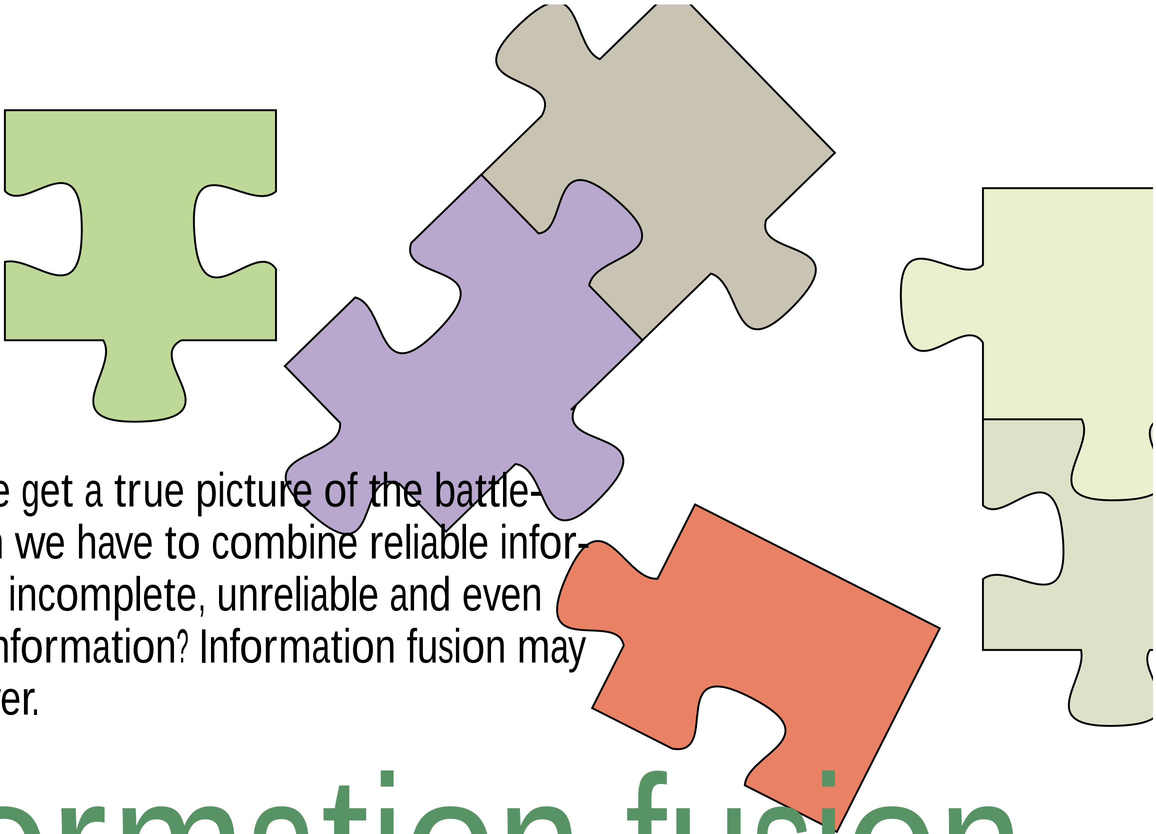


How can we get a true picture of the battlespace, when we have to combine reliable information with incomplete, unreliable and even misleading information? Information fusion may be the answer.

Information fusion in the future Swedish RMA defence

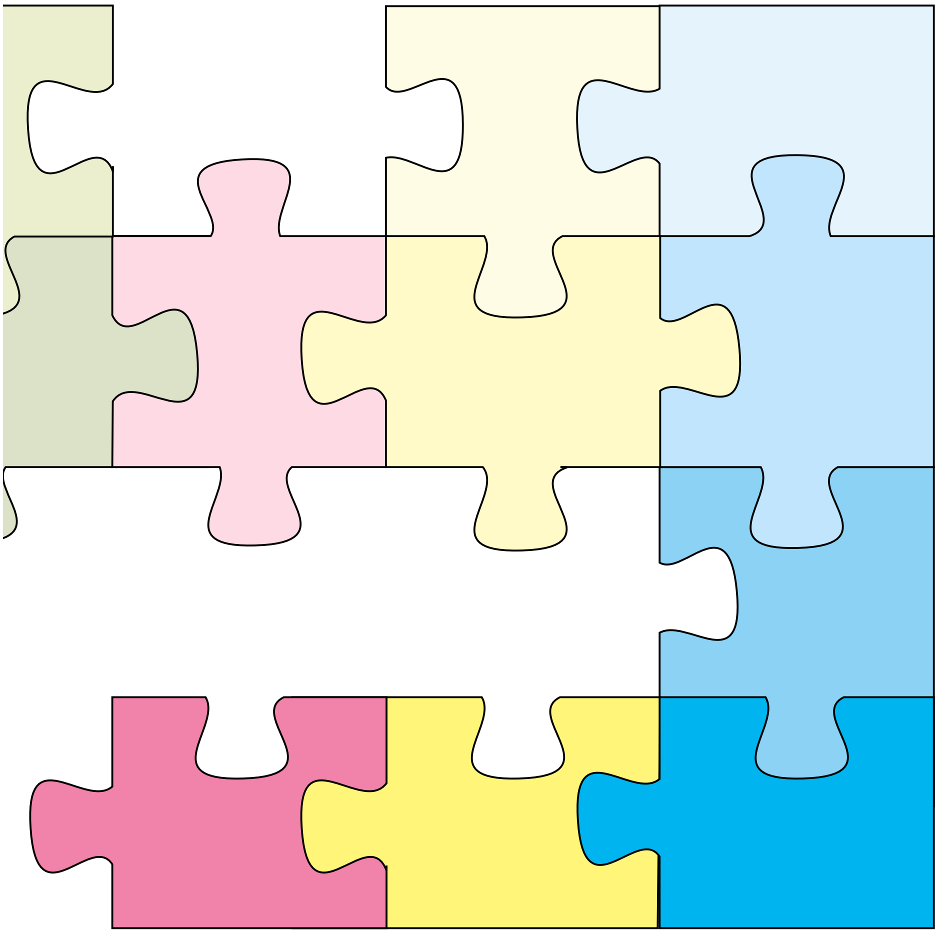
Per Svensson

The future command and control information system (CCIS) will be an integrated, networked information communication and processing system interconnecting human operators, intelligent computing systems, distributed sensor systems, and piloted and autonomous platforms. Military units, sensors, weapons and communications will have to be capable of rapid force projection to counter various threats, as well as of performing surprise or improvised attacks. In a twenty-year perspective, this will have to be carried out in such a way that information transfer, information correlation, situation analysis, tactical decision making, and weapons projection can be performed with much less delay than is necessary today.

The CCIS will become an increasingly important vehicle to improve endurance, reduce resource consumption and obtain shorter reaction times. The organization will be built around distributed, high endurance command posts, while allowing for higher echelons to assume command in critical situations which require maximal coordination. The future CCIS will also have to offer greatly improved facilities for realistic training in new scenarios.

Decision support systems, based on data and information fusion and war-gaming technology and employing advanced presentation modes will have to be developed to meet requirements for faster access to information adequate for decision making, in particular consistent situation pictures for different purposes. These will need to be created dynamically as projections or "views" of a common distributed, dynamic situation model. Information will be distributed over the network and will be stored using technology for distributed databases which allow restricted but consistent access to data in spite of occasional, or in the worst case permanent, interruption of communications. The databases must be capable of managing and presenting multimedia, geographical information and a number of other complex datatypes in real time.

Multisensor fusion, the technology needed to process the continuous inflow of sensor data into a unified dynamic target situation picture, has been developed during the last two or



three decades to a high level of robustness and precision. Today this is an established methodology for surveillance and command-control applications in the airspace and on the surface of the sea. Corresponding ground target applications are however considerably less developed, mainly because of their much greater complexity. In future CCISs information from all these scenarios, and eventually activities below the surface and in cyberspace as well, will need to be integrated.

In the future, however, processing of information will have to be carried much further than in the current generation of battle command systems, since the long-range goal is to provide a *decision-relevant, real-time, distributed* situation picture of the entire battlespace (more precisely, of any selected aspect and part of it). Before this important step can be taken, the emerging technology of *information fusion* will have to be extensively developed.

Information fusion in the future CCIS

Information fusion is a new concept whose meaning has not yet fully stabilized. Within FOA this term is used as a collective concept for the data fusion processes *situation analysis, impact* or *threat analysis* and *adaption* or *feedback* (levels 2-4) in the so-called JDL model [1].

Information fusion, in this sense, denotes data fusion processes which exploit the dynamic target situation picture produced by multisensor fusion (level 1), by combining its information with any available and relevant a priori information, in order to refine and interpret the battlespace situation picture. The a priori information typically consists of geographical data, other important information about the tactical environment such as the location of civilian populations and protected buildings, intelligence about the opponent´s tactics, equipment and organization, known facts about the opponent´s logistics situation, as well as other kinds of tactical know-how.

The intelligence interpretation process aims at delivering a complete picture of the opponent´s options and intentions, as well as available, evaluated courses of action for own forces. Information fusion also comprises techniques for proactive or reactive planning and management of own collection resources such as sensors and sensor platforms, in order to make best use of these resources in relation to identified intelligence requirements. Any information fusion system or method available or contemplated today would satisfy only a very limited subset of these objectives. Thus, information fusion technologies will have to be explored and evaluated in many experimental systems and scenarios before becoming a standard feature of command and control systems. Many fundamental issues remain to be addressed, among these for example development of a precise meaning of basic concepts such as information quality, useful when developing decision models based on uncertain information, and development of a validated methodology for combining qualitative human judgments with quantitative models of uncertainty.

Potential benefits of successfully integrating information fusion methods into the CCIS include:

- *by moving from* manual to automated or semi-automated intelligence processing one would presumably

be able to master situations where the complexity of today´s methods is too high in comparison with the size of available staff, e.g. interpretation of target situation pictures of the future "digital" battlespace, or where the time pressure is greater than humans can safely handle, e.g. defence against sea-to-sea missiles or tactical ballistic missiles,
- *improved capability to* handle situations where quantitative uncertainty management is important in itself, e.g. when one wants to exploit collected information in the most cost-efficient manner, using existing collection resources (assuming one cannot afford to deploy as many sensors as would be required to detect, localize and identify all potential targets, how could one make best use of our limited sensor resources in a given situation?),
- *capability of identifying* and assessing situations where direct observational information is not available, but where it is possible to draw indirect conclusions using other sources which may indicate the existence of a certain kind of threat (in this case, an automatic system would function as an "assistant" to the analyst, who may or may not have himself inferred the existence of the threat).

Information fusion is a complex, cross-disciplinary research area which is becoming increasingly important both in Sweden and internationally. In combination with multisensor fusion and technology for network-based information systems, it forms the methodological core of the RMA concept.

Information quality and management of uncertain information

Critically important for a military decision maker in a combat operation is the ability to continually judge the quality of the information on which his estimates and decisions will be based [2].

In the case of information from human sources quality estimation is a very difficult task, with which intelligence analysts have always had to cope. The task gets even tougher if one wants to employ such data as input to a formal computational process, since to do so usually requires the translation of a qualitative measure (e.g. "possible submarine") into a quantitative one, such as a probability value or an approximate probability distribution.

To satisfy reasonable quality requirements when exploiting results from, e.g. a simulated war scenario, there are many more steps that need to be taken. Implicit or - preferably - explicit error estimates for all input parameters of the model need to be established. Further, the model itself will need to be designed in a far more sophisticated way than most of today's wargaming models. In particular, it needs to be systematically equipped with built-in error estimates and has to be based on cautiously analyzed validity criteria.

Intelligence information is potentially uncertain in a number of ways. Thus, formalized processing of such information has to be based on scientifically sound methods for management of uncertainty. The following list, adapted from [3], demonstrates the complexity of this task:
- *intelligence information is* almost always incomplete, since it is usually not feasible to identify, not to mention to collect, all relevant information,
- *intelligence information is* frequently unspecific; collected information is almost always compatible with more than one possible state,
- *data is frequently* imprecise in more than one way; technical means of collection always have limitations, human capabilities of perception and interpretation are limited as well, and humans communicate using a usually imprecise and ambiguous language:
- *information usually originates* from several sources with varying degrees of reliability; even when sources report with high accuracy, both technical and human sources may be affected by systematic bias,
- *information may be* contradictory or conflicting; multiple, and in some cases even single, sources will very likely report conflicting information,
- *information frequently reflects* interpretations rather than facts; information used by analysts is mostly based on conclusions, i.e. another analyst or sometimes perhaps a journalist already processed the raw data and thereby introduced uncertainty through the inference process.

The academic research field Management of Uncertainty, growing rapidly in recent years, is developing methodology and technology for management and analysis of data which are associated with errors of different kinds. A number of approaches have been developed to cope with such problems, characterized by the need to make inferences on the basis of insufficient and uncertain information. Usually, the consequences of decisions based on such information are also uncertain. Information fusion is becoming an important application area for this methodology.

Some information fusion R&D programmes in other countries

NATO Data Fusion Demonstrator
DFD is a technology demonstrator developed by six NATO countries (UK, Germany, Canada, The Netherlands, Denmark, and Italy) over a number of years. The system was completed and demonstrated in 1998. The demonstration was based on simulation of a Cold War invasion scenario.

The scenario generates a flow of formalized intelligence reports, i.e. battlefield sensors are abstracted as report generators whose output is structured according to the NATO

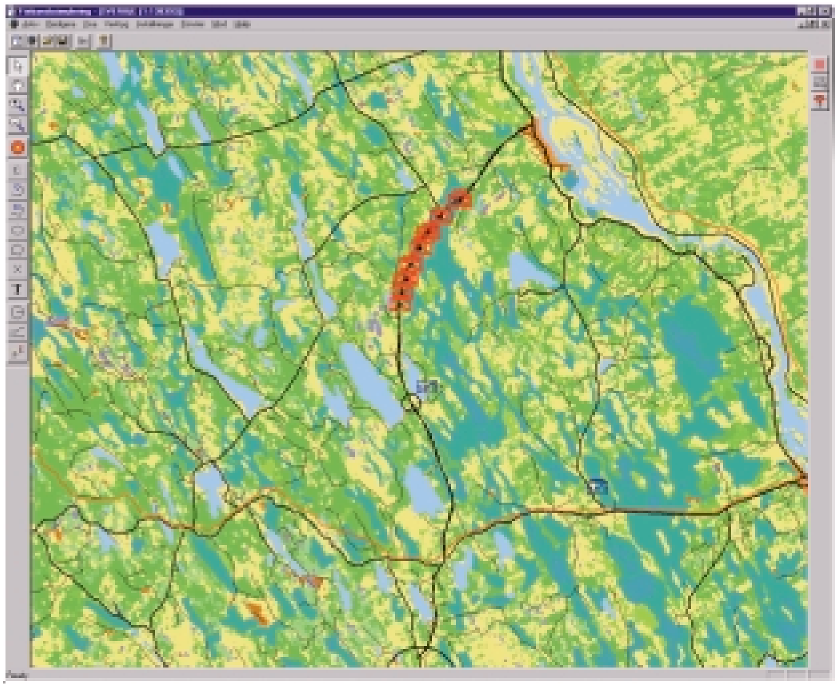


Fig 1. *In this simulated scenario, an enemy column moves south along a road. A scout patrol located near the opposite shore of the lake continuously observes the encircled area and reports its opinion about the type of each vehicle as it passes.*

format standard AdatP3. Various fusion methods and algorithms are applied to this information flow, in conjunction with a priori geographical and doctrinal information. The process produces a situation picture which is then automatically compared with the simulated "ground truth".

The final evaluation of the DFD project assessed the operational potential of automated information fusion and concluded that there are rich opportunities to increase the level of automation in the tactical intelligence process, thereby relieving the pressure on the intelligence officer. Several areas were also identified where continued research and development is needed before a fieldable system can be built.

Task Group on Information Fusion

Since the beginning of this year a study project within NATO Research and Technology Organization/Information Systems Technology is going on, which can be seen as a follow-up project to DFD with more limited collaboration ambitions. During three years the participating countries' research organizations will collectively study the following problem: improve the capability to perform information fusion (data fusion levels 2 and 3) within an ASC (All Source Cell) belonging to a "combined/joint headquarter", i e, the staff of a deployment force with members from several allied nations and all service arms. The rapid deployment force is assumed to have been created to carry out peacekeeping and peace enforcing operations in a predefined scenario (Banja Luka, Bosnia 2005).

Initially, a conceptual model of the tasks of an ASC is being created, in conjunction with an operating environment which includes both a socio-political and a physical situation. The planned continuation involves the development and evaluation of a functional model of an ASC, followed by identification of functions which might be automated.

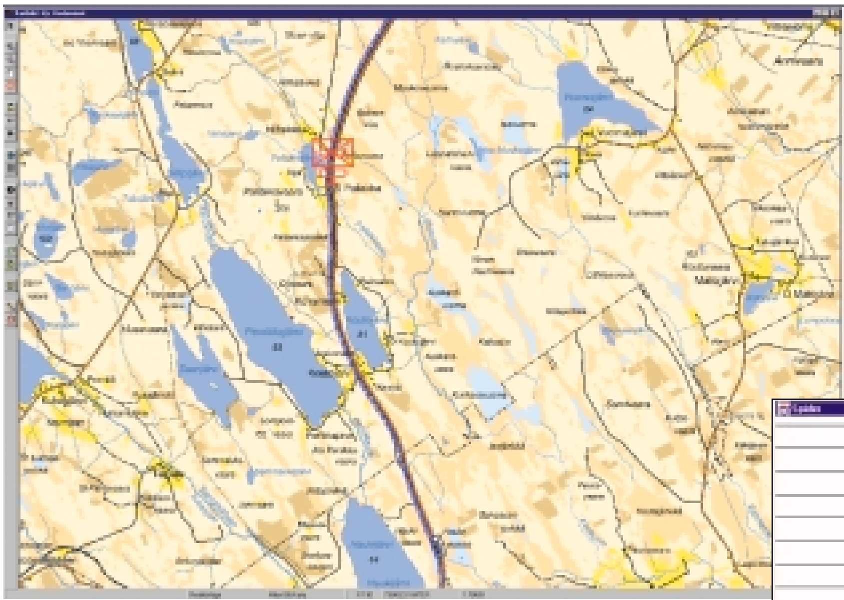
Euclid Advanced Workstation for Command and Control Systems

Within the development programme Euclid of the Western European Armaments Group (WEAG), a project has been completed which was intended to stimulate the use of artificial intelligence and advanced software technology in future CCIS. The project was completed in 1998 and was led by Logica UK Ltd., in cooperation with a number of companies and institutes from Denmark, France, Italy, The Netherlands, Norway, and Spain.

The following functions were developed to support the intelligence function:

Automatic report analysis. The purpose of automatic report analysis (ARA) is to reduce the amount of data that needs to be considered by the intelligence staff and to make sure that important information is prioritized. ARA reads simulated reports from either a predefined ground or a maritime combat scenario, extracts the information content from structured intelligence messages and uses this to create a Wide Area Picture. Inference using fuzzy logic and fuzzy clustering has been demonstrated in a maritime scenario. The method has been capable of recognizing important ship formations and behaviours, such as the main body of a "task force", a surface attack group, the median line of an advance route, and screening behaviour.

Tactical threat evaluation. In tactical threat evaluation one tries to recognize the plan executed by the opponent. Models of possible enemy plans have been predefined, which deliver clues as to which information is to be expected while the plan is executed. Reports about the opponent are used to estimate the likelihood that he follows a certain plan,



In fig 3, we see how the computed matching scores for each of the alternative army unit models vary as successive reports are being processed. In this example only four unit models are used for simplicity, although in a future real system there will need to be dozens or more. The method used is sensitive to the observed sequence of vehicle types in the column. Technically, it is based on so-called Hidden Markov Models, HMM. It is not yet known if this method can be made robust enough to be of practical use.

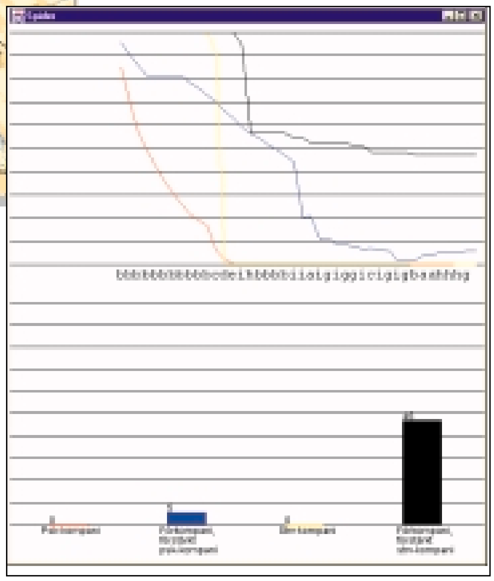


Fig 2 and 3*. After analyzing the received reports in real time, the information fusion component of the CCIS concludes that the observations received from the scout patrol, among alternative force structures considered best fit an "advance company of a reinforced tank company". A moving symbol representing such an army unit is displayed on the system's map display.*

as well as which stage of the plan is currently executed. Plan recognition has been demonstrated in a scenario where the commander of a landing operation observes a defending force.

Computation of trafficable corridors and Course-of-Action comparisons. Digital terrain data are stored in an object-relational database and may be presented as exchangeable overlay displays, showing areas of varying trafficability. From this information corridors of a given width are computed, sufficient for passage with vehicles of a certain type.

The method is based on a computational technique called generalized Voronoi diagrams. The corridors represent possible routes of approach and nodes between these, forming the basis for developing Courses-of-Action (CoAs). The CoA development is then carried out as a manual work group process. Support is provided for comparing own and enemy CoAs using weapons effect indices and weighted force strength values. These methods combine subjective evaluations of relative weapons effects with a probability analysis of the outcome.

CCIS led by DARPA in cooperation with DERA

The objective of CCIS is to demonstrate distributed information processing within a command and control system. It includes the following themes:

Compact tactical picture distribution. Develop capability for portable tactical situation analysis

Distributed tracking architectures. Demonstrate and experiment with distributed target tracking systems

Target detection. Demonstrate how different target types may be detected, tracked and included in the tactical situation analysis.

CCIS contains the following subprojects:

- develop, evaluate and demonstrate systems which can contribute to the establishment of a common operational picture for strategic surveillance operations, and provide support to the operator when analyzing different options and exploring new solutions,
- develop technologies to create a consistent operational picture using data and information fusion, geographical data and databases with a priori information,
- develop a *Distributed Information Demonstrator* (DERA Land Systems).

The situation in Sweden

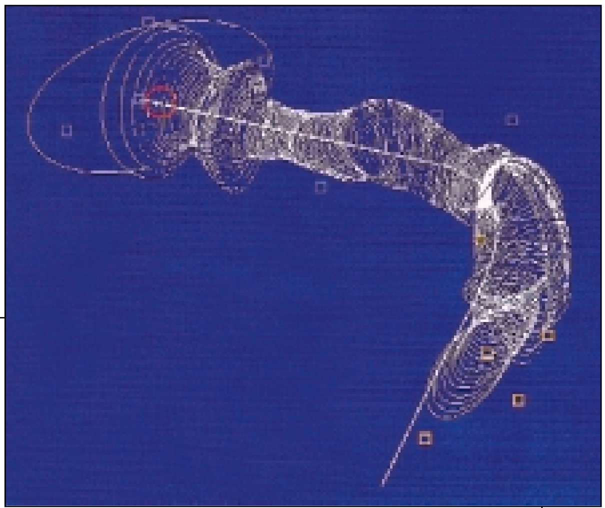
In connection with its ambitious program to develop a Swedish RMA defence, the Swedish Armed Forces (SwAF) are revealing an increased interest in the application of information fusion methods to Command

and Control Information Systems.

Currently, the research effort supported by SwAF is still relatively small, however, and consists mainly of the FOA project Tactical Information Fusion, which was initiated at the beginning of this year as a follow-up of an earlier preliminary study. The project aims at designing and evaluating a demonstrator, to some extent similar to the NATO DFD, but based on more modern methods for uncertainty management and using COTS/GOTS software wherever possible and appropriate.

Recently SwAF has asked FOA to present a proposal for a more ambitious project to replace the current one, which in addition to developing information fusion tools for ground forces would also consider joint operations of land, air and sea forces, as well as international operations.

The Swedish National Board for Industrial and Technical Development (NUTEK) has partly financed the project IQ Ledning [2], which analyzes the concept of Information Quality in a CCIS context, and aims to establish quality measures for information obtained from future CCIS. This project, which was initiated in 1999, is a cooperation between SAAB Technologies, the Department of Numerical Analysis and Computer Science at the Royal



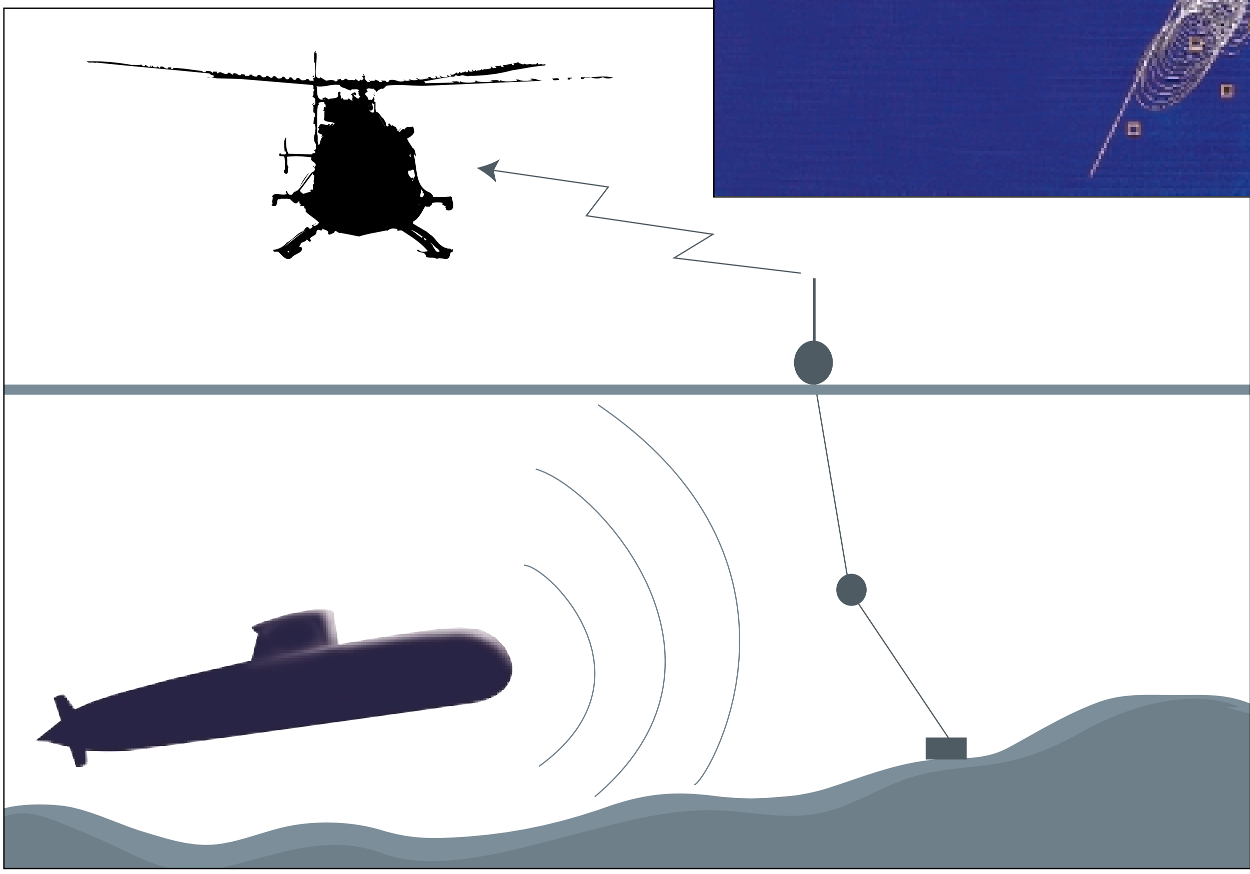


Fig 4 and 5. *Passive, non-directional sonobuoys are launched into the sea from a helicopter which tries to track a submarine in the shallow and acoustically very complex waters of an archipelago. The sonobuoys have to be dropped at locations quite close to the submarine (probably as close as 100-300 meters).*

A multisensor fusion algorithm makes use of information from all hearing buoys to obtain successive location estimates. These estimates are passed through a very simple Kalman filter representing limiting maneuverability properties of a wide class of submarines, resulting in a succession of predicted position estimates (white 95% confidence ellipses).

As the submarine is moving away from the buoys, an optimization algorithm uses the prediction estimates together with other known information (mainly the sonar equation) to decide where and when the next buoy should be dropped. This tracking method has only been demonstrated using simulation. It has not yet been shown that an effective such tracking system can be built.

Institute of Technology (NADA/KTH), the Department of Command and Control at the National Defence College (FHS), and the Department of Data and Information Fusion at FOA.

A project financed by the National Aerospace Research Program (NFFP) has recently started. It is carried out by SAAB and FOA in cooperation and aims at developing methods and tools for information fusion in ground target scenarios.

A number of other projects in the area of data and information fusion at FOA are devoted to multisensor fusion and platform-based applications. It is plausible, however, that the distinction between platform-based and CCIS applications of information fusion will gradually become less well-defined, as platforms become more tightly integrated in the network-based defence of the future.

Two simple information fusion applications

In [4], we discuss the application of *Hidden Markov Modeling* (HMM) techniques to the *column recognition problem*, where a non-cooperative military unit consisting of a sequence of objects forms a trans-portation column. The task is to infer the object composition and organizational structure of the column from imperfect observations of individual objects, in combination with generic a priori information about the organizational structure of the non-cooperative forces. See Figs. 1-3.

In [5], we study possible benefits of using *multi-sensor data fusion* and *adaptive planning* in the problem of determining and tracking the position of a submarine in archipelagic anti-submarine warfare (AASW) using passive, non-directional sonobuoys. The system automatically places buoys at near-optimal locations within the area. The information from the sonobuoys is used to calculate the position of the subma-rine. A Kalman filter-based prediction method for the position of the target was developed. This method models the kinematics of a generic submarine and fuses this apriori knowledge with position estimates from sensor measurements to obtain an optimal estimate of the submarine's position at a near-future point in time. An optimization algorithm then calculates the position of the next sonobuoy to be deployed. See Figs. 4-5.

Conclusions

Information fusion is an emerging technology mainly addressing the needs of the command and control and intelligence functions. It includes computational processes in support of interpretation, modeling, and presentation of the tactical situation for various command levels, and it enables a more effectively focused information collection.

A major unresolved issue is to what extent these tasks can be effectively carried out by computer systems. The technology of information fusion is in its infancy, and research in this field is still to some degree characterized by free experimentation. We do not know where the boundary between human and computerized situation and impact analysis will be drawn in the future. However, there are good grounds to predict that information fusion will in the long term offer great performance and efficiency improvements. Intelligent combination of human and machine processing tasks will undoubtedly offer also shorter-term advantages. This bright forecast is contingent on a moderate but steady increase in international research and development efforts over many years.

An important management issue is how to successively introduce information fusion methods during the evolutionary development of the CCIS. A closely related, yet largely unsolved problem is how to design the architecture of a CCIS to create a solid and secure base for the application of such methods.

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