16th ICCRTS: Collective C2 in Multinational Civil-Military Operations

Title: A Smarter Common Operational Picture: The Application of Abstraction Hierarchies to Naval Command and Control.

Topics:

(Primary) Topic 5: Collaboration, Shared Awareness, and Decision Making
Topic 4: Information and Knowledge Exploitation
Topic 6: Experimentation, Metrics, and Analysis

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Abstract

The last decade shows significant steps in connecting military command and control systems from different defense forces optimizing joint and combined operations. However, a Common Operational Picture (COP) that provides all actors with sufficient, accurate, and timely information is still an elusive target. Additional and more abstract information is required to comprehend the situation better, including a representation of the friendly, neutral and hostile courses of action and the roles of units therein.

A starting point for a more advanced COP is work by Rasmussen and Vicente on *abstraction decomposition spaces*. While working with complex socio-technical systems, people construct a mental model with several levels of abstraction allowing humans to diagnose unexpected behavior and problems faster and better.

This paper describes a multi-level information model that we intend to use as the framework for a COP. A task analysis has led to the identification of input and output of command and control processes that have been used to populate the information model. Using various warfare scenarios, discussions with naval personnel were used to validate the model. Experiments with naval personnel are planned for the future in order to evaluate the effects on performance, situational awareness, and coordination with other parties.

1. INTRODUCTION

Military operations are among the hardest endeavors that humans can undertake and are getting progressively complicated as today's operations are more than just fighting an opponent but also contain objectives such as re-constructive work, counterinsurgency, and political talking. The circumstances can change rapidly from construction work with relaxed patrols to short and sharp engagements. Besides the general information gathering and distribution problem, there is also an adversary that is intelligently plotting to subvert the undertaking, to undermine confidence and morale, and to destroy material and human lives. In addition, the opponents are less easy to define as these are revolutionaries, insurgents, or terrorists that easily blend in within a large population of neutral civilians.

Currently, much effort is related to generating an operational picture that allow commanders to grasp the situation better and that in turn improves the decision making process. Historically, these operational pictures are oriented around tracks in the case of the Air Force and Navy, and around army aggregates (army units) in the case of the Army. In addition, these efforts strive to get the right information to the right people at the right time. The Common Operational Picture (COP) is a common catch phrase to denote both a situational description and the associated plans and decisions. However, current common pictures only tell part of the story. They are limited to a near real-time representation of observed platforms and so far lack ways of integrating these observations into a larger whole (a truly situational picture). Furthermore, these COPs fail to reflect which processes or goals are to be achieved by which platforms and aggregates. Individual tracks do not represent a sufficient level of abstraction to enable good tactical awareness and decision making. As stated in previous work (Arciszewski, de Greef, van Delft, 2009) "*besides tracks, which represent very tangible objects in the ship's surroundings, more abstract objects like formations and task groups, mission objectives, and tactical patterns also play a role in military command and control. It is at these levels of abstraction that warfare officers switch from a perception of the current situation to an interpretation of the current situation and predictions of the future situation.*"

Currently, a COP fails to support possible projections or give indications on how observed platforms match planned or expected movements or actions. Joint military exercises have shown shortcomings in the current COP pointing out a lack of information such as:
(a) unit capabilities and status information;
(b) support for planning and monitoring the operation execution through a better representation of commander's intent; and,
(c) combat support information and predictions about future status.

We feel that the tactical information present in current COPs is too focused on tracks (platforms) to allow a good tactical understanding and coordination both in shared situational awareness and decision making. This study focuses on designing and validating additional layers of abstraction and ways of communicating these between command nodes that yield a better understanding of the situation at all command nodes, and in turn lead to better and faster decision making. This involves both a representation of the own forces, their plans and their individual roles, and a representation of the neutral and hostile parties and their respective plans (probable courses of action) and individual roles.

It is our purpose to build an abstract model for the military domain that describes a tactical situation at higher abstraction levels than currently in use and that can be used as an information model for a C2 framework for joint operations. The starting point of our journey is the work by Rasmussen on abstraction decomposition spaces (Rasmussen, 1985). Abstraction-decomposition spaces are used to characterize constraints and relationships in complex socio-technical systems. The concept of an abstraction-decomposition space was first introduced by Rasmussen to model the thought processes of humans during diagnostic problem solving. He showed that human operators tend to switch between different functional abstraction levels and levels of granularity when solving problems. This switching-behavior allows a rapid assessment of the problem (the situation) and consequent decision making. This hierarchical approach should match well with existing military thinking and nomenclature. After all, officers are accustomed to looking at units as parts of a larger whole and in assessing their roles and tasks as part of a larger design. Therefore in our view the theory offers a substantial starting point for a common operational picture.

Using such an improved, multi-leveled model, we hypothesize that:

- Every actor in a military operation will have a better Situation Awareness (SA) in terms of perception, comprehension, and projection the future situation (SA level 1, 2 & 3 (Endsley, 2003)) and will improve the understanding and prediction of actions of interdependent actors.
- Actors will require less explicit communication in order to understand the total situation or the status of individual actions.
- Actors will need less time to react to events that endanger mission goals.
- Actors who were not involved previously will understand the situation faster.
- Actors will have different communication patterns.
- Actors will be able to better understand higher order intentions, in turn supporting adaptation to changing situations.

The next section discusses the theoretical background of abstraction decomposition spaces and section 3 applies the theoretical framework to the military domain. Section 4 discusses how to deal with the time dependence of military operations in relation to abstraction decomposition spaces. Section 5 introduces the idea of separate spaces for the blue forces and the enemy and the interactions involved. In section 6 we turn from the abstraction decomposition to the processes that are involved in producing the necessary information for the new operational picture. Section 7 uses scenarios to explain the workings of the proposed abstraction decomposition model in terms of examples. Finally, conclusions and discussions are put down in section 8.

The objective of this study is to create an abstraction decomposition space for naval command and control assisting warfare officers creating a tactical picture. Such a tactical abstraction decomposition space aims to extend current COPs. On order to achieve such a goal, a number steps need to be taken. First the abstraction decomposition spaces theory (discussed in section 2) needs to be applied to the military domain (section 3). This application involves defining five abstraction levels and three levels of granularity. Subsequently, the paper discusses that the essence of command and control is the matching of observations with plans. Section 4 therefore introduces the temporal dimension and links time with plans. Following this section, section 5 shows that there exists a tactical abstraction decomposition space for the own forces, the adversaries, and the neutrals linking the mental structure of warfare offices. On its turn, section 6 elaborates on the processes that are central to tactical thinking and these processes can be used to design (partially) automated support. The processes are distillated via the tactical abstraction decomposition space in combination with a decision tree. Finally, section 7 combines all previous theoretical sections in an exemplary amphibious landing scenario.

2. BACKGROUND - ABSTRACTION DECOMPOSITION SPACES

When working with a complex technical or sociological system, research has shown (Rasmussen, 1985) that humans construct several mental models at different levels of abstraction of the system in question. They switch between these different mental models while they attempt to understand the (mal)functioning of the system and to diagnose problems with it. These multiple mental models are shaped along two dimensions (abstraction and decomposition), aided by inspection of the real thing and knowledge of the underlying (physical) laws. The abstraction dimension describes system functioning at different abstraction levels and tends to gravitate from a fairly high-level description of the system as a whole (i.e. a macro perspective) to detailed models of the functioning of specific (hardware) parts (i.e. micro level of detail). These means-end relations allow answers to *how* certain goals of the system are achieved by moving down in abstraction, whereas moving up reveals *why* certain elements exist. The highest level of the model defines the overall purposes and goals of the system while elements at the lowest levels describe physical components of the system and their function. The decomposition level allows people to divide a system in parts (i.e., a part-whole relation) via large subsections of the system (e.g., a complete turbine) to small parts or components (valves, chips).

Rasmussen suggested that automation that is designed to aid people with the control of complex systems should reflect these different levels of abstraction and decomposition. The software should model the underlying physical, chemical, and/or biological laws in order to show aberrations in the proper functioning of the system at all levels of abstraction. The interface to such a multi-layered model is sometimes called an *ecological interface* because it represents the actual environment (ecology) the human is dealing with.

After deliberating at what levels of abstraction ‘the system’ should be described and what kind of information this should entail, the next step in the modeling process is to define the processes required to generate information at each level. This can be achieved by a *control task analysis* (Vicente, 1999) that describes the tasks that are performed while controlling the system (keeping the system within its prescribed, safe boundaries) and the information resulting from each processing step and needed for each consequent step. A *decision ladder* (Rasmussen, 1985) can be used as a starting point for the analysis. Such a graph succinctly describes the process steps necessary for an understanding of the system and the ensuing decision and action processes driving it toward a desired state. The output of each process can be used to populate the information model that informs the user of the state of the system, whereas a description of the processes can be valuable to design automated support aiding the user in his or her analysis and decision making.

3. APPLICATION TO THE MILITARY DOMAIN

This section applies the theory of abstraction-decomposition spaces to the military domain. First, the abstraction hierarchy is discussed in relation to military operations. Next the part-whole dimension of the military abstraction decomposition space is discussed. Prior to defining an abstraction decomposition space, it is necessary to define the system (work domain) that is being modeled. In this study, ***we draw the system boundary around a single force single nation military operation***. We thus do not take into account the entire defense force of a nation or coalition, but restrict the physical forms to those units that directly participate in an operation.

3.1 The Tactical Abstraction Hierarchy

While Rasmussen (1985) applied abstraction hierarchies to nuclear power plants, recent work has applied the abstraction hierarchy theory to the military domain. Burns, Bryant & Chalmers (2000), for example, describe an abstraction hierarchy of two types of navy frigates. Likewise, Chalmers, Easter & Potter (2000) describe the abstraction hierarchy of a naval frigate and Treurniet, van Delft & Paradis (1998) describe a naval scenario at different abstraction levels. They all focus on individual warships and thus deal with a more limited system scope than we intent to do. Alternatively, the work of Bennet, Posey & Shattuck (2008) on a command and control system at army brigade level approximates what we want but the application to the navy domain requires a different perspective. As such, in the following we propose five abstraction hierarchy levels underlying military navy operations. A summary of the levels can be found in Figure 1.

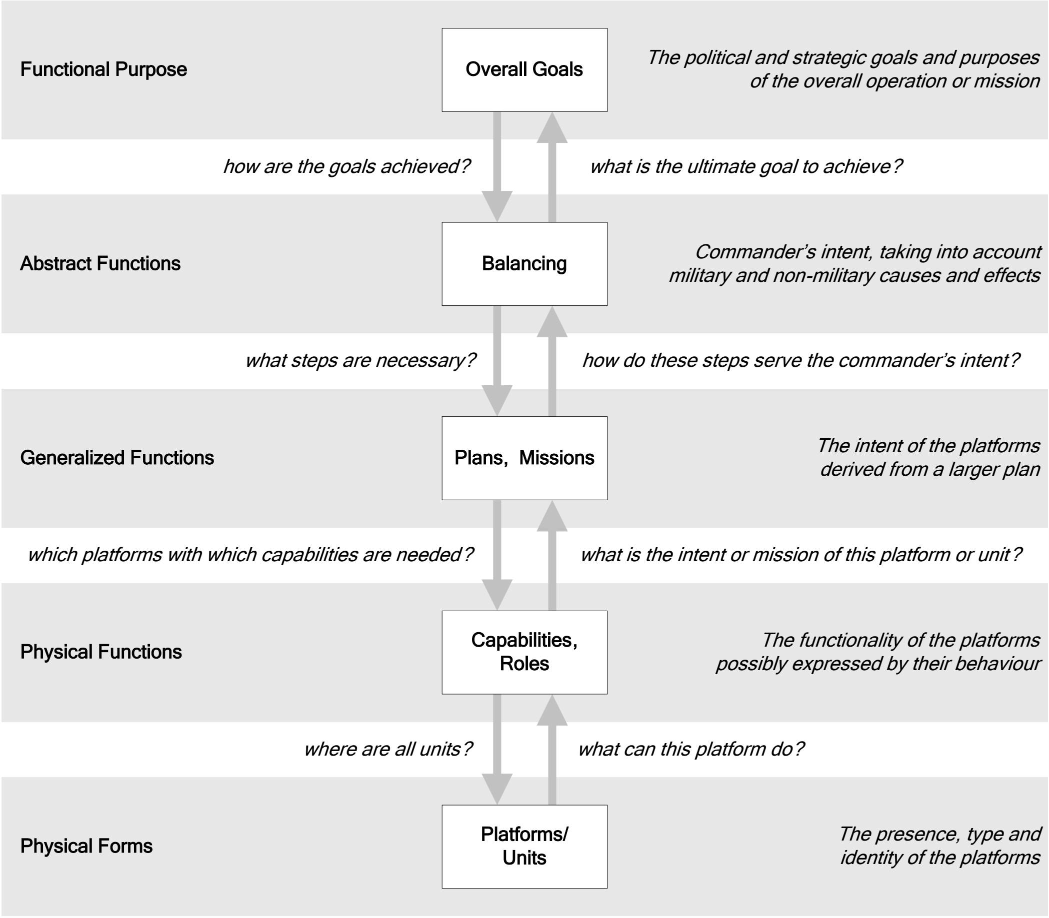

Figure 1 - The different levels of the proposed Tactical Abstraction Hierarchy.

The Functional Purpose Level

The functional purpose level describes the overall goal(s) and purpose(s) of the entire operation. The relationships between the goals at this level indicate potential trade-offs and constraints within the operation. In military terms, the overall goal of the operation of the entire task force is described in generic terms like peace enforcement between two or more conflicting parties in an geographic area, anti-piracy (law enforcement) in a maritime area, or the destruction of the opposing forces in a total war. Purposes and constraints that set limits on actions may also be stated at this level and may partially conflict with each other. These restrictions can originate in international law, political considerations, rules of engagement, or other constraints.

As the functional purpose gives an overview of the goals and objectives, it doesn't provide an answer to the question *how* these are to be achieved. The means-end relations between the functional purpose level and the next lower levels provide the first answers.

The Abstract Functions Level

The abstract functions level describes the underlying laws and principles that govern the system. For a military operation this translates into doctrine and operational procedures, but also things like the principle of the application of military force, the balance of power and the unbalance a military commander wants to achieve for a breakthrough. One could say that at this level the *commander's intent* is formulated (and monitored). Alternatively, operations other than war (e.g., peace keeping, peace enforcement, nation building) require more considerations to enter using pages from any operational handbook. This means taking into account economical, political, tribal, sociological, psychological causes and effects to give an answer how to achieve the goal of the operation.

The abstract function level thus restates the abstract goal of the operation in goals achievable by military or other means, as further worked out at the next level, the generalized function.

The Generalized Functions Level

The generalized functions level is where the goals or purposes of the operation are translated into *a plan* by which they will be achieved. In other words: the generalized function level indicates **how** the goals of the operation are achieved and **how** constraints jeopardize the operation. Translated into the military domain, the generalized level expresses the *commander's intent* (as described at the abstract function level) into terms of *plans and missions*. The generalized function level also considers the possible courses of action of the adversary by estimating and incorporating them into plans as well. Plans are mostly expressed in a temporal-geographical fashion because units must reach specific locations at specific times in order to execute the plan successfully. This intentional level is a description that is independent from the units that are performing the mission. Examples of such missions are surveillance of the battlespace, air defence, and attack of a surface task force.

The means-end relation to the lower level states *how* a mission is executed by which physical units. An attack at a surface task force requires, for example, a combination of surface surveillance and a surface attack, so we need an aggregate of one or more actors that are capable of surveillance and one or more that are capable of surface attack.

The Physical Functions Level

The physical functions level describes the ‘real world’ physical processes that are executed in order to achieve the higher-order means as expressed at the generalized function level (i.e., the missions). This level explains what physical functions are required, based on capabilities and roles. The means-ends relation leading to this abstraction level is a mapping of missions (described at the generalized function level) to physical platforms/units capable of executing those missions. There is a need for something to fulfill a particular role, and that role is then assigned to any physical entity that is available and capable of fulfilling that role. This level thus describes *the capabilities* and *roles* of the platforms involved.

The *behavior* of a platform is an important indication of its role. As examples, adherence to predefined area indicates a surveillance or combat air patrol function; adherence to a civilian airway, squawking friendly identification, and agreement with a preordained flight plan all indicate commercial civilian transport; a helicopter that follows a trajectory to or from an oil rig indicates a civilian supply and transport function as well; a stationary trajectory at stand-off range with search-radar emissions indicates hostile surveillance; and finally, a low, inbound trajectory with small closest point of approach (CPA) combined with emissions from a fire-control radar indicate a surface attack (as does a weapon launch). These behaviors are getting more important when considering enemy platforms.

The physical function level describes what the physical platforms can do (their capabilities) and what they are actually doing (their role). Why they are doing that is answered at the next higher level, the mission level (the generalized function level).

The Physical Form Level

The physical form level (sometimes expressed as the *physical object level*) describes the condition, location, and appearance of the physical components. Physical characteristics include things as color, dimensions, and shape. Single *platforms* (tracks) fill this level in the model admirably. Tracks have a well-known position and things like shape and dimensions are known once a track has been classified (or serve to classify the platform). Identity is also part of the description at the level of the physical form because it is static (the ‘flag’ at the bow or the tailfin defines it).

Conclusion

A recognized air or maritime picture (RAP, RMP) more or less coincides with the lowest level of our proposal for a military abstraction hierarchy. This is a first glimpse of the potential benefits of an entire decomposition-abstraction space as such an entire information model incorporates several more descriptions of the situation at ever higher levels of abstraction.

3.2 The Part-Whole Hierarchy

The part-whole dimension of an abstraction decomposition space describes the organization in terms of parts (i.e., single units) and its relation to larger aggregates. This dimension is also referred to as the decomposition dimension. The part-whole hierarchy should reflect the units assigned to the missions *as intended to achieve the goal*.

Missions, operations, or tasks are usually assigned to standard military units (e.g., division, brigade, battalion, platoon) so that identification of a unit can help in walking through the abstraction hierarchy. For naval operations, the ships of the task force are selected according to the mission demands and the part-whole relationships could be temporary and valid for this operation only.

The lower layers of the part-whole and abstraction hierarchies overlap: the physical form level of the abstraction hierarchy (platforms or army units) overlap with the individual units of the part-whole hierarchy. At the other end, the highest level of abstraction coincides with the largest whole in the part-whole hierarchy (the task force executing the operation). In between we have defined one or more aggregate levels that reflect the command structure of the task force. In other words, we have created a complete continuum of larger and smaller models and representations.

4. TIME-DEPENDENT BEHAVIOR IN MILITARY OPERATIONS

4.1 Plans instead of Physical Laws

In the theory of abstraction decomposition spaces two very distinct types of domains can be recognized, namely causal and intentional domains. The causal domain is a domain that can be described explicitly by physical laws, such as the thermodynamic laws that underlie the workings of a power plant. On the other hand, intentional domains are described by social laws such as conventions, standards, (in)formal rules of conduct, policies, concepts of operations, or doctrines. Consequently, there is a significant difference when we try to build an abstraction-decomposition space in these two types of domain.

The causal domain utilizes physical laws to describe the functioning of the system. These laws are mapped on the abstract and generalized functional layers and guide significant insight into the proper workings (or malfunctioning) of the system at these different levels of abstraction. Within the intentional military domain, an equivalent for these physical laws are the *plans* (the *intentions*) of the military commanders. The physical or chemical equilibrium operators are seeking to achieve in a electrical plant, for example, find their analogy in an adherence to the plan that the participating military units attempt to achieve. In contrast with physical systems, most military operations are dynamic: there is an intentional change from an initial (current) state to an end state (goal). The intentional *plans* of military operations state at what time units are supposed to be at a certain position or boundary line, which actions units should perform, and what outcomes are expected from these actions. As such they describe intermediate states of the military system that can be used as intermediate goals and as checking points to see whether everything is going fine. As with plants in the causal domain, where deviations from stable states indicate trouble, deviations from the plan in the military domain are indications something is going wrong and corrective action is necessary. Especially where friendly and hostile courses of action meet or intersect, problems can be expected and must be anticipated and reacted to.

4.2 Large State Changes

In our models, a distinction is made between two levels of dynamics in the tactical abstraction decomposition space. The higher dynamic level completely 'reshuffles' the abstraction decomposition space when we arrive in another phase in the military operation. The lower level dynamic keeps the abstraction decomposition space relatively stable given the deployment of a particular phase.

At the higher dynamic level the tactical abstraction-decomposition space itself is changed drastically because units take on other roles, units are swapped with other units, and aggregates are added, removed, or replaced. Such a reshuffle is the result of the fact that we enter a completely new phase in the overall military operation (Figure 2 shows an example consisting of four such phases). The higher dynamic level relate to the main states (e.g., ***Transit***, ***Deployment***). An amphibious operation offers a good example. Land units start to play a role in the operational theatre during the disembarkation. At the same time, surface units take on a lesser role or are perhaps replaced by other units that are better at providing land support.
The multi-purpose nature of human teams and military platforms plays a crucial role in the reconfigurability of hierarchies between stages in a military operation.

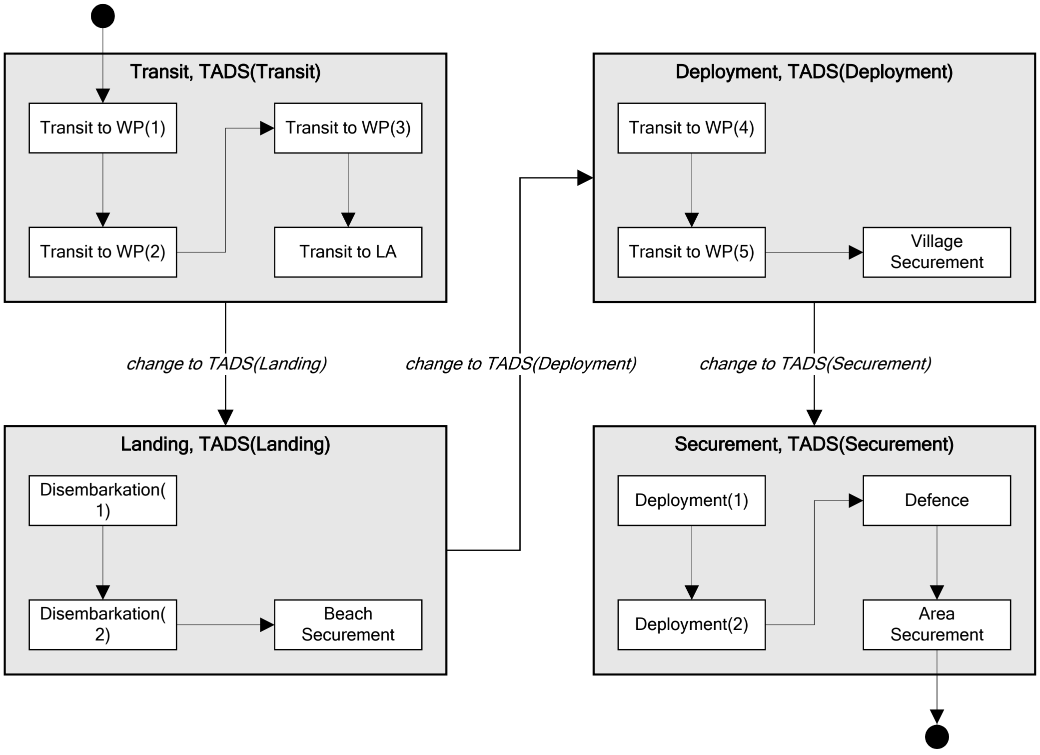

Figure 2 - State transition diagram of an operation with every major state (high dynamic level) described by a new abstraction-decomposition space, and at the lower dynamic level the tactical abstraction decomposition space is fairly stable. WP stands for waypoint, TADS for tactical abstraction decomposition space, and LA for landing area.

The lower dynamic level is where the contents of the tactical abstraction-decomposition space is relatively static but individual components are expected to move, engage, and be destroyed. A timeline is part of this descriptive level, marking the different positions that the units and aggregates must reach at certain times and the engagements that are planned in advance. Although changes in the ‘variables’ of the tactical abstraction-decomposition space are thus anticipated, especially when engagements are planned, the rough outlines in terms of participating units, unit roles, aggregate tasks and missions, are expected to remain more or less the same. Units could stall or disappear, be redrawn and replaced by reserve units but the overall picture should remain relatively stable. These are the internal states in Figure 2 (e.g., *Transit to way-point (WP)*(*n*), *Disembarkation*(*n*)). This static state is analogous to a proper functioning of an industrial plant, where components may fail, be replaced on the fly or where mass or energy flows may be rerouted through other parts of the system but where the overall functioning of the system remains the same for all purposes.

4.3 Comparing Observations with Plans

During operations, observations of the developing situation in the battlefield should be compared with the stated plans, expectations, and possible courses of actions. This incorporates both our own and the adversary’s plans. The best match should provide the people in the field with an idea of what is going on. Minor mismatches will always occur and should be accommodated in some way; large mismatches should initiate a re-evaluation of the situation and a statement of the alternative course of action that is likely happening at this moment.

This *association process* ought to clarify the current situation as observed by the participants in terms of what was expected beforehand. These expectations should therefore be couched in similar terms as the present tactical situation in order that they can be compared. Large deviations between observed and expected situation are an indication, first that the situation is difficult to interpret in terms of previously agreed courses of action, second that it can be misunderstood by some participants and that an alternative working model is badly needed to restore common understanding, and third that things do not go as planned and that corrective action is likely necessary.

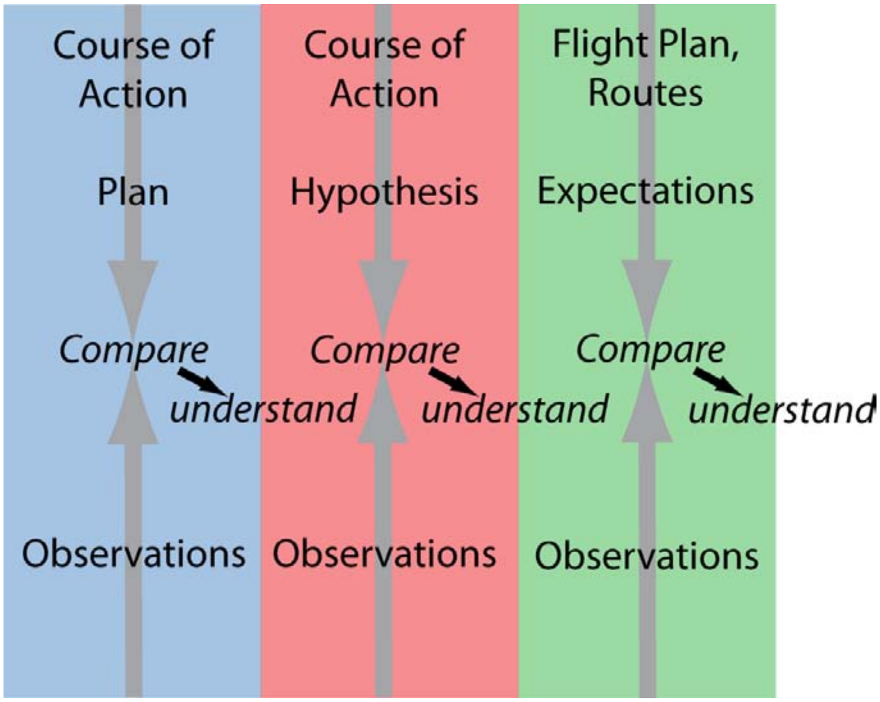

Figure 3 - Comparison of the expected situation and the observations leads to an understanding of what the object is doing.

In this view, the confirmation of a military purpose (a mission) is the correlation with a predefined course of action, either from ourselves or from the enemy. In the first case, a military pattern by blue forces that is unfolding matches (parts of) the stated plan; in the latter case, a military pattern by red forces matches (parts of) one or more courses of action that we have judged plausible for our adversary. As neutral (commercial) parties also stick to plans (flight plans, shipping plans), the same ideas with respect to matching expectations and observations can be applied to civilian entities. In such cases, entities that fail to conform to any conceivable plan may raise suspicion. For an overview see Figure 3.

5. MULTIPLE ABSTRACTION-DECOMPOSITION SPACES

Besides the fact that we have to deal with a plethora of non-physical (non-exact) laws from the military, economical, sociological, and other domains, we also have to deal with an abstraction-decomposition space where half or more of the information is unknown and can be only surmised from snippets of observations and information that happen to come our way. This includes the goals, considerations, plans and involved units of the adversary and also all neutral and/or civilian parties involved in the operation or present in the theatre. In the construction of the tactical picture, only estimates of the civilian, neutral, and adverse sides are available. Most of the sense-making work during the operation is performed on the estimation of the opposing force (OPFOR) and neutral side because the friendly forces (BLUEFOR) side is reasonably well known. A large part of the adverse abstraction-decomposition space is therefore conjectural, because it must be derived from intelligence and observations with possible large errors.

In order to stress the differences between the three sides, we have opted to construct distinct hierarchies. First, the BLUEFOR side is planned and controlled by the users/participants of the system. Second, the OPFOR side, which is predicted but certainly not controlled by these same users. The third side is the neutral side (green) consisting of civilian entities and military units of countries that are not involved in the conflict. The division between domains is only needed in so far as it can clarify the total tactical abstraction hierarchy: it shows that we have no control over the red and green side and that these parts are based on partial evidence, estimates, and judgments.

Conventional military abstraction-decomposition spaces are *mirror models*: both sides use the similar types of platforms for the same (physical/generalized) functions, the same abstract functions and the same functional purposes. The BLUEFOR and OPFOR abstraction-decomposition spaces therefore will look the same to a large degree.
In current military operations (peace-keeping, peace-enforcing, counter-insurgency) threats have an *asymmetric* character, with loose groups with less hierarchical levels on the adverse side and the abstraction-decomposition space for the adversary will therefore be more amorphous and less congruent with the blue one.
Because the OPFOR and the neutral abstraction decomposition spaces are not known, part of the work the human operators have to do involves *constructing* the non-blue abstraction decomposition spaces from the observations. At the lowest level this boils down to the building of the RMP or RAP; at higher levels this means expressing the ideas one has about the plans and intentions of the opponent.

6. INFORMATION-PROCESSING TASKS

A control task analysis (Vicente, 1999) yields a description of the processes involved in the system and which information results from these processes. Also, the control task analysis provides an indication on the sequence of tasks and their dependencies. The following sections provides a control task analysis with an emphasis on the single process of the *interpretation* of the current situation: the focus of this studies lies in the building of the situational picture and not with the decision making process. Interpreting the situation requires data that are gathered by an observational process. The observational process is highly automated aboard naval vessels so we do not pay much attention to that process in the present work.

The focus of our current work is on situation assessment, the interpretation of the tactical situation as it unfolds. Current situation assessment is about filling in attributes of observed tracks by means of processes like *classification* and *identification* (see e.g., Arciszewski, de Greef, van Delft, 2009). The most used attributes for these processes are identification response, sensor observations, and adherence to geographical areas like airways, sea lanes and fishing grounds. The classification and identification process take place in the lowest level of the abstraction hierarchy, the physical form level.
Situation assessment is extended with more single-platform processes like *capability assessment* and *role assessment* (providing information at the physical function level) and *mission assessment* at the generalized function level, both for individual platforms and

for aggregates. The latter process thus provides information for single platforms and for unit combinations that in unison perform more complex, combined missions.

Finally, at the abstract function level, the accomplishment of the operational goal can be checked in military, economical, sociological, psychological, etc. terms. In other words, whether the missions that are underway or have been completed have indeed contributed in the anticipated way to the accomplishment of the ultimate goal. This phase, however, will be omitted within this study and is key to future studies.

6.1 Identity & Classification Assessment

The classification process aims to establish the type of the platform (e.g. an F-16 or type 45 air defense destroyer) while the identification process determines its identity or allegiance in terms of it being friendly, neutral, or hostile. Both processes use physical attributes such as the current geographical positions, velocities and height profiles, Electronic Support Measures (ESM) data, Non-Cooperative Target Recognition Radar (NCTR) data such as high-resolution radar or laser profiling, identification data, behavior data such as adherence to predefined military or civilian sea lanes or airways or other areas.

6.2 Capability Assessment

The capability assessment process aims to comprehend (available) capabilities of a platform, which can be valuable in determining its opportunities. Capabilities can be deduced either from a definite classification of a platform (e.g., an A10 platform has very distinct ground support capabilities) or these must be further inferred from intelligence data. System support is easily conceivable using a predefined platform database.

6.3 Role Assessment

The sensors and weapons (the payload) a platform can carry (derived from general database information) determine the *possible roles* of a platform. Of course, the roles it can effectively carry out depend on the platform’s capabilities: its remaining fuel, state of its propulsion, crew state, and so on. Damage can limit a platform’s capabilities even if it has not been destroyed.

Further information about a platform’s role can be derived from its *behavior*: especially its trajectory, but other actions as well (e.g., its use of its sensors). Such behavioral information is already being used to establish the identity of a platform (for example, unidentified fast incoming platforms become suspect using the identification rules). Some automation can come to the aid of the users if possible roles are linked to capabilities and rules are stated that link certain behaviors with certain roles as well.

6.4 Mission Assessment

The mission assessment process aims to determine which role is being carried positioned in a spatial and temporal way. For example, a platform (or aggregate) might execute an air strike the moment the blue forces deploy their landing force. Therefore, we can match the expected position and associated actions as a function of time with its current position and behavior. For friendly objects, the degree of mission accomplishment can be estimated using the agreements or the differences with the plan. For instance, for a transit the difference in planned and reached position might or might not differ as a function of time. For more complex missions, measures of correlation can always be devised. For example, for an air defense mission the correlation measure can be the difference between expected losses and actual losses. In case of neutral and hostile objects, mission assessment combines possible roles with hypothesized expectations (specified as courses of action) and the combined behavior of groups or aggregates of platforms. These aggregates can be groups of multiple platforms showing similar behavior (attack formations) or multiple groups showing behavior that corresponds to certain military patterns (surveillance combined with one or more attack formations). Section 7 gives some examples of such considerations.

7. APPLICATION TO MILITARY SCENARIOS

In order to explain and assess the validity of the composed abstraction decomposition space a naval scenario was created and projected on the abstraction decomposition space. The scenario evolves around an amphibious landing at a coastal area located in the Northwest of Figure 4.

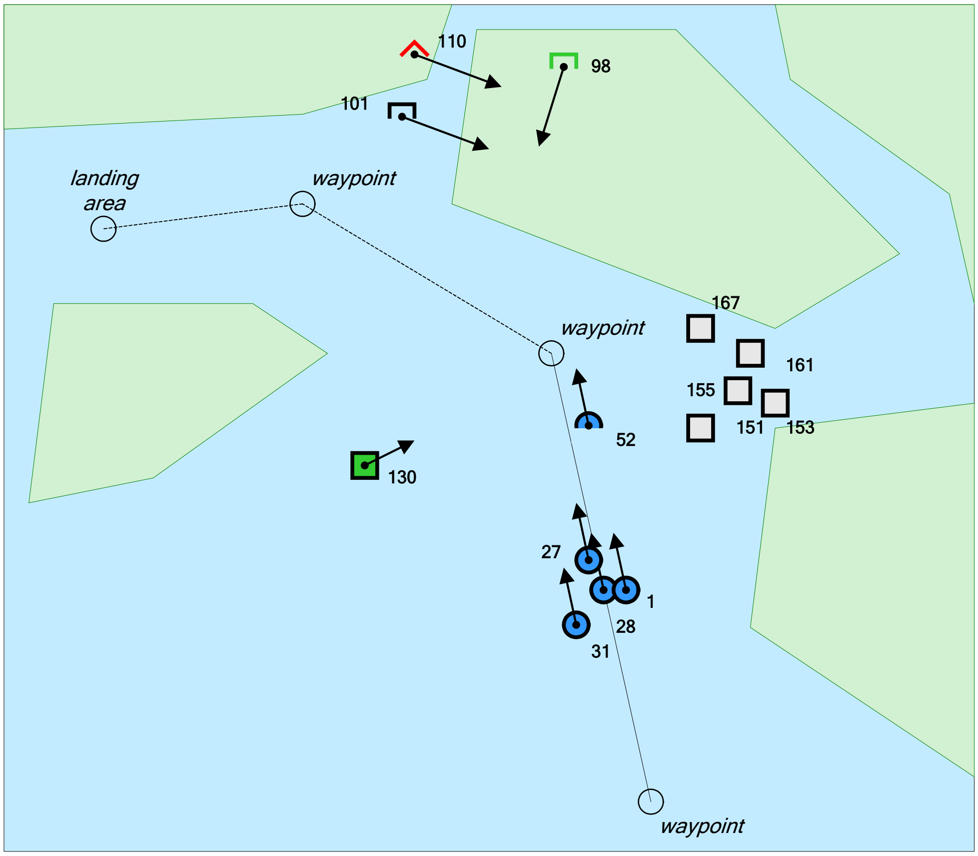

Figure 4 - The amphibious landing scenario with the relevant tracks and their associated velocity vectors.

The scenario describes a blue task force coming from the South East and sailing in a Northwestern direction towards the landing area where the landing platform dock (LPD) will disembark the troops for an amphibious landing. The LPD sails in a task group of four platforms.

A navy helicopter flies ahead with a reconnaissance mission while the three tracks around the LPD serve to perform air and surface defense. During the transit phase, a number of potential threats are observed. First, in the east a number of vessels lie still within striking distance of the planned transit route, potentially hiding a surface threat as indicated by intelligence information and political indicators. Second, an air track in the northeast has been identified as possibly hostile due to its trajectory and radar emissions.

The major challenge during the operation is to match observations of platforms with expectations expressed as allied plans, enemy courses of actions, and commercial flight and sailing plans. Prior to discussing the match between observations and expectations, the time dependent behavior (i.e., a plan) for the blue allied side is discussed.

7.1 Time dependent behavior

Section 4 discussed time dependent behavior in the military domain and shows that there are two different dynamics in an operation. The high dynamic abstraction decomposition space tells, from a planning perspective, the big steps that are planned in the operation. Figure 5 shows these big steps in the generalized function level starting with the transit phase at t=1 and ending with the area securement phase starting at t=4. On the other hand, the lower level dynamics are displayed in lower part of Figure 5 where, for the transit phase, some of the attributes of the platforms change over time.

Plans can be seen as s series of different abstraction decomposition spaces connected over time (see Figure 5). The differences in abstraction decomposition spaces describe at the lower level where every platform has to be at what time or, and at a higher level of abstraction and decomposition, which roles are executed at what time. A different abstraction decomposition space is needed when the situation at other times can no longer be interpolated or extrapolated from other points in the description.

While Figure 5 shows the ‘blue’ planned time behavior, time-dependent expectations can be hypothesized for the ‘red’ side as well. Such courses of action describe expected threats that can appear at specific time intervals and from general or specific directions. The challenge is to match these hypothesized threats with observations (and to create new hypotheses if no expectations match with the observations).

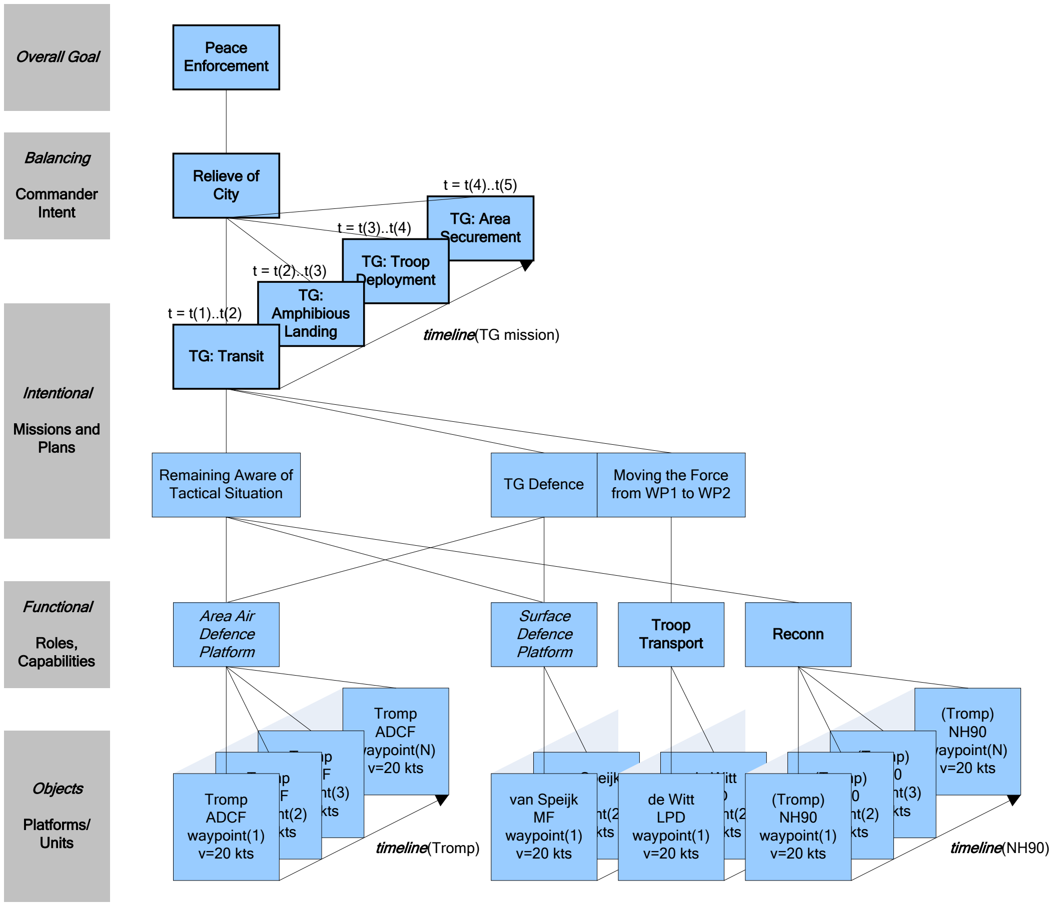

Figure 5 - The Plan for the Transit Mission BLUEFOR where each stage of the operation (e.g., transit) has a different instantiation of the tactical abstraction hierarchy.

7.2 Matching of Hypotheses with Observations

As stated previously, the major challenge in warfare is to match observational data of platforms with expectations expressed as hypotheses. The tactical abstraction hierarchies consist of two layers, namely the expected courses-of-action layer and the actual observation layer (Figure 6).

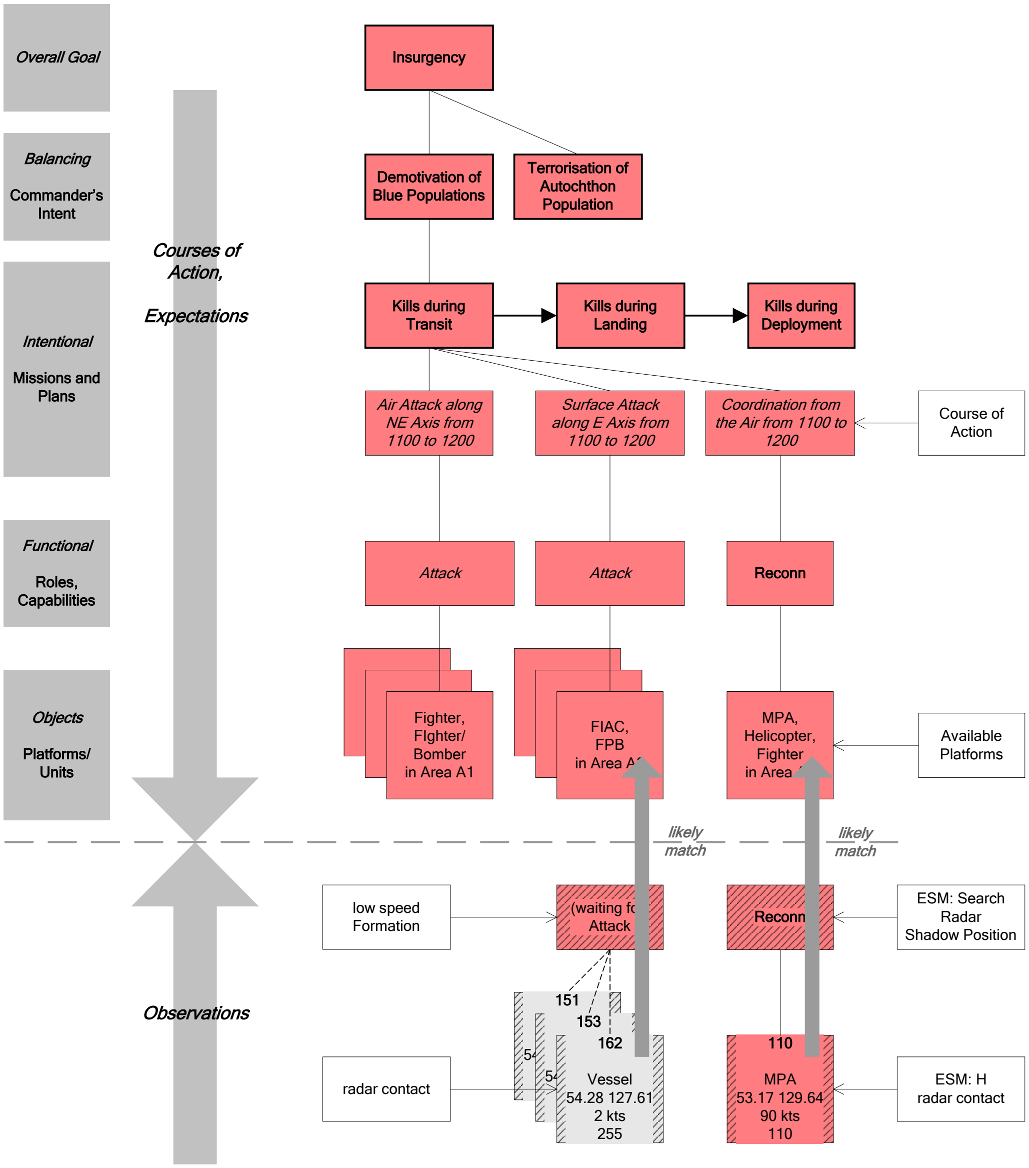

Figure 6 - Matching the red side expected courses of action with the actual situation is a critical job in command and control.

Objects in the two layers will be associated with each other, linking the observations to expectations. These associations are preferably one-on-one (meaning we can identify one observed platform or unit with an expected one) or, worse, many-to-many matches where multiple interpretations of the current situation are possible in light of the predictions. Figure 6 expresses a number of hypotheses for the enemy side. It is surmised that the other side’s intention is to demotivate the blue side by engaging the blue task group either during transit, landing, or subsequent deployment. During the transit, the enemy could attack the blue task group by means of an air attack or a surface attack, eliminating or incapacitating a part of the task group. The hypothesized surface attack from the east requires a number of fast patrol boats (FPB) or fast inshore attack craft (FIAC). It is one of the jobs of the operator to try to match this expectancy with any observations of objects and their behavior. Or if no match is possible try to synthesize a new mission that explains the observations.

During the transit phase, several of such potential matches are observed. In the east a number of vessels lie still within striking distance of the planned transit route. These could be either fishing boats plying the rich fishing grounds close to the shore, or they could be the attack force waiting for the right moment to strike. The attack force could also be hiding among some fishing boats. Anyway, there is enough reason to pay close attention to this group of small vessels. Likewise, the aircraft in the Northeast closely matches the predicted reconnaissance aircraft and thus increases the possibility of an imminent attack and of the match between observed vessels and FPB lying in wait.

8. DISCUSSION

Current COPs are too restrictive in scope and fail to support possible projections or give indications on how observed platforms match planned or expected movements or actions. Recent joint exercises have shown shortcomings in current COPs. Among other things there is a lack of information such as: (a) unit capabilities and status information; (b) support for planning and monitoring the operation execution through a better representation of commander's intent; and, (c) combat support information and predictions about future status.

We feel that the tactical information present in current common operational pictures is too much focused on tracks (platforms) to allow a good tactical understanding and coordination. We believe that additional layers of abstraction is needed to achieve a better understanding of the situation, in turn leading to better and faster decision making.

The starting point for this information extension has been the abstraction-decomposition space as proposed by Rasmussen (1985) that models the work environment (or the work domain) for socio-technical systems. The abstraction-decomposition space is a reflection of the mental models constructed by people in order to comprehend the (mal)functioning of a large system.

In this study we have described an abstraction-decomposition space for military operations. The *overall goal level* describes the overall goal(s) and purpose(s) of the entire operation. Constraints on these goals can originate in international law, political considerations, rules of engagement, or other sources. The next level down describes the underlying laws and principles that govern the military operation, including military doctrine and concepts of operations and the principles of the application of military force. Economical, political, sociological, anthropological, and psychological causes and effects must be added to this description, especially for operations other than war. At this level the commander's intent is formulated. The *mission level* is where the commander's intent is translated into plans and missions for groups of units and, at the individual level, for platforms. The level also describes the possible courses of action of the adversary. The capabilities and limitations of the physical platforms and units and the functions they can execute or are actually executing are expressed at the *functional level*. The functions are executed in order to achieve the higher-order goals of the missions expressed at the intentional level. The *physical object level* finally describes the location, condition, and appearance of the physical units and platforms.

Using a scenario, we have shown that information pertinent to military operations and tactical situations can be expressed or represented in this abstraction-decomposition model in a coherent fashion. Such information includes predefined expectations as laid down in BLUEFOR plans, possible OPFOR courses of action, civilian flight plans/ seafaring schedules, and observations. In some cases it will prove possible to match observations and expectations, leading to a better understanding of the situation. Where observations cannot be directly linked to expected occurrences, the abstraction hierarchy can be used to summarize all available information about the track, in turn leading to a better insight into the intentions of the observed entity.

We expect that by making all this information accessible to the users of the COP, omissions and errors will be caught earlier and with more ease so that errors with the interpretation of the situation will be made less frequently. For easy cases, the automation could be programmed to reach the same conclusions as humans, so that such cases can be counterchecked by the automation. In addition, automation would leave the human more time to investigate the more difficult cases, improving the resolution of these cases in turn.

The concept does have its risks. First of all, having to enter higher-level assumptions and conclusions into the system could increase the workload of the users significantly. This is hopefully offset by (partial) automation and the benefits of a better understanding of the situation by the command teams. Second, there is the risk of a combinatorial explosion of hypotheses attempting to explain the observations in an ambiguous situation. Automation is especially prone to such combinatorial excesses. This can probably be checked by introducing generic classes of commercial and military intents and by prohibiting large numbers of solutions when solid evidence is lacking. Workarounds must be provided in the automation, however, to avoid such combinatorial problems. A similar problem is introduced by the fact that the system (the theatre of operations) is open-ended: there are no boundaries to what is included in the situation. Since a complete description of ‘everything’ that can occur in the theatre is impossible, good generic fall-back descriptions of entities and activities must be provided, as well as ‘catch-all’ boxes that can serve as hooks for entities that elude a good classification (similar to the ‘unknown’ identity of the identification process). Finally, the approach introduces the risk of *biases*. For example, users of the system could narrow down their search for solutions to only those that are explicitly available. Or they could accept possible solutions from the automation too readily. Shoe-horning observations into a small number of predefined cases should be avoided as much as possible.

In the light of these risks, the next step in the process will be an evaluation of the ideas and concepts with representatives from the Netherlands defense forces. For that purpose we will start with simple, interactive demonstration systems to let them acquaint themselves with the concepts and criticize the ideas. Incorporating these criticisms, we will follow this up with the construction of an interactive simulation environment including displays and display elements that can present all the information available in the model, where the concepts can be evaluated in practice and where the advantages and disadvantages of the use of these ideas can be quantified.

ACKNOWLEDGMENTS

The work described in this study was supported by the MOD-NL DR&D organization under the program ‘smart operations’ (V929).

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