As stated earlier, the OODA loop provides an abstract model for decision making and according to Roy [2], SA takes place in the observe and orient phases of the OODA loop. Since sensing (sub-object processing) obviously is part of the observe phase as well, adding the OODA loop to Figure 4 results in the following model (Figure 5):

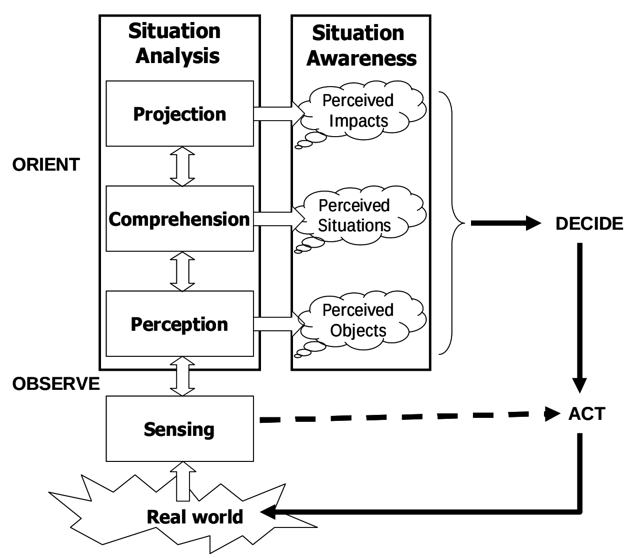

Figure 5 : The OODA loop added to Figure 4 (human perspective). Observe and orient are parts of the SA process. The result of this process, i.e., SAW, is used as basis for decision making.

In Figure 5, the SA processes are performed by a human, who achieves some degree of SAW in order to make a decision. Note that it also is possible to act directly on a sensation, e.g. reflex behavior (the dotted line in Figure 5).

A brief example is provided in order to illustrate how the model can be applied. Imagine driving your car to the supermarket. You hear a sound and see flashing lights (sensing). In your rear-view mirror you identify an ambulance approaching (perception). From this you comprehend that the ambulance is responding to an emergency call (comprehension). You project that the ambulance will not be able to pass you in a safe way, but if you move to the side it will (projection). You have now reached a level of SAW through SA and an appropriate decision can be made. You decide to move onto the curb and start turning your steering wheel.

5.2 Automatic SA

Figure 6 illustrates the machine perspective of the proposed model (note that the models in Figure 5 and Figure 6 are equal, apart from where the SA takes place).

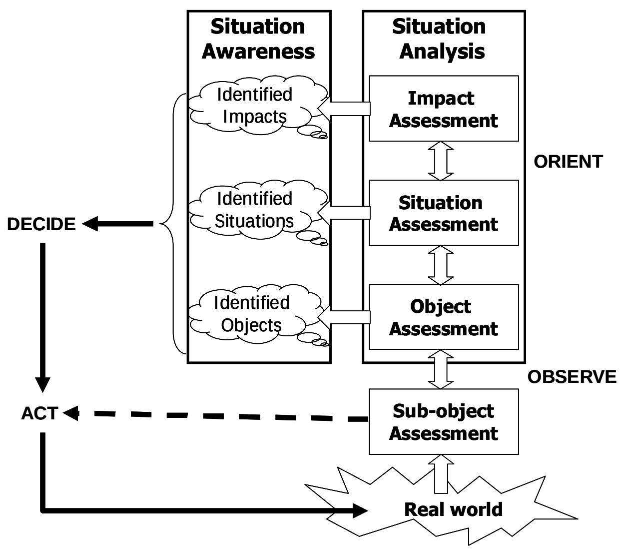

Figure 6 : The OODA loop added to Figure 3 (machine perspective).

To illustrate how our model can be applied in an automatic system, consider the following scenario. An autonomous rover explores the surface of Mars. While moving, the rover senses a change on the ground in front of it with its onboard sensors (sub-object assessment). By analyzing the sensory input, a number of different objects can be identified (object assessment). By fusing these observations with a map database the rover can correctly identify that there is a precipice in front of it (situation assessment). The rover projects an immediate break-down if it continues on its current path (impact assessment). It therefore decides to turn around. We argue that the rover uses some degree of SAW as basis for the decision to turn around.

5.3 Semi-automatic

Automatic and manual systems are both extremes, rarely found in real world applications. Most situations demands systems which can combine the strengths of humans and machines. Here we term such systems semi-automatic systems. Hence, we have identified a need for a unified model integrating manual and automatic SA. Such a descriptive model could lay the foundation for a more detailed normative model which could be used when constructing technical solutions. We therefore propose a combined model, depicted in Figure 7. It is important to note that the model supports interaction at various levels. At one level the SA can be automatic, while at another it could be manual and again automatic at the next level. Naturally, interaction between humans and machines is possible at all individual levels. This means that the SA truly becomes semi-automatic.

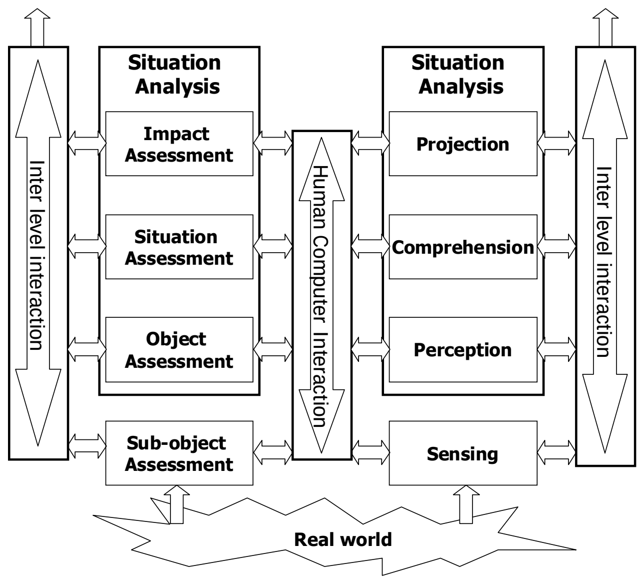

Figure 7: The unified model for Situation Analysis.

In Figure 7, human SA can be seen on the right side and the machine SA on the left side. The human and machine perspectives are basically the same as presented earlier. However, they have now been extended with inter-level interaction channels. These channels are used to communicate SAW between levels and are needed in order to allow internal communication between non-adjacent levels, as well as external communication with a decision maker (depicted by the upward arrows coming out of the interaction channels). They are also used to communicate the result from the sub-object level so that it can be used as input to assessments at higher levels. The interaction between a human and a machine is illustrated by the central human computer interaction (HCI) channel. It allows for SAW to be exchanged between human and machine, for assessment at various levels. This exchange is not as straight forward as the figure might be taken to imply. It demands similar information models within the interacting systems, a research field in its own right. This problem is, however, not unique to the human-computer interaction. It is the same problem when machines, or even humans, exchange information, for a similar argument see [18]. Different information models might result in loss of information. In order to avoid clutter, some simplifications have been done in Figure 7 compared with previous figures. The output (SAW) from the SA processes is now implicit in the figure. SAW can be both the input and output of the SA processes.

By combing the two perspectives one could explain how technological decision support at various levels of abstraction can support human awareness at various levels of understanding needed to take a decision. As a simple example of this type of interaction, consider the following scenario. A radar system surveys an area of interest and detects a signal (sub-object assessment). In the tracking phase, the system identifies an aircraft (object assessment). The result is communicated to an operator (through HCI functions). The operator, who knows that there are no friendly aircrafts in the area, comprehends that the aircraft is hostile (situation assessment). Following the trajectory of the aircraft, the machine projects that it is bound for a nuclear power plant (impact assessment), and communicates this to an operator. The operator achieves some degree of SAW and makes a decision to raise the alarm. This type of interaction need to be extended in order to address increasingly complex problems.

The model can also account for level 4 (process refinement), and level 5 (cognitive refinement) of the JDL model. Process refinement would be to modify an assessment process at some level, or the interaction between some levels. This process might be initiated by internal demand (e.g. awareness of the situation that some sensor is not focused at the right area) or external feedback (e.g. feedback from a decision maker that the situation awareness has some flaws). Cognitive refinement is the equivalent of process refinement, but at the human side. It should, however, be noted that process and cognitive refinement overlap in the HCI interaction channel. Both of these aspects need to be taken into account when refining HCI processes.

6 A common situation awareness?

Within the military domain, it is not only the case that a commander should utilize decision support systems to achieve correct SAW before making strategic, operational, or tactical decisions. Equally important is to disseminate this awareness (often also referred to as situation understanding) to the subordinate commanders. This is done by including SAW in the operations orders that the commander issues. The idea is to allow that all involved parties have the same understanding of the situation. In order to facilitate this ability, the model needs to be extended to include multiple humans and interaction possibilities between them. This extension is also necessary to allow for cooperation between humans during the SA process. In a similar fashion, the model needs to be extended with multiple machines and interaction between them to allow usage of multiple sources of machine SAW, see Figure 8.

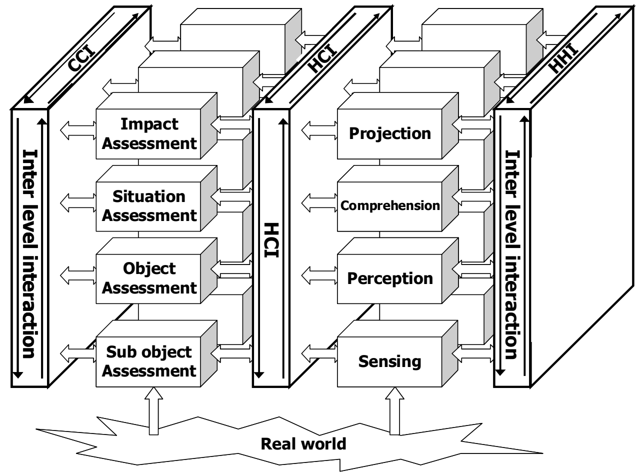

Figure 8: SA involving multiple machines interacting with multiple humans.

The leftmost interaction channel (CCI) allows for computer-computer interaction. The key enabler of this type of interaction is interoperability. Important tools are protocols and standards, e.g. the use of common information exchange models such as the Joint Consultation Command & Control Information Exchange Data Model (JC3IEDM). The rightmost interaction channel (HHI) allows for human-human interaction. Important aspects here are for instance methods and culture. The HCI (in the middle) allows for interaction between multiple computers and multiple users.

The figure also clearly illustrates the problem of achieving a common SAW, which, as Lambert [14] points out, results from the union of technology, psychology and interaction.

Even though the extended model would allow exchange of SAW between humans and machines, it deserves to be highlighted that there is no guarantee that a human, or machine for that matter, actually interprets the information in the intended way. It depends on many aspects that are outside the model, e.g., experience and alertness. We argue however, that this is an important area for further research. If solutions to the problems can be identified maybe these also can be used to solve the related problem of distribution of *intention* with a certain decisions. Subordinates would then have direct access to their commanders understanding of the current situation (SAW), the orders (i.e., the actions that should be taken) and the intention with the orders (i.e., what the commander want to achieve to change the current situation).

7 Conclusion

The increasing amount of uncertain and incomplete information calls for assistance from DF/IF systems. These systems work as key enablers for efficient decision making and do often require interaction between human operators and automated processes. Such semi-automatic systems are hard to describe using traditional models such as the JDL model or Endsley's definition of SAW on their own.

This paper argues for extending the scope of SA by suggesting a unified model for SA. The need for such a unified model is apparent when considering that many tasks require exchange and fusion of automatic as well as manual analyses for improved decision support. We therefore propose a unified SA model $(SAM)^2$ which can model SA systems with any degree of automation, ranging from manual to fully automatic.

When $(SAM)^2$ is extended to include also integration of multiple machines in multiple operators, concepts such as common SAW and Common Operational Picture (COP) to be discussed. We argue that the only option to achieve common SAW and COP is to allow iterative interaction between humans and machines. Therefore the way forward is to further extend the model we have suggested here.

8 Future work

Needless to say, lots of work remains to be done before a fully integrated $(SAM)^2$ system is available. We have here chosen to highlight some of the areas where we will continue our work.

Automation of the lower levels of the JDL and $(SAM)^2$ models (levels 0 and 1) are present in many of today's decision support/command and control systems. However, when it comes to higher levels such as impact assessment, there are very few existing operational systems, i.e. these tasks are still performed manually. We believe that most of these tasks can not be fully automated within the near future. Nevertheless, many semi-automatic systems will in the future be able to support humans to solve these problems. Much of the research performed at the impact assessment level focuses on probabilistic inference methods such as Bayesian networks and variants thereof. Such methods demand expert knowledge to be elicited in advance, but due to the dynamic nature of the threats of today and tomorrow, it must be possible to update these knowledge representations on the-fly. Therefore, the choice of method and the interface allowing for interaction between human and machine is crucial.

In the information fusion community, the lack of research in HCI related issues has been acknowledged by many authors e.g. [12,13]. More research is needed in order to understand information access preferences, how users perceive and process information, and interact with the system. New advances should enhance the link between effective human cognition and the information fusion system (middle layer in Figure 8), increasing the general effectiveness of the information system as a whole. Future work in this area should include, for example, aspects such as whether or not the presentation of information influences decision making (deployment of data quality, uncertainty, relevance, etc.), how to support cooperative work and how to overcome human perceptual deficiencies.

One interesting feature of the $(SAM)^2$ model is its communication channels that explicitly allow for output from any SA process to be used as input to any other SA process, i.e. the assessment levels are not sequential. For example, the result of an impact assessment can be used as input to an object or situation assessment. At least two interesting research problems have been identified which exploits this fact: (1) how can anticipated future situations be used in order to detect special areas of interest, which later can be used for sensor management, and (2) how can anticipated future situations be used to strengthen or even validate the understanding of the current situation. Naturally, many other interesting problems exist in which the results of higher levels are used to strengthen or even allow for certain kinds of tasks to be solved at lower levels.

Even though most tasks for higher level analysis are hard to fully automate, the amount of automation at these levels needs to be increased as well, in order to allow for new capabilities to be developed. Tasks that can gain from a fully automated support need to be identified and used to explore to which degree higher level SA processes can be performed automatically.

A central issue for achieving SAW is to understand the continuously evolving situation. It thus becomes interesting to investigate if for certain kinds of tasks, the comprehension of the situation can be automated. It is however important to remember that the ultimate goal for any decision support system is to allow for a decision maker to more efficiently achieve, keep, and maintain SAW in order to make good decisions. In case too many tasks are performed automatically, the SAW of the decision maker might actually become worse. This is an interesting topic since it might demand that a fully automatic system explicitly maintains a state similar to SAW on its own. One interesting research problem is therefore to investigate if an automatic system can be said to achieve SAW, and in case it can, to investigate what the requirements of such a system are.

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