A Framework for Analysis of Decision Processes in Teams

Hans E. Keus
TNO Physics and Electronics Laboratory
The Hague
The Netherlands

Abstract

For the analysis and optimisation of Decision Processes of small teams (2-20 persons) as well as individual decision makers an Analysis Framework is under development within Task Group 006 (Modelling of Organisations and Decision Architectures) of the NATO RTO/IST Panel.
A team from 6 nations, The Netherlands, France, The United States, Norway, the Czech Republic and Canada are developing this framework which is comprised of models on decision processes and the functioning of teams, a analysis area model for analysis and a procedural description on how to apply the modelling framework to specific problem domains. The model on decision processes is based upon some basic axioms on human decision making. The model on team functioning identifies elementary behavioural functions related to teams and an integration model is proposed between team functions and human decision making. The total analysis and optimisation framework also includes formal description techniques with which the modelling and analysis results can be captured and described and a set of measures of merit with which decision making and team functioning can be measured.
This paper describes the applicable problems domains and the current state of development of the Analysis Framework.

1. Introduction

The concepts presented in this paper reflect the current state of work of the international NATO IST TG006[1] Task Group on Modelling of Organisation and Decision Making. TG006 aims to propose a methodology for describing and analysing organisations with respect to decision processes, taking into account human factors. This document takes a first step at developing such a methodology. It introduces a set of models and tools, enclosed in a framework structure that can be applied to systematically assess the structure and performance of an organisation. It takes into account various aspects of team decision making. In the end it aims to provide a way to develop recommendations on how to improve decision making in an organisation by means of additional support tools or organisational adjustments.

[1] The author wishes to thank the members of the TG006 for their support in developing this framework and also G. Klein, M. Endsley and R. Rousseau for their constructive review of an earlier version of this document.

1.1 Terms and Concepts

Because decision making can only be described in fairly abstract terms, we need to avoid confusion of terminology. Generally, the term 'decision making' is used as an *umbrella term* (Klein, 1992) for all activities involved in choosing one solution in the total solution space of a problem. We also adopt this stance, but we are going to diverge a little from the standard terminology from here on. We would like to introduce a distinction between *decision making, decision process* and *option selection (or decide on action).* If we talk about decision making, we adopt the general definition:

decision making
Decision making refers to the act of judging, evaluating, choosing, selecting, picking, and resolving options. Decision making concerns known alternatives, goals and missions.
'Decision making' thus refers to the entire act in a single term. If we describe decision making as an act that consists of several sub-processes, then we refer to it as a *decision process.* We define a decision process as follows:

decision process
The decision process contains a sequence of activities that as a whole constitute decision making. These activities include such activities as observing the environment, situational awareness, decide on action. A *decision process model* therefore refers to an abstract representation of all the processes that are part of decision making.

When decision making is viewed as a process, then option selection, the actual selection of the decision, is a *part* of the entire decision process. There are other processes that are contained within the decision process, but which are not part of the actual option selection. These are nevertheless necessary prerequisites for option selection. For instance, information or data gathering is such an elementary process. Often, the term *option selection* is taken be synonymous with decision making. We state that *option selection* is a *sub-process* of the decision process. This concurs with what Klein and others (Orasanu, 1993) have observed in research.

2. Goals and Context

2.1 TG006 Goals

The IST-TG006 project aims to study decision processes within complex and demanding military operations. Research on decision making involves identifying the specific characteristics of the environments where decision making takes place, modelling the organisational structure of decision process and particularly, studying the human factors that are involved in decision making. The assumption is that by studying decision making organisations and modelling the decision making process we can not only assist organisations in making better decisions, but also contribute to develop better training and support tools.

This general statement of work may quickly lead to an fairly academic exercise if we do not concentrate on establishing beforehand how the knowledge gained from this study is going to be applied. Therefore the results gained from this research are applied to several case studies. These examples of military decision making will enable us to evaluate and refine our modelling efforts.

2.2 Application area of TG006

Our assumption is that decisions are always made within the context of fulfilling a specific task. Since the characteristics of a task (or rather: goal) directs the decision processes, it is essential that we specify on which kinds of tasks this research is aimed at. Two criteria have been used in selecting the application areas of this TG006 work:

- *Small teams*

We restrict ourselves to small teams, i.e. ranging from a single person to a team of about twenty members. Larger organisations are harder to study, because they usually involve more than one particular decision making processes which are more or less independent and take place at different levels. In general one could assume that the total decision making in these larger organisations can be decomposed into smaller ones for which the results of our study should be applicable again. However we will not make that explicit assumption and only restrict ourselves to small teams.

- *Fairly structured environments*

A peace-establishing process (e.g. the middle East) is a good example of a less structured problem domain. It involves a highly complex and unclear problem domain (what are the factors that contribute to the war) *and* solution space (what can we do about it?). Due to these factors these types of scenario's to are hard to characterise. We have not aimed our results to be applicable in such a domain. Initially we restrict our modelling activities to fairly structured problem domains in order to get a grip on contributing factors and issues that affect decision making performance. Later on we may consider the applicability in other problem domains. C2 tasks, like threat evaluation of radar contacts, is a complex procedure as well, but has a relatively small solution space (if the contact is a threat we may need to engage it, if it is not we do not need to engage it). This makes C2 tasks more suitable for our purposes.

Three decision making scenarios (case-studies) have been selected which meet these requirements:
1. *Ship-based C2,*
2. *Logistics*
3. *Weather forecasting.*

These case-studies represent specific organisational structures, domains and goals. Each of the cases will have its own characteristics in terms of qualitative identifiers (measures that signify how well a task has been performed). Within the TG006 work these three case studies will be used to develop, test and refine the Analysis Framework. It should be mentioned that one

important pragmatic reason of choosing these cases was because they were available through the personal expertise of the TG006 members.

2.3 Intentions of this paper

This paper aims to provide insight in the current state of the Analysis Framework as it is developed within TG006. It describes the most important concepts and models and it ends with a summary of our current research activities to enhance and complete the framework. It is by no means a finished product and it will be fine tuned during the last year of the TG006 study year (ending mid 2003).

3. Decision Modelling Framework

3.1 General Approach

In figure 3.1 the general approach we have used is shown. We will use this drawing to explain our approach to the analysis of team decision making processes.

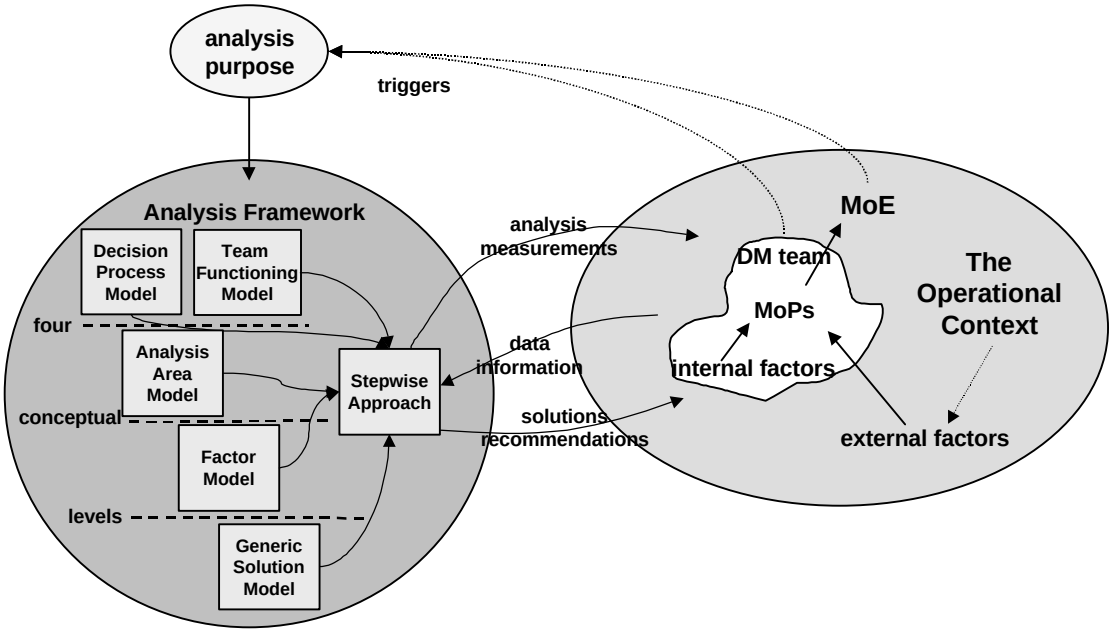

Figure 3.1 The General Approach.

First of all we have the decision making team (DMT) which operates in a certain operational context which is part of the real world. We will assume this DMT has a specific goal (or mission) to fulfil. The overall performance of the DMT is expressed by a measure of effectiveness (MoE). Inside the team we have measures of performance (MoP) with respect to different aspects of team functioning and decision making. The MoPs result in the observable and measurable MoE on the 'outside' of the team. The need for a decision performance analysis originates from discrepancies between the desired MoE or the internal MoPs and the

actual observed ones an. Of course there can be other reasons for analysing a teams decision making process, like for instance a desire to reduce human involvement in the decision making process (manning reduction is a well-known reason in the maritime context). For our purposes it is important we have a well defined purpose of the analysis of the DMT since this helps to direct the analysis process.

The analysis takes place using the Analysis Framework (AF) we developed. Conceptually the AF consist of a number of models. These are the models as shown in Figure 3.1: The Decision Process model, the Team Functioning Model, the Analysis Area Model, the Factor Model and the Generic Solution Model. These models will be explained in this paper.

One of the elements of the AF is a stepwise approach which directs the analysis process how to use the concepts described in the models. From this stepwise approach analyses and measurements are conducted of the DMT and its environment, here denoted by the operational context. This is shown in Figure 3.1 as the analysis and measurements arrow. This step provides the data and information required to study MoPs of the DMT, to analyse them and to formulate solutions and recommendations for the team and if applicable for the operational context too. Linked to the essential models are some more specialised models and formal description techniques we will refer to in the paper. Figure 3.1 illustrates the general approach and places the concepts of the analysis framework in a context.

3.2 Four Conceptual Layers

We distinguish four levels of abstraction in the analysis framework (see Figure 3.1).

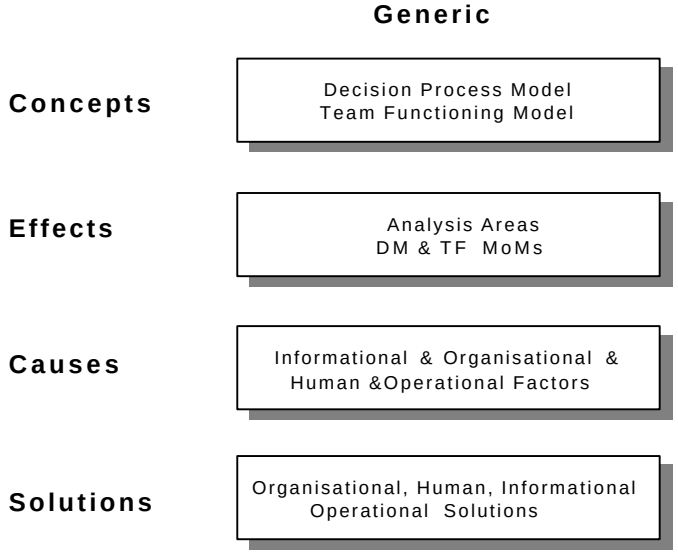

Figure 3.1: The conceptual levels in the analysis framework.

The first level contains the generic concepts we use in our framework. Basically these are descriptions of our area of attention: decision processes of organisations and teams. This is why use two essential models here: the decision process model and the team functioning

model. They provide us with an understanding of what decision making is and what team specific functions are.
The *decision process model* describes the basic steps that are made in decision making. There are two basic categories of decision making models (Lipshitz, 1993): *process models* and *typological models.* The former describes the order of processes in which decisions are made (like Klein's model (Klein, 1993), whereas the latter classifies decision processes into types and describes the situation these processes are used in (like the Rasmussen model of skill-, rule and knowledge based behaviour (Rasmussen, 1983). For our purposes we use a process model, because we need to be able to pinpoint the specific events in the decision process at which improvement can be achieved.

The team functioning model contains specific team functions that occur in team decision making. Together the decision process model and the team functioning model make up the *team decision process model*. These models are described in more detail in the next section.

The effect level deals with the observable characteristics of how well the DMT functions. Here we have the measures of performance of specific team decision makings aspects and of the overall measure of effectiveness of the team. We call these the Measures of Merit (MoM). They are characteristics which can be measured and analysed. Therefore this level also contains specific analysis methods related to various aspects of decision making. Central to this level is the *analysis area model* which contains the areas of interest to study decision processes. The MoMs for decision making and team functioning are all related to one or more of these areas of attention. Since these models are generic, they only contain measures that are ubiquitous, and independent for specific application domains. These generic measures are intended to be applicable to all scenarios as described in section 2.2.

The causes level contains factors (causes) which influence the decision making process, and is divided into organisational, human, informational and operational factors. Each of these factors can contribute to degradation (or, for that matter, improvement) of the decision making process.

The solutions level, finally, contains generic designs or measures for organisational and informational improvements and a generic architecture for decision support tools.

The following sections describe the various sub-models included in the framework, starting with the generic level.

4. The Conceptual Level

4.1 The Decision Process Model

4.1.1 Premises

One of the essential models in the framework is the decision process model. At the basis of the DPM there are four concepts which can be traced back to the OODA loop (Observe-Orient-

Decide-Act) introduced by Boyd. The OODA theory was specifically developed for pilots in combat aircraft where fast decision making is essential for success. We will not copy the plain sequence of the four tasks that Boyd has introduced but we use these tasks and add to them other essential elements in the process of decision making. The DPM is centered around the following basic premises:

1) Our first premise is that in order to decide on any possible action the decision maker needs three basic ingredients:
   a) skills;
   b) information;
   c) and understanding.

   He should have an understanding of the situation he is in. In order to achieve that understanding information is required. This can be external data (through the process of data gathering) or it can be internal information already available to the decision makers or the team (such as the knowledge and experience of the team members). The skills applied in order to decide on a possible course of action result an action. In principle this is just an acknowledgement of the four essential tasks identified by Boyd enriched with the capabilities essential in decision making: skills, experience.

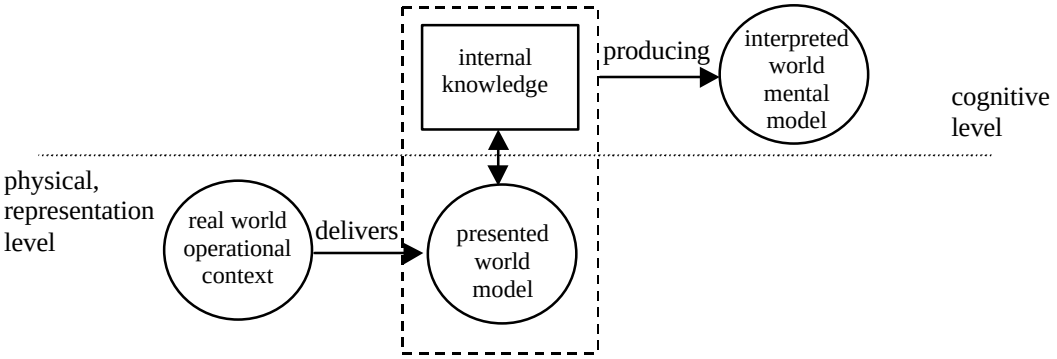

Figure 4.1 The world models.

2) The second premise is very much related to the first one and is related to perception. It is concerned with the fact that information and understanding that information is crucial in decision making. In order to reason about events, data, information and to understand it we assume that there are three essential different 'world' representations relevant to the process of decision making.
   a) The first is *the real world* itself, or more precise the actual *operational context* which is relevant to the team and in which events take place.
   b) The second is the presentation of (or parts of) the operational context for the benefit of the decision makers: the *presented world or model*. Usually this is graphical, audio, video or other data and information.
   c) The third is the *internal model* or *mental model* in the minds of the decision makers. This is the interpretation of the presented model using internal knowledge.

   Especially when dealing with team decision making differences between mental models of individual decision makers can be the cause of wrong decision making. Although it is not

required that the mental models must be equal but they should at least not be conflicting. In Figure 4.1 the three 'world' models are shown.

3) The third premise is that decision making is not a one directional process. It is comprised of continuous switching between states of information gathering, information interpretation and assessment of this information in order to make the actual decision. In the process of moving from one state to the other inferencing, deduction, pattern recognition and a lot of other cognitive processes may play an important role. Our purpose is not to specify and explain the cognitive processes involved but to allow referencing to them from our model. There are already specific models made by others which already address these processes.

4.1.2 The DPM

When we combined the elements contained in each of the three axioms we can construct the Decision Process Model as shown in Figure 4.1.

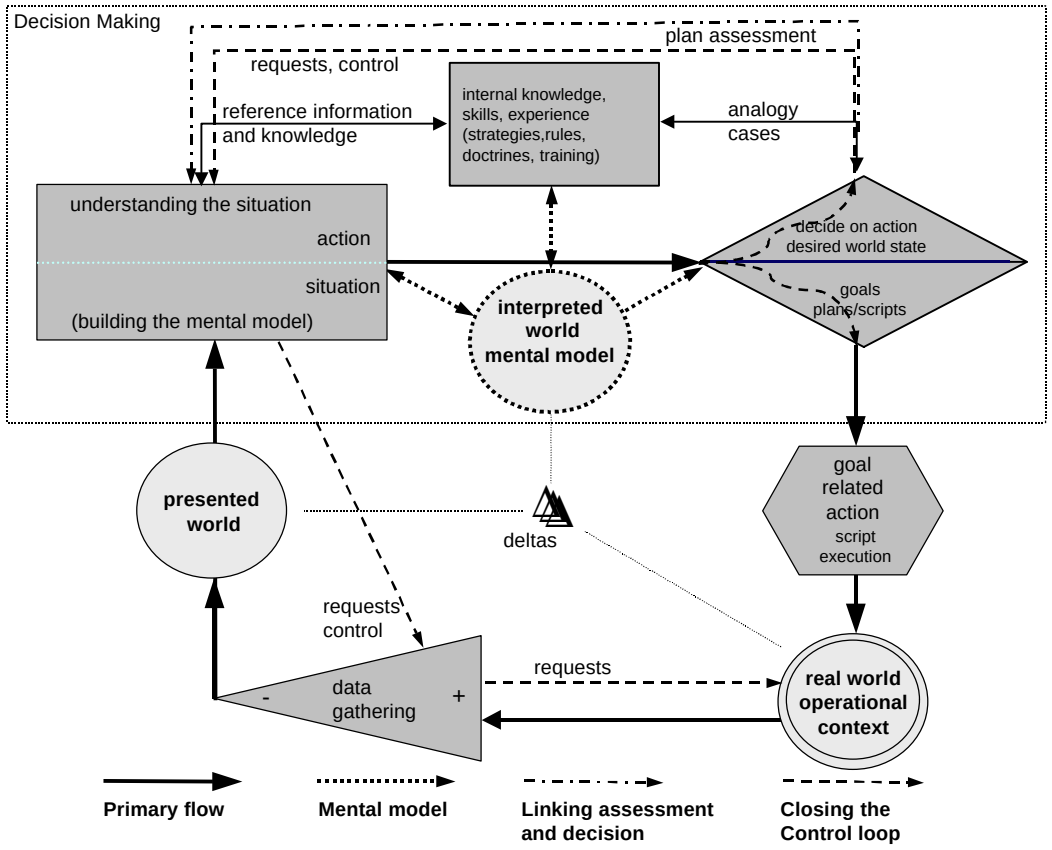

Figure 4.1 The Decision Process Model

Figure 4.1 is a high level representation of the decision making process. There are two reasons for the high level of abstraction of the model.

- *Using a general model allows for problem-specific detailing*

Since decision making strategies can differ significantly for different problem domains it is impossible to capture all types of procedural decision making itself in one model. Therefore we aim at a level of detail for *general* framework which is general enough for many problem domains.

- *The model is intended to identify the major processes involved in decision making*

This model is an integral part of our proposed framework. Its main purpose is to identify the major elements of the decision process. This enables the analysis process to trace all relevant factors which influence the quality of the decision making process. It is not meant to explain the actual decision making itself. If necessary specialised models can be used to study those aspects (like the specific available models of Klein, Rasmussen, Endsley, Noble, Wearn, etc.).

4.1.3 Explanation of the DPM

The process which provides the presented world or model we have called *data gathering*. This usually is a process which collects, correlated, fuses and presents data. The data can come from observation devices but also from information systems or human observation.
Observations of the environment lead to a *presented world*, i.e. a reflection of the way the operational context is seen by all information sources. This presented world together with internal knowledge, skill, experience provides the basis for creating a *situational awareness*. This process we have called *understanding the situation*.
It consist of several sub-processes and states. One of the main difficulties operations encounter in creating situation awareness is a lack of information and lack of confidence. By actively gathering additional information one can strive to resolve this shortage. The *request* connection serves as a placeholder for all activities the decision maker initiates to gather information that supports his situation awareness and increases his level of confidence. The *control* connection stops, starts and controls the information gathering process. This connection is necessary for e.g. filtering of information. The *request* connection from the gathering procedure to the world represents the actual collecting of the information.

Having a situational awareness essentially means that the decision maker has *interpreted* the world in terms of tactical scenario's, assumptions about what is happening and projections of causes of action that are likely to happen. Since it is the operator's understanding of the situation this interpretation may be subject to errors. Therefore the operator may try to validate his situational awareness by gathering more information (i.e. by using the feedback loop to the information gathering process), or might just use his present understanding for the actual decide-on-action part.

The *decide-on-action process* consists of several key-elements, which deal with selecting an option. At this stage the operator *has* an interpretation of the situation. Aside from this situational awareness, the operator has fixed mission goals (protect high value unit, defend own

ship, protect crew, etc..). Which strategy is used to chose a particular decision (e.g. select an option or action) depends on the situation, the preference of the operator and the type of the problem and rules of engagements in military situations. In general the decision process is guided by mission goals, plans and risk assessments. When evaluating a goal related action the operator will aim to validate his plan for action within his existing situation awareness or strive to match the elements of his plan with observations from the actual world (by calling upon the information gathering process). For this reason a direct coupling exists in the model between the situation awareness process and the decide-on-action process. Finally, the goal related action or script execution resulting from the selected decision has a certain impact on the 'real world', which in turn can be observed by means of the information gathering process.

It is well established that the process of making decisions is not a single sequential process, but rather a continuing cycle of processes, including evaluation, verification, matching and feedback procedures. Even though the model above suggests that the processes involved in decision making are executed sequentially, these processes are more likely to be executed concurrently and recursively. One of the features of our model to capture this kind of decision making strategy is the inclusion of the information requests and the control loops.

4.1.4 Relation to other Decision Process Models

The decision process model (Figure 4.1) is a generic representation. Essentially, it can be replaced by any other model that represents decision making, be it either more detailed, abstract or even having a fundamentally different take on decision making, as long as it is in agreement with the other models in the framework. The presented decision process model is designed to cover the majority of decision process models. If the use of a more detailed or specific model is needed this can be derived from or projected to our model. Within TG006 an analysis has been performed in which we derived more specific models from our DPM.

4.2 Team Functioning

The decision process model as described in section 4.1 is a model of decision making irrespective of the number of (human) decision makers. It focuses only on identifying and relating the major elements of a decision making process. Since decision making within teams differs from individual decision making another model is present in our framework, the *team functioning model,* which identifies the specific characteristics of decision making which are involved when taking a team or an organisation into account. We define a team as follows:

A team is an organised and structured set of interacting entities, which carry out decision making processes under constraints, in order to achieve a common goal.

The most elementary characteristics with respect to team functioning are represented in Figure 4.1. These characteristics are elementary elements of the functioning of a team. We can recognise these elements in the characterisation of a team as noted by Dyer and Morgan (Dyer, 1984, Morgan, 1986):

- a team is a set of two or more individuals;
- a team has more than one information source;

- there is interdependence and co-ordination among members;
- there is adaptive management of internal resources;
- team members share common valued goals;
- within a team defined roles and responsibilities exist;
- task relevant knowledge is available.

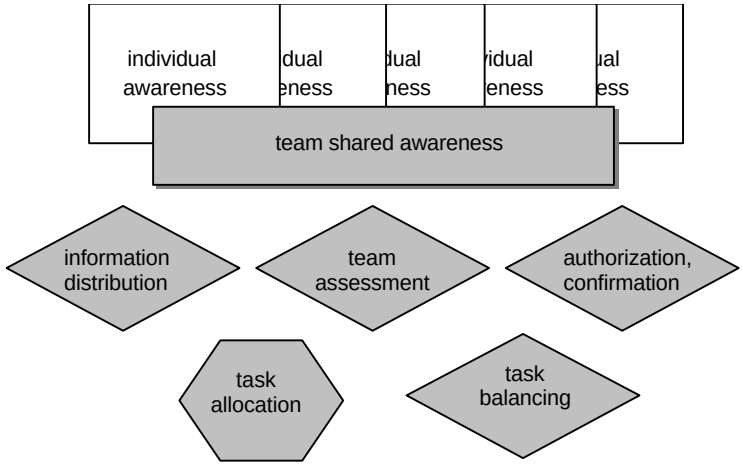

Figure 4.1: Elementary Team Functioning Characteristics

All these specifications of a team reoccur in the following elements of team functioning:

- *Shared awareness*

Empirical data suggests (Cannon-Bowers, 1993) that teams employ a *shared situational awareness*. These 'shared mental models' refer to organised knowledge shared by team members, which can be used to create a context within which decisions can be made (Orasanu, 1990). Another well-suited description for this concept is '*team mind*' (Klein and Thorsden, 1989). As can be seen in the model (Figure 4.1) shared awareness is a cross-section of the interpretations of the perceived world (mental model) the team-members have. This set of 'common' interpretation needs frequent verification and is controlled by the team assessment procedure.

- *Team assessment*

Team members are interdependent and work in a co-ordinated fashion. This implies that all team members must frequently validate whether their individual awareness is still compatible with those of the other team members. Failing to do so would render the decision making process unreliable, because of differences in interpretation of their decision making environment and would consequently lead to errors. The team assessment also involves as kind of self appraisal of the team functioning and of related individual functioning. This process of self-assessment is captured in the *team assessment process*, which may, if required, result in information redistribution or task reallocation, in order to establish a better shared awareness and workload in the team. This concept is also referred to as *team maintenance*.

- *Task allocation and balancing*

Given the initial task structure, members have been allocated specific tasks. Due to excessive workload or performance problems tasks can be reallocated to different team-members if necessary. The dynamic allocation of tasks is captured in a *task allocation and balancing* procedure. This procedure (re-)allocates active tasks among the team members in such a way that workload is better distributed. This implies that certain decision making processes should be able to be reallocated. This demands a certain level of adaptation in the execution of tasks of the individual team members.

- *Information distribution*

Since there is more than one information source within a team and different team members may require different information for their specific tasks information distribution is an essential characteristic of team functioning. This task can be performed by human actors as well as by an information management system or by both. Inadequate information distribution is a cause of many sub-optimal functioning of teams.

- *Confirmation and authorisation*

Because of organisational structures, decisions made by team members often have to be confirmed and authorised by some of the other team members (or by external decision makers in which case it falls outside the scope of the team). The process of confirmation and authorisation is usually an integral part of military team decision making and influences decision making performance. It attributes to the overall quality of decisions made, because of constant verification and checking. It may however disrupt decision making if the organisational structure does not allow for timely confirmation or did not take into account to create sufficient shared awareness and common information.

4.2.1 A DPM Based Team Decision Process model

When we combine the team functioning characteristics of Figure 4.1 with the generic decision process model of Figure 4.1 we get a team decision process model. The team decision process model is very much like the decision process model, except that it incorporates the team functioning processes we introduced in the previous section. These processes, in fact, enable the team to function as a decision making team instead of a set of independent decision makers.

In Figure 4.1 we can identify all the elementary team functioning characteristics although for simplicity we have combined task allocation and task balancing in one single process. We also encounter an important extra (internal) information flow between individual actions and information distributions.

Each team member has his own specific set of goals related to his task within the team and which either contributes to the overall mission goal or to internal team goals. The internal team goals usually are meant to provide other team members with processed information.

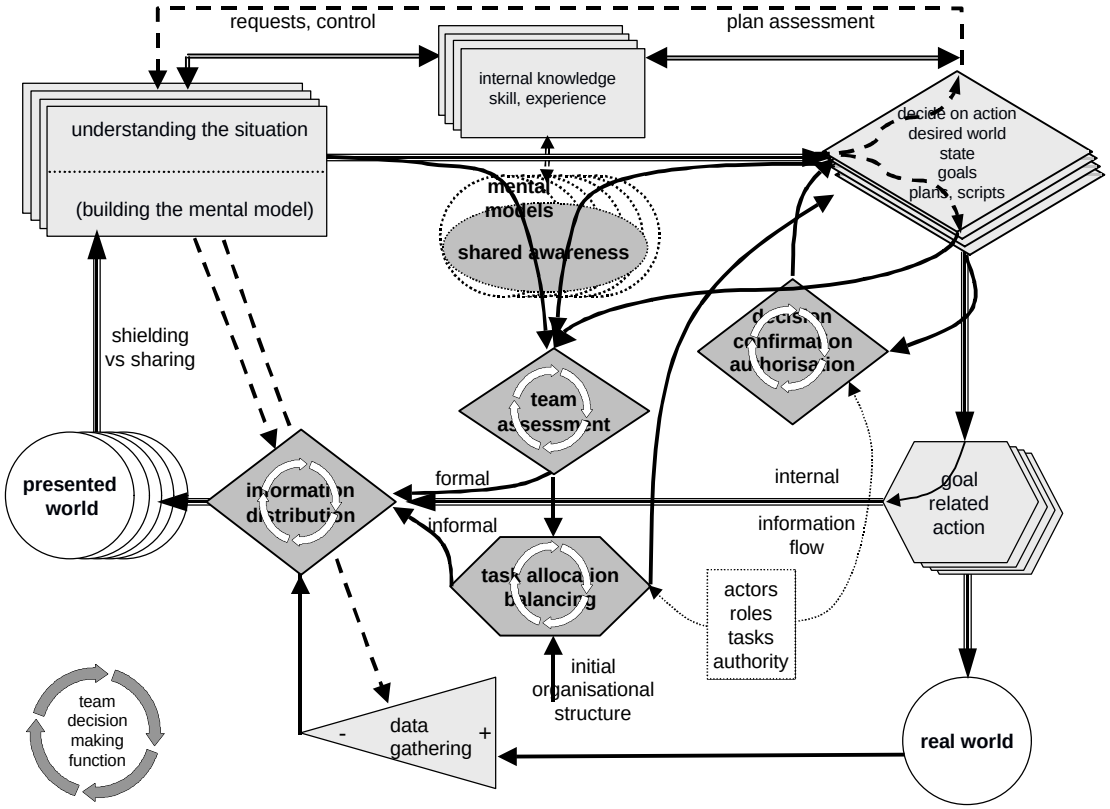

Figure 4.1: Team Decision Process Model

Furthermore, the main elements of the generic decision process model are *multiplied in the team model.* Each team member is assumed to have their own presented world, situational awareness, interpreted world and decision making processes and consequent actions. In the model these duplicates are denoted by multiple instances of that particular element.

4.2.2 Other Research on Team Decision Making

In section 4.1.4, we stated that the decision process models in the framework can be specialised if required or preferred. The same holds for the team decision process model. The model provided in Figure 4.1 may be extended or detailed by any model which models team decision making in more detail.

We have studied the relations between the TDM and other models and found that mappings can be made between the TDM and the other models. For the length limitations of this paper we will not further describe this.

5. The Effect Level

In the previous section we described the main models on decision processes as part of the conceptual level. The next step is to describe the second level in our framework model: *the*

effect level. On this level we deal with how well the decision process is carried out and with the specific performance indicators of the decision process.
We have identified two major concepts on this level: the analysis areas of the decision process and the measures of merit. We will discuss the analysis area model first.

5.1.1 The Analysis Area Model

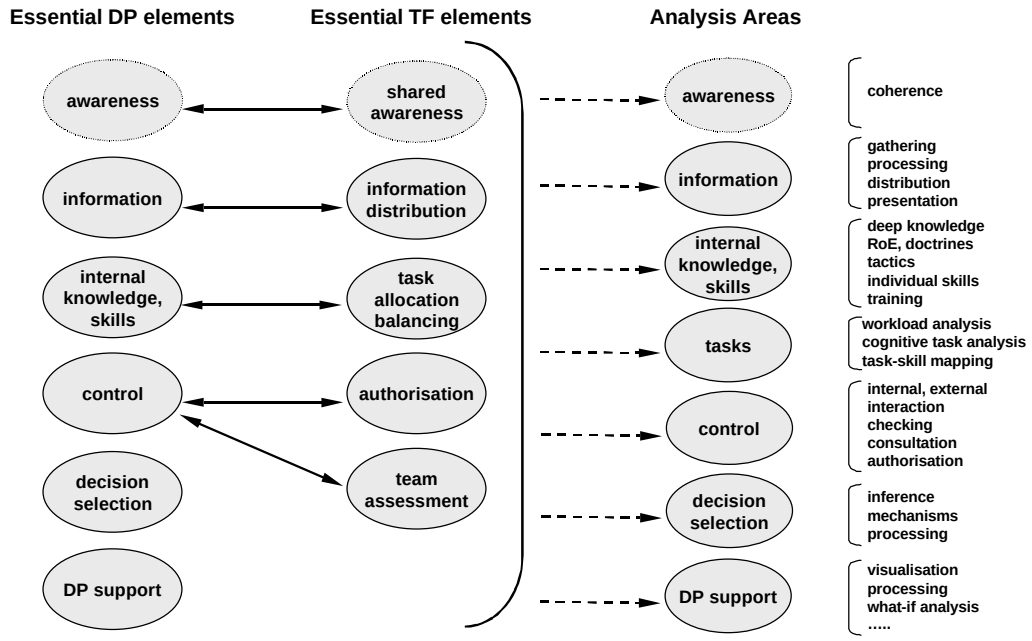

Figure 5.1: Analysis area model

Although the two decision process models of section 4 can already be used in analysing a particular decision process we aim to give more guidance for the analysis process itself. In order to do that we identified major areas of analysis within which all the concepts of the models are included. Figure 5.1 depicts these areas in a schematic way.
The process of deriving these areas is show in the figure. They are based upon the main characteristics within the two models on decision making and team decision making. When we combine similar or related ones we end up with the analysis areas. We can regard this model as an intermediate between the conceptual models and the actual observable parameters like the measures of performance.
Each of the analysis areas is related to one or more processes in the models of decision processes. These areas make up the numerous aspects that can be distinguished and analysed in decision processes. Therefore this is an intermediate model which serves to identify specific performance parameters of decision process (measures of merit) and causes of sub-optimal decision making (the factors described in chapter 6). The areas also can be used to derive more specification tools to describe organisations and decision processes in a somewhat more formalised way.

Information
This area describes all characteristics of the input data and information and of data processing functions, like total amount of data and information, rate, frequency, repetition, accuracy and uncertainty, complexity, availability, stability and or validity and classification of information. Also we find here the distribution of data among team members and the actual presentation of the data and information.

Internal knowledge, skill
Internal knowledge is that kind of information, knowledge or understanding which is not provided from the outside but needs to be available inside the process itself, either in human form or in knowledge repositories. This area can be used to deal with topics like skill, rule and knowledge-based reasoning and with training and education of personnel.

Tasks
The task area deals with the assigned tasks of team members, workload distribution, dynamic task reallocation. This task area has a central place in the analysis area model. When we relate it with information we will have situations like information overload for specific tasks. Combining it with 'control' we can study decision hierarchies, type of organisations, type of actual decision making like consensus, by veto, by majority. Analysis methods are for instance functional decomposition or cognitive task analysis.

Control
Control deals with internal mechanisms which monitor or check the correctness of actions, the sequence of actions, the correctness of information, etc. They can either be human-based (the decision maker itself) or machine-based (computer programs). Interaction of human decision makers with each other, with system functions and the hierarchical organisation is part of what needs to be analysed here (e.g. communication analysis). External control deals with elements like supervisory control from the outside of the decision process. When in an organisation tasks are being delegated to a lower level a parallel control mechanism should be put into place to monitor and control that the work is carried out correctly. We have here concepts like responsibility, hierarchical organisations. Typical descriptors may be the type of control in a team and organisation, consultation, frequency, importance, amount, means of communication, etc.

Decision selection
Decision selection is the mechanism of selecting between all possible and probable solutions the actual (final, goal related) decision. This in itself is a world of analysis we just simply captured in one single area. We believe however that a lot of processes related to decision selection have already been decomposed by our conceptual models and have found a place in one of the other analysis areas. For the moment we concentrate ourselves therefor on issues like selecting one decision among many and the mechanism to do that, like multiple hypothesis calculus, inference and correlation mechanisms, pattern matching. etc.

Decision Support

This area deals with the tools that are used for the decision process. For the analysis we concentrate on speed, correctness, appropriateness, etc. all resulting in an amount of actual support for specific decision process functions.

Resulting from these analysis areas we need to select or design the tools or procedures to measure the performance of the decision process. There are two kind of tools we can distinguish: the actual procedural analysis methods to be applied and the performance indicators to be used in these analysis methods. In this paper we will describe only the latter in the next section.

5.1.2 Measures of Merit

The metrics or *performance indicators* can be used to assess decision making in the existing organisation and after reorganisation or addition of support tools. Within the context of this research, we will denote these indicators with the general term *measures of merit* and they are an integral part of the framework. Like we showed in the General Approach of Figure 3.1. All MoM inside the team we call measures of performance.

For each of the models in our framework, decision process, team decision process and generic support architecture separate measures of merit exist. Aside from these there are also higher order measures which are applicable. These include indicators like reaching the mission goal. For military organisations the term Measure of Force Effectiveness (MoFE) is used, following the terminology of RTO TR-9 within the context of Command and Control system assessments. Within organisations however we can distinguish measures of merit on different levels, for example indicators that describe the performance on individual level. This leads to the following hierarchy of measures of merit as shown in Figure 5.1.
The flow of influence extends from individual performance and support system performance up to the team performance. If performance on individual level is low, then chances are that performance on higher level will be affected as well.

Some constraints that any measure should adhere to are the following:

- Is it *discriminatory*? That is, does it identify real differences between alternatives?
- Is it *measurable*? That is, is it possible to compute or estimate it?
- Is it *quantitative*? That is, can it be assigned numbers or ranks?
- Is it *objective*? That is, is it defined or derived independent of subjective opinion?
- Is it *sensitive*? That is, does it reflect changes in system variables?

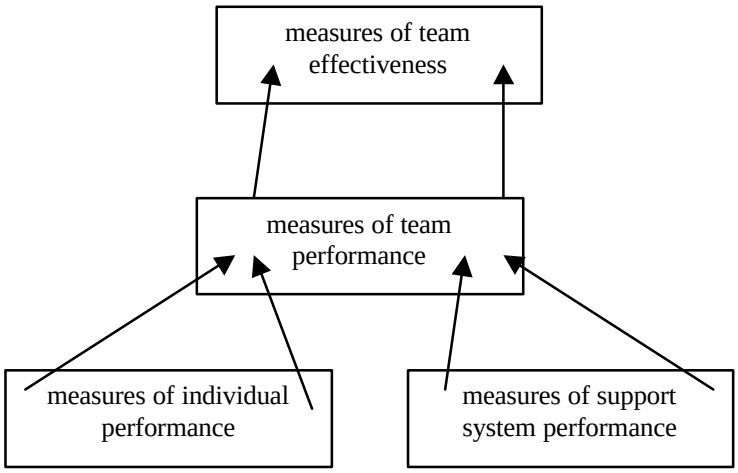

Figure 5.1: Levels of Measures of Merit

Some of these constraints are difficult to meet. We might want to use *robustness* as a measure for example, but this is a difficult concept to quantify, due the high level of abstraction of the term: it needs to be broken up in order to fulfil the characteristics mentioned above. A concept one might propose as a measure of merit is in fact an aggregation of other measures of merit on a lower abstraction level. Robustness can, for instance, be broken up in *fault tolerance* and *redundancy*. In turn, these may not satisfy all criteria as well. In short, there are various *levels* of measures. The key challenge is to define measures at a low enough level in order to use them in analysis.

Current work within TG006 is trying to derive the MoMs from the formalised models, relating them to the Analysis Area Model, and to relate them to specific analysis methods. In a later paper we will brief on these results.

6. The Causes Level

Decision making performance (either in a team or by individuals) is heavily influenced by four groups of factors:

1. Operational context factors.
2. Human factors
3. Organisational factors.
4. Informational factors.

Operational context factors

These factors, are imposed by the mission, the working environment and situation encountered. They affect all stages of the decision process and are for the most part fixed (i.e. cannot be easily altered). These factors would include the presence of shifting or ill defined goals, time constraints and uncertain dynamic environments. These ‘naturalistic’ environmental factors are described to great extent in (Klein, 1993). Examples are rule of engagement (RoE), doctrine, but also physical factors, like propagation conditions, weather, etc.

Human Factors
As long as humans play a substantial role in the decision process the human factor aspects will also be a major issue determining the quality of decision making. Aspects involved here are work loads, team communication, skills and training level, internal knowledge, cognitive abilities, adaptive capabilities, etc.

Organisational factors
Team performance is heavily influenced by many organisational factors. These are factors concerning the structure of the organisation and the specific responsibilities and decision authorisation definitions. Some obvious factors are: the team structure, authorisation constraints, required procedures, organisational hierarchy, etc.

Informational factors
Information is crucial for correct decision making. Retrieval of adequate information can become hampered in many ways. Information may, on the other hand, be easily retrieved but may be incorrect or incomplete. These information-related problems may cause malfunctioning of the decision making process itself, lead to errors in judgement and erroneous decisions. Examples of such factors are the presentation of information and whether the information is complete and accurate.

areas	1	2	3	4	5	6	7
environment							
human factor							
organisation							
information							

Figure 6.1 The factor analysis area matrix.

When we combine the factors with the analysis areas described in Figure 5.1 we create a matrix as shown in Figure 6.1. This matrix can be used for plotting measured problems and analysis results in a structured manner. Not all cells will be relevant in the analysis of a particular DP, some will even be void. The matrix can be used as a starting point in order to identify probable cause areas or hot spots. Subsequent analysis can then be executed in order to identify the actual problem causes.

7. The Solution Level

The intention of the solution level is to identify and specify solutions for improvement of decision processes. One of the generic solutions we wish to develop is a generic architecture for decision support tools (DST). This is a high level architecture which is generic enough to be applicable for a wide range of decision support tools and which can be detailed sufficiently to serve as a the high level design for a specific DST. It should incorporate in its structure all the relevant aspects to decision processes as discussed in the previous sections. The results of the performance analysis of a decision process can be used for detailing the generic DST architecture in order to arrive at a specific DST for that decision process. Several methods of deriving from the models in the analysis framework a generic architecture are being investigated.
One of the architectures under consideration is shown in Figure 7.1. It is based upon distinguishing the following categories of components:

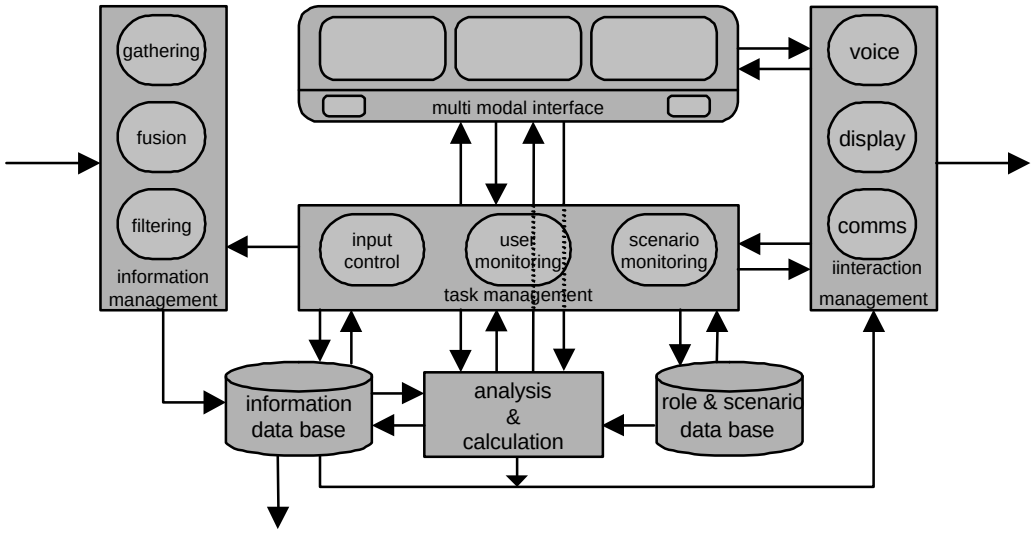

Figure 7.1: Generic Decision Support Systems Architecture

- *Information gathering components*

These components provision the support system with appropriate data and information. Information can be collected by connection to databases, using agents, reading sensory output, etc. All the components within this set participate in the information gathering process

- *Interaction management components*

User interface components provide the operator with insight in the process, e.g. by offering information to the operator and receiving information the operator supplies to the support system. This can be accomplished by means of display, voice or other ways of communication.

- *Data stores and information processing components*

Data stores hold all static and dynamic task related information. Data stores include knowledge bases, profiles, databases etc. Information processing components are responsible for retrieving, analysing and processing the information stores in data stores. These components are used to check data, deduct new information, perform complex calculations and filter out irrelevant information.

- *Task management components*

In order to provide the operator with appropriate information, the support system needs to have an idea of which tasks the operator is performing at any given time. This requires monitoring of the actions of the operator and insight in the state of the scenario and environment. Using this knowledge the *task management components* can provide the operator with support information that support his task in progress. This kind of support is therefore role and scenario dependent. These components also control time management, deal with progress monitoring and monitor and control workload topics.
Note that this generic architecture does not specify *how* the support system should be developed, it merely addresses, in general terms, all classes of components that should be (and usually are) included. The generic support tool system is a truly *generic* architecture: every support tool can be projected on this model.

8. Decision Process Analysis Flow

In the previous chapters we have introduced a framework that includes models representing several aspects of decision making. This chapter aims to connect these models in such a way that they can be used, in a joint fashion, to analyse the decision making performance of an organisation and to generate suggestions on how to improve them. We do not claim to provide a ready-to-use guideline for analysis in this version of this document yet. This section will provide some indications on how to use the framework and its models and shows how to integrate all elements.

8.1 Suggested procedural approach

Analysis of the organisation should yield two results:
a) insight in the factors that affect decision making;
b) designs for improvement of the decision making process.
In order to achieve these goals the analysis framework can be applied as illustrated in Figure 8.1.

The steps as shown in Figure 8.1 are the following:
1. Determination of the major goals and tasks in the particular problem domain or decision process which needs to be analysed. This first step is elementary in guiding the analysis processes in the framework.
2. Determination of the major characteristics of the DP and establishing boundary conditions for them. These are the main demands on the DP which always have to be met.
3. Establish the relation with the main analysis areas and select the suitable analysis methods.

4. Establish the set of Measure of Merit and the related analysis methods for these MoMs.
5. Perform the actual analysis.
6. Translation onto the factors model
7. Determine the solutions based on the discovered factors. Part of the solution may be to design and develop specific decision support tools.

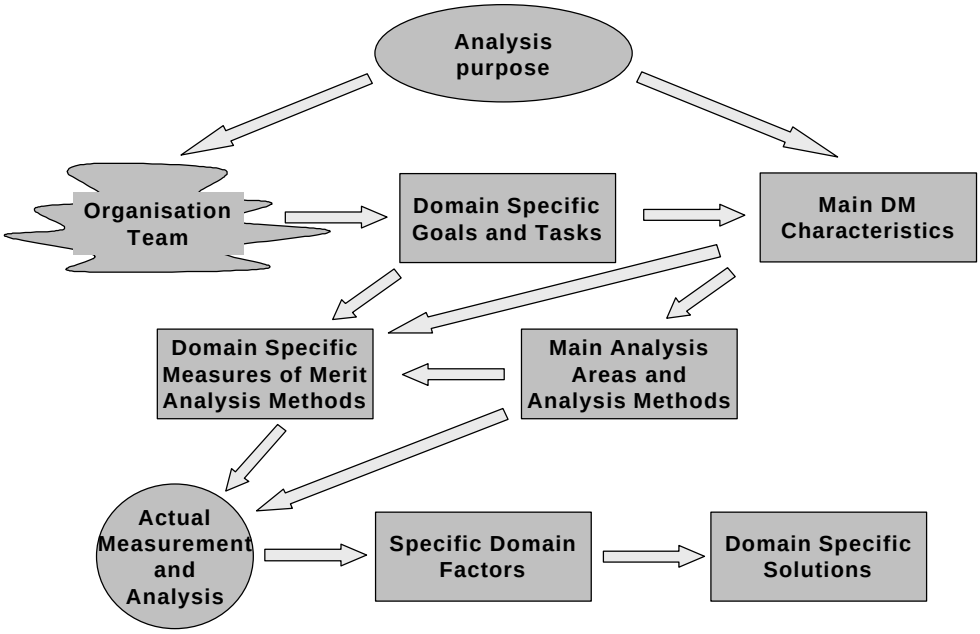

Figure 8.1: Application of the analysis framework

These steps enable us to get insight in which factors influence the decision processes, why these factors affect the performance (moreover, which measures of merit they affect), and how we can devise support tools to alleviate the problems encountered. Because of the complex nature of the problem the sequence of steps may be altered or steps may be repeated several times in order to attain a usable representation of the processes and resources involved. In fact the steps may be executed as a continuing cycle, in order to get enough refinement.

9. Current and Future R&D

In TG006 we apply the Analysis Framework described in this document to the case studies mentioned in section 2.2. Already the AF has gone through several refinement stages by this process, although we have not finished that work yet. During our research we concentrate particularly on the following issues:

- the completeness and suitability (for analysis guidance purposes that is) of the analysis area model;
- the applicability of the factor-analysis matrix;

- to correlate the MoEs (especially team performance) with the conceptual models and the analysis area model;
- the identification of specific dedicated analysis methods and relate them to the analysis area model and the MoEs;
- the derivation of a generic decision support tool architecture which can be applied in many domains and should enhance interoperability of decision support systems;
- the correctness, coherence, omissions, inconsistencies, ambiguities in our models and concepts by using formal specification models;

The final results of the TG006 work will be published by the NATO RTO in a formal report by the end of 2003.

10. References

Cannon-Bowers, J.A. and Salas, E. (1991). *Cognitive Psychology and Team Training: Shared Mental Models of Complex Systems.* Bulletin Human Actors Society, 33(12), 1-4.

Dyer, J.L. (1984), *Team Research and Team Training: A State of the Art Review.* In F.A. Muckler (red), Human Factors Review 1984 (pp. 285-323). Santa Monica, CA: Human Factors and Ergonomics Society.

Endsley, M.R. (1995). *Toward a Theory of Situation Awareness in Dynamic Systems.* Human Factors 37(1), pp. 32-64.

Klein, G.A. and Thordsen, M.L. (1989). *Cognitive Processes of the team mind.* Klein Associates, Yellow Springs, OH.

Klein, G.A., Beach, L.R. and Zsambok, C.E. (1992). *A Literature Review of Analytical and Naturalistic Decision Making.* TADMUS Project, Task 2, Final Technical Report, Naval Command, Control and Ocean Surveillance Center, San Diego, CA.

Klein, G. A. (1993). *A Recognition-Primed Decision (RPD) Model of Rapid Decision Making.* In Decision Making in Action: Models and Methods. Edited by Gary A. Klein, Judith Orasanu, Roberta Calderwood, and Caroline E. Zsambok, 1993, pp 138 – 147.

Lipshitz, R. (1993). *Converging Themes in the Study of Decision Making in Realistic Settings.* In Decision Making in Action: Models and Methods. Edited by Gary A. Klein, Judith Orasanu, Roberta Calderwood, and Caroline E. Zsambok, 1993, pp 52-103.

Noble, D. (1989). *Application of a theory of cognition to situation assessment.* Vienna, VA: Engineering Research Associated.

Morgan, B.B., Glickman, E.A., Woodard, E.A., Blaiwes, A.S., and Salas, E. (1986). *Measurement of Team Behaviours in a Navy Environment.* (NTSC Report No. TR-86-014). Orlando: Center for Applied Psychological Studies.

Orasanu, J. (1990). *Shared Mental Models and Crew Decision Making*. Technical Report No. 46, Princeton University, Cognitive Sciences Laboratory.

Orasanu, J. & Connolly, T. (1993). *The Reinvention of Decision Making.* In Decision Making in Action: Models and Methods. Edited by Gary A. Klein, Judith Orasanu, Roberta Calderwood, and Caroline E. Zsambok, 1993, pp 3-20.

Orasanu, J. & Salas, E. (1993). *Team Decision Making in Complex Environments.* In Decision Making in Action: Models and Methods. Edited by Gary A. Klein, Judith Orasanu, Roberta Calderwood, and Caroline E. Zsambok, 1993, pp 327-345.

Rasmussen, J. (1983). *Skill, Rules and Knowledge: Signals, Signs, and Symbols, and Other Distinctions in Human Performance Models,* IEEE Transactions on Systems, Man and Cybernetics, SMC-13(3), pp. 257-266.

Salas, E., Prince, C., Baker, D.P. & Shresta, L. (1995). *Situation Awareness in Team Performance: Implications for Measurement and Training.* Human Factors, 37(1), 123-136.