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Title of Paper: Modelling the Formal and Informal in Agile Organizations Operating in a Networked Coalition Environment – Theoretical Foundations of the DARNSTORMS Model

Topics: C2 Analysis, C2 Modelling and Simulation, Social Domain Issues

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Developing a Requisite Analytic Trade-Space for Assessing Agile Mission Grouping – Theoretical Foundations of Modelling Networked Operations

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Abstract: A typical military organization is a complex, socio-technical system in which behaviour emerges from the interaction of factors and processes from across physical, informational, cognitive, organizational, social and cultural domains. The risks and benefits of establishing new agile organizations operating in network-enabled coalition environments can be examined through the use of modelling and simulation. Developing such new and complex organizations requires advancement in modelling and simulation concepts and techniques.

Here we explore the underlying fundamental and practical aspects of modelling agile networked coalition organizations. We bring together theories for modelling formal C3 structures within military organizations with the modelling of informal broad social processes, within the context of the wider scientific literature.

The overall conceptual model comprises four key elements: (1) A representation of tasks and capabilities for individuals and organizations; (2) An individual and organizational representation of decision making and task execution; (3) A representation of organizational structures and structure related processes, including forming teams and assigning tasks; and (4) A representation of the cultural factors and non-task activities at individual and organizational knowledge. This paper is the second of three offered to the Symposium; the first deals with problem-definition and the third will focus on software implementation issues.

1. INTRODUCTION

At the operational level, the success of Network Centric (Enabled) Warfare depends fundamentally on the ability to achieve effective collaboration between distributed team members (operators and warfighting capabilities) by taking advantage of superior information networks. This demands not just the ability to communicate and share information freely and effectively, but also the ability to successfully share an understanding of other teams members capabilities and world views, of the task and its dependencies, and of the situation (the common operational picture).

Agile Mission Grouping (AMG) is a solution strategy to cope with: a) an increased dynamism in the operations space, making it less practical to pre-ordain mission group composition and way of working; and b) a desire to make best use of fleeting opportunities to achieve useful effect that arise without warning. A number of key elements have to be in place for a force to be capable of agile AMG. For example, it needs to be supported by the right technologies, such as a rich communication network and bandwidth; an optimum command and control (C2) structure with the right information network architecture; the right doctrine and culture; and the right people.

Facing the highly complex interplay between these elements and the competing demands on resources in a modern networked force, it becomes apparent that most national defence forces have to make investment trade-offs in order to achieve highly effective networked capabilities both across their own forces and in coalition with allied forces. Some of these analytical challenges may be alleviated to an extent with the help of modelling and simulation. A carefully designed

modelling and simulation tool can give analysts the freedom to explore a range of issues over a wide parameter space, finding possibly the local maxima (minima) here and there, in order to provide the senior decision-makers a number of possible options for manoeuvring in a quite often narrow trading-space.

This paper explores the underlying fundamental and practical aspects of modelling agile networked coalition organizations. We bring together theories for modelling formal C3 structures within military organizations with the modelling of informal broad social processes, within the context of the wider scientific literature. A conceptual model is proposed which attempts to incorporate many of the informal and formal organisational issues which the armed forces face with AMG.

The Organization-Oriented Systems approach is a computational framework that enables the modelling of dynamic organizations embedded in dynamic environments. This includes the modelling of their decision processes, coordinated operations, and the formal relationships and structure (in particular C3) that they adopt and change as the situation unfolds.

The Team Maturity model is an algorithm which focuses on team performance based on team composition, context and maturity. It represents social and cultural variables on the key C2 activities of an HQ, and the ability of teams to progress through the team maturity process.

The theories used as the basis for modelling the formal structures and the informal social processes are described in Section 2. Section 3 describes the combined theoretical framework and the relationships between concepts. We conclude in Section 4 with some future work.

2. EXISTING AND SUPPORTING THEORIES

The following section aims to explain the theoretical basis for the two models and seeks to underpin the legitimacy of combining them. Although they are motivated by different ends and built on conceptually distinct theoretical bases, both provide solutions to areas which the other model pays little attention.

Section 3.1 introduces the Organization-Oriented Systems approach. Section 3.2 provides a description of the theory base in which the Team Maturity models. The aim is to provide an understanding for the rationale of the two approaches before providing the description of the combination and an explanation of the interface.

2.1 Organization-Oriented Systems

The Organization-Oriented Systems approach [1] provides a computational framework for approaches from Organization and Management Theory and in particular theories of Command, Control, and Communication.

In the Organization-Oriented approach an organization-oriented system is composed of a set of organizations. Each organization is a first class entity. There is no inherent requirement to represent all the sub-teams of an organization. The level of detail of decomposition is left to the designer or analyst.

The knowledge and behaviour of each organization is specified through the possible social structures that the organization can adopt, the possible organizational plans that the organization can use, the type of social knowledge that the internal organizational model that the organization may have, and the belief knowledgebase that the organization can reason about.

The organizational structures and the organizational plans are context sensitive means of achieving particular goals or responding to environmental conditions. The context in which such means are employed is the mental state of the organization (i.e., beliefs, goals, and intentions) and the social mental attitudes it is aware of (i.e., the social relationships it has with other organizations and the social relationships that other organizations have with each other).

The Organization-Oriented Systems approach has been applied to the modelling of military organizations and Network Centric Warfare concepts of operation [2]. In application the Analyst has the opportunity to flexibly specify relationships between components of the system in a way that controls the overall decision-making behaviour of the modelled organization.

An advantage of this approach is that in a single framework one can model different types of social phenomena, e.g., “blind obedience” in which a commanded organization always adopts as its own goal the goal adopted by the commanding organization; “dominant coalition” in which the goals adopted by the whole organization are determined by the goals adopted by a small set of commanders of the organization; etc.

The use of organizations as first class entities allows the analyst to model organizations at varying levels of detail and complexity. Within a single scenario very large organizations can be represented without having to represent unnecessary detail whilst at the same time organizations of interest can include a detailed specification of internal structure and behaviour.

A further advantage of this approach is that in a single framework one can model systems with emergent behaviour, i.e., where the behaviour of the organization may be more than the sum of the behaviours of its individual components, and also model compositional behaviour, i.e., where the behaviour of the organization is merely derived from the behaviours of the individual agents that constitute the organization.

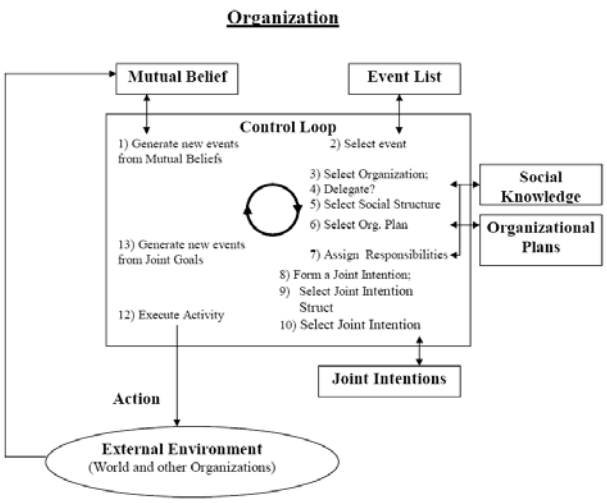


Figure 1: A computational representation for an Organization

The computational architecture of an organization that exhibits social behaviour incorporates and extends concepts from many approaches and is primarily inspired by and based on a combination of the following work:

- The work on mathematical models of Belief-Desire-Intention (BDI) agents by Rao and Georgeff [3, 4];
- Mathematical models of distributed knowledge based systems by Halpern and Moses [5];
- The work on philosophical aspects of joint activity by Tuomela [6];
- The work on models of human organizations by Mintzberg [7] and on Command, Control, and Communication systems described in Harris and White [8];
- The work on bounded rationality in human organizations by Simon [9]; and
- The work on teams and multi-agent systems by Kinny et. al. [10].

Within the Organization-Oriented approach an organization includes a mutual belief knowledgebase (MB), a set of joint goals (JG), and a set of joint intentions (JI). The mutual beliefs, joint goals, and joint intentions are referred to as the mental state of the organization.

In addition the architecture includes a set of known social structures (referred to as a structure library and denoted by SS), a set of organizational plans (referred to as a plan library and denoted by OP), and an internal organizational model captures the social mental attitudes that the organization is aware of for itself and between other organizations (referred to as a social knowledge base and denoted by SK). These include Command, Control, and Communication and the sub-team relationships (also referred to as sub-organization).

The structure and plan libraries are provided by the system developer. The belief and social knowledge bases can be initialized but are primarily updated based on input from the environment or as an outcome of executing joint intentions. Joint intentions are incrementally formed by using plans from the plan library as templates or "recipes". The social knowledge base can also be updated by adopting social structures using structure templates from the structure library.

In addition to the above libraries and mental attitudes we include a number of selection functions that reflect the choice available to the organization. That is, they implement the decision procedures used when selecting from different alternative joint goals, social structures, organizational plans, and joint intentions.

An organization is modelled as a first class computation entity. The sub-team relationships between organizations determine the organizations composition and allow sub-teams to change while retaining the existence of the organization as a whole. This approach allows for modelling organizations at different levels of detail and abstraction.

The main process of a single organization can be described as a continuous loop in which multiple sub-processes are called upon. We refer to this as the main control loop. The following main control loop is for the architecture of a single organization (see Figure 1). When discussing the details of this architecture we refer to the organization that has been implemented using the particular architecture as the executing organization.

The main objective of an organization is to achieve adopted joint goals or react to environmental changes. Each such event is referred to as a triggering event. We will start the main control loop with the process of observing the environment. The main control loop includes the following abstract steps (Figure 1):

1. Observe the environment. If there are changes to the perceived environment, create a triggering event and add it to the set of triggering events JG;

2. Select a triggering event *e* using the selection function SE.

3. If *e* does not have an associated organization, select an Organization ω to achieve *e* from the set of known organizations contained in the social knowledgebase SK using the selection function SO;

4. If ω is not the executing organization Delegate the Responsibility to ω and goto 1;

5. Select a Social Structure σ, to be adopted by ω when responding to *e*, using the selection function SS;

6. Select an Organizational Plan *p* from OP, to be used by ω with social structure σ when responding to *e*, using the selection function SP;

7. Adopt the social structure σ, select an allocation of sub-teams specified in TK to the activities specified in *p*, and assign the responsibilities;

8. Form a Joint Intention for ω, using *e*, σ, *p*, and the chosen assignment of responsibilities and Add the Joint Intention to the joint intention structure JI;

9. Select a Set of Joint Intentions *I* from JI using the selection function SSI ;

10. Select a Joint Intention *i* from I;

11. Select an activity α in *i* using the selection function SI;

12. Execute the Activity α;

13. Generate new joint goal events and add them to the set of triggering events JG;

14. Return to Step 1.

There are substantial details that are hidden in each of the above steps. In particular the way the social relationship with the selected organization ω affects the above decisions and behaviour. Furthermore the way the selected social structure σ affects the way selections are being made. Further details can be found elsewhere [1].

In general the social mental attitudes affect the behaviour of the organization in the following ways:

- an organization will accept a joint goal only from organizations that command it;
- an organization will communicate to its controlling organizations the possible choices available to it;
- the selection of social structure, organizational plan, joint intention structure, and joint intention, are all done by the controlling organizations;
- an organization will communicate the successful or failed execution of a joint intention to its controlling organizations;
- an organization will communicate the successful or failed attempt to achieve a joint goal to its commanding organizations.
- an organization will communicate changes to its mutual beliefs to the organizations it has relevant communication relationships with.

The main organizational processes performed by an organization are as follows:

- **Adding a Triggering Event**: Triggering events are generated by changes to the mutual beliefs or the adopted goals of an organization. Triggering events may have an organization and social structure associated with them. When the organization adds or deletes a mutual belief about the environment a new triggering event is created. This event is added to the set of events *E*. Similarly when an organization adopts or discards a joint goal a triggering event is generated. Again this event is added to *E*. In our architecture performing the activity of adopting a joint goal will occur in the context of a joint intention. Such joint intentions are executed by an organization and with an adopted social structure. This information about the originating intention is also associated with the triggering event.
- **Selecting an Organization**: If an organization has already been specified for the triggering event then the selection process simply returns the specified organization. Alternatively an organization that will be best suited to respond to the triggering event has to be selected. There are two problems that need to be addressed: (1) which organization will make the selection; and (2) how to make the selection. The selection of an organization depends on the skills and capabilities of that organization. Recall that a control relationship implies that the controlling organization determines the means by which a goal is to be achieved. In the context of the architecture this implies that a controlling organization will make decisions for the controlled organizations. In particular a controlling organization will select an organization that will respond to the triggering event. The triggering event may have been generated from a joint intention. In this case it will have associated with it the original organization and social structure under which the event has been created. This social structure specifies which organizations control the executing organization. All of these controlling organizations are responsible for jointly making the selection for the executing organization. Alternatively the event may have been generated because of a change in the mutual beliefs of the organization. Such a triggering event does not have an originating organization and social structure associated with it. In this case it is the responsibility of the executing organization to select the responding organization. The executing organization has to convey to the controlling organization the need for a decision to be made. This may involve a sequence of communications at the end of which the executing organization will be informed of the decision, i.e., the selected organization.
- **Delegating a Responsibility**: After an organization has been selected the executing organization has to delegate the responsibility of responding to the triggering event to the selected organization. Such delegation can only occur if there is a command relationship between the executing organization and the selected organization. If such a relationship does not exist then another organization has to be selected. It is important to note here that the organization has been selected by the controlling organizations. The internal social knowledge of the controlling organizations may be different than the

internal social knowledge of the executing organization. This may result in a potential conflict as would be the case in human organizations. One way to eliminate this potential conflict is to communicate to the controlling organizations the information associated with the triggering event. That is the originating organization and the adopted social structure of the originating organization. This information will include a set of social relationships between the executing organization and other organizations. Such communication corresponds to the staff information flow described Mintzberg [7]. If the command relationship between the executing organization and the selected organization does exist then the process of delegation will commence. Delegation of a responsibility involves three distinct steps: (1) the transfer of responsibility; (2) acting on this responsibility; and (3) communicating the result of the actions, i.e., success or failure. The first step is the process of one organization exercising its authority over another organization. The third step corresponds to the performance information flow described by Mintzberg [7].

- **Selecting a Social Structure**: The process of selecting a social structure is similar to the process of selecting an organization. Again there are two problems that need to be addressed: (1) who will select the social structure; and (2) how is a social structure selected. Again, the controlling organizations are responsible for selecting a social structure. The selection of a social structure is based on the information contained in the library of social structures and the internal social knowledge. Based on this library one can generate a set of applicable social structures for the triggering event. One can then generate a role assignment for each of the applicable social structures. A selection function is then used to make the selection. Note that the selection also includes the role assignment for the social structure. It is important to note that if the controlling organization is making the selection then the evaluation of applicability will be based on the set of mutual beliefs *MB* of the controlling organization and not the executing organization. Again this may lead to a potential conflict as the selected social structure may not be applicable when evaluated by the executing organization. One way to eliminate this potential conflict is to also communicate to the controlling organizations the set of applicable social structures as evaluated by the executing organization. Such communication corresponds to the staff information flow described by Mintzberg [7].

- **Selecting an Organizational Plan**: The process of selecting an organizational plan is similar to the process of selecting a social structure. Again we would have the controlling organizations making the decision on the choice of applicable organizational plan. The primary difference between the selection of a social structure and an organizational plan comes from the difference in the purpose of the two. That is, selecting an organizational plan also involves the unification between the required and originating organizations and social structures.

- **Adopting a Social Structure**: After all the decisions as to the means of responding to a triggering event have been made the organization is now required to act on these decisions. Acting on these decisions involves adopting the social structure, creating a joint intention, and adding the new joint intention to the set of intentions for the relevant organization. The process of an organization *!* adopting a social structure . with an associated role assignment . involves two steps: (1) adding . and . to the knowledge about *!* contained in the internal social knowledge; and (2) synchronizing the social knowledge of *!* with other organizations. The first step is simple. As to the second step, we require that when an organization adopts a social structure the internal social model of the commanding organizations according to the originating social structure be updated.

- **Forming a Joint Intention**: Given the organizational plan, required organization, originating organization, and originating social structure the organization is now in a position to create a joint intention. Creating a joint intention is a process of instantiating the organizational plan with the associated unifying information. An organizational plan can also have role names in the activities it describes. The role assignment can thus be viewed as another unifier. The process of instantiating an organizational plan also involves instantiating the role names with the assigned sub-teams.

- **Adding a Joint Intention to Joint Intention Structure**: A joint intention for an organization can be created because of one of three situations: (1) this is a joint intention created to achieve a sub-goal generated by the same organization as part of executing another joint intention; (2) this is a joint intention created to achieve a sub-goal generated by another organization as part of executing another joint intention; or (3) this is a joint intention created as a reaction to a triggering event with no originating organization. We refer to the new joint intention created in the first situation as a *sub-joint-intention*. We refer to joint intentions in the other two situations as a *root-joint-intention*. Both types of joint intentions will be added to the set of joint intentions for the relevant organization. The process of adding a joint intention to the set of joint intentions will depend on the type of joint intention. A sub-joint-intention is added to an existing joint intention structure. A root-joint-intention is added as a new element of the set of joint intentions.

- **Selecting a Set of Joint Intentions**: The executing organization is now in a position to select a joint intention to execute. The joint intention structure of the executing organization includes multiple sets of joint intentions adopted by the organization on behalf of other organizations. The executing organization now has to express its preference as to its commitment to different organizations. The decision may depend on its role within the social structure adopted be these organizations, previous relationships, or some utility function (e.g., one organization pays it more for its services than the other). We refer to this decision as a *social preference*. Here we include the social preference in the selection function *SSI*.

- **Selecting a Joint Intention**: After a selection has been made as to the organization for which the next intention is to be executed one has to select the next joint intention from the set of intentions. Again this decision is to be made by the controllers of the organization. Again there may be conflict between the executing organization and the controlling organizations as to the options available. One can overcome this conflict by communicating the set of joint intentions to the controlling organizations. Such communication corresponds to the staff information flow described by Mintzberg [7]. It is important to note here that a joint intention is derived from an organizational plan and as such is hierarchical in nature (i.e., it includes a specification of sub-goals). In the selection of a joint intention there is thus the implicit command to adopt the sub-goals when required. The controlling organization is thus required to have a command relationship with respect to the sub-goals specified in the joint intention. This requirement imposes constraints on the joint intentions that a controlling organization can select for the controlled organization. An example of such a situation can be clearly identified in a military unit. Given a command to perform an attack an established plan of attack may include an illegal command, that is, a command that is outside the bounds of authority as perceived by the commanded organization. It is thus the responsibility of the commanded organization to reject this command and refuse to execute that part of the established plan of attack.

- **Selecting an Activity**: In addition to the selection of a joint intention one has to select the activity to be performed. If there are options then the selection is made by the controlling organizations and communicated back to the executing organization.

- **Executing a Joint Intention**: The process of executing a joint intention involves performing the selected activity. It may be the case that there are no more activities to perform. This can either be because the intention has completed successfully or because it has failed. In either case the joint intention will be marked as succeeded or failed. As mentioned performing an activity may involve executing an action or adopting a new sub-goal. Executing an action may either succeed or fail depending on the action and the state of the environment. Adopting a sub-goal involves adding a new triggering event to the set of events *E*. The attempt to respond to a triggering event is successful if there is a corresponding joint intention that has been marked as success. Note that that joint intention may have caused other joint intentions to be created. That is, the execution of a joint intention may generate a tree of sub-intentions.

2.2 Team Maturity Models

STORM was built in response to a need, by the OA community, for a requisite model capable of dealing with issues surrounding agile, ad hoc team formation. It is built on a synthesis of transactional memory and team maturity theories, and the specific selection of models are based on pragmatic decisions made following thorough research and scoping of existing frameworks capable of representing complex, organizational behaviour. STORM is not a behaviour driven, actionable model capable of adaptation, instead, it focuses on team performance based on team composition, context and maturity.

STORM is an algorithm which uses an object oriented approach and was built as part of an overall conceptual model architecture comprising four key elements – a task model, a team model, an organisational model and a social model [11]. STORM itself comprises an explicit model with implicit organization and social models represented as settable parameters.

The structural core of STORM lies predominantly in two conceptually distinct theories which represent different aspects of teamworking. The first of these two theories provides a representation of taskwork. Since many OA models already represent the key C2 activities of an HQ, the present work has focussed on representing the impact of social and cultural variables on these. In particular we have chosen to focus upon the impact of performance rather than behavioural ones. This was a pragmatic choice based upon the immaturity of the theory base capable of supporting the kind of predictive behavioural modelling that would be needed. At the core of the STORM model lies the idea that social and cultural impacts on task performance can be described in terms of the ability of teams to progress through the team maturity process described by Tuckman and Jensen's [12]. This is a theory built upon a review of team and group studies which found a series of stages of development through which teams progress from their conceptualisation in order to become a successful and efficient team.

The second architectural element is an agent/team representation to provide variability in behaviour and performance. We have heavily exploited the work of Noble [13], who uses transactive memory theory to derive key knowledge enablers required by teams to perform effectively.

Tuckman & Jenson's (1977) Maturity Model

The maturity model proposed by Tuckman and Jenson [12] is particularly useful in the context of agile teamworking due to its dynamic nature. It describes and prescribes progression through phases of team maturity. Furthermore the model allows for the team to move forwards and backwards through the stages of maturity. There are many instances in which progression through the stages may be stunted, for example, should the team require reconfiguring in the instance of members leaving the team. If the change was minimal, although the team would probably revert to a former stage of maturity, it may not mean starting from the beginning of the maturity process. This model allows for such changes to be made in a team.

Tuckman and Jenson [12] proposed a theory of teamwork analysis which explains team maturity from initial team conceptualisation, through to being a coherent team with the ability to perform tasks, then through to disintegration. Tuckman [14] identifies the team as both a social entity and also a task-oriented entity. In order for a team to perform the task for which they were conceptualised it is necessary to have developed some form of social order within which the team members have adopted roles. Tuckman and Jenson [12] describe team maturity as progression through 5 stages with initial emphasis concentrated on interpersonal aspects of team behaviour, once this social order is established, or at least accepted by the team, they have coherency which allows them to focus the team's efforts on task performance. The 5 stages through which a team passes during its life span includes *Forming*, *Storming*, *Norming*, *Performing* and *Adjourning*. Developing an understanding the processes which occur during the team life cycle invites a potential opportunity for manipulation of teams with the aim of speeding the rate at which a team progresses through the maturity process.

- **Forming:** The initial stage of team formation is sometimes referred to as 'orientation to the task'. This is the stage at which the team members are brought together for the purpose of the task, during which they identify the task, its parameters and means in which they are to proceed with the task. It is also the stage at which the identity of other team members is learnt. This is essential in order for the members of the team when establishing roles and responsibilities within the team.

- **Storming:** Once team membership is determined and the reason for team establishment is identified the group enters the storming phase. This stage is interpersonal in nature and is often referred to as the stage of 'intra-group conflict' as the group struggles to achieve clear functional roles for the team members whom strive for individuality. Team members, at this stage, are likely to resist the team's task, particularly in instances when the team goal is incongruent with their own. In order to mitigate the conflict which can arise in this stage, it is essential that the team possesses knowledge of interpersonal communication, in other words the team understands how to communicate with other members. This knowledge can arise from two sources: experience and location (Mistry, Mathieson & Waters [15]. Previous experience can provide information on how to communicate with the team and location will determine the method of communication. A concern arising from the use of distributed teams is the lack of resulting face-to-face interaction which could impact performance. In a military survey 97% of Commanders identified this as an issue which degraded quality and quantity of information communicated across dispersed teams (Henderson, Mills and Lynam [16]).

- **Norming:** Following the stage of intra-group conflict the team members have established roles, the next stage is to develop group cohesion; this occurs in the norming stage. Now the task and team roles have been decided upon and accepted, following the previous stage of conflict, harmony within the team can be achieved and efforts can be transferred from the interpersonal onto task related behaviours.

  Communication between team members should be increasingly relaxed and informal as the team becomes accustomed to working alongside each other, and are developing a sense of trust (Mistry et al. [15]). Because of the decreasing effort expenditure required to be directed at the interpersonal aspects of the team as interaction becomes more natural and less contrived, this stage sees the team focussing on the team goal and how this will be accomplished, in addition to determining task priorities.

- **Performing:** This is the stage at which the team becomes significantly more task oriented and are far less concerned with the social, interpersonal aspects as these are established. There is significantly more expenditure of effort on the performance of the task, for which the team was initially formed, than there is in any of the other maturity stages. Productivity of the team will be highest during this stage, whilst conflict amongst team members will be lowest. Belief in the team concept will increase with every accomplishment. Communication is essential at this stage in order to maintain motivation, re-emphasise the strength of the team and determine which practices are the most efficient.

- **Adjourning:** The team enters the final stage of adjourning once the task has been completed and the team no longer serves a purpose, hence the disintegration of the team. Tuckman and Jensen [12] consider Adjourning as the final stage, involving the group disbanding either because the task has been completed or the members have left.

- **Transforming:** Given the nature of AMG it was deemed necessary to provide an additional maturity stage whereby the team neither adjourns, nor continues to perform, but instead transforms in recognition of the fact that AMG will involve teams that adapt and change in composition, and/or the context or task assignment alters. In the present construct we define Transforming as a transitional stage in which the team is able to change in ways which affects its knowledge, and hence maturity, without losing its essential identity as a team. For example, a change in the team goal, dictated by dynamic change in the customer goal may require a change in the composition of the team. Thus, in the same way, knowledge of team membership will need updating.

Noble's (2004) Foundations of Effective Teamwork

The second architectural element is an agent/team representation to provide variability in team performance. STORM heavily exploits the work of Noble [13], which uses transactive memory theory to derive key knowledge enablers required by teams to perform effectively. Within the STORM architecture the maturity level of the team is a reconceptualisation of the processes which are occurring at the level of the knowledge enablers. According to the processes which are taking place at the level of the enablers this indicates how mature the team is, for example, if the majority of the teams efforts are expended on interpersonal aspects in the knowledge enablers, this feeds up into the maturity levels and would indicate that the team was still relatively immature.

Table 1: First six knowledge enablers: Team preparation

Knowledge Enabler	Definition
Goal Understanding	Knowing what the customer wants
Understanding of roles, tasks and schedules	Knowing who's supposed to do what & when, & with what information and resources
Understanding of relationships and dependencies	Knowing how entities, events & tasks impact the plan
Understanding others	Knowing what other team members' backgrounds, capabilities, & preferences are
Understanding of team "business rules"	Having & knowing effective & agreed upon rules for team member interaction.
Task skills	Knowing how to do one's assigned work

Table 2: Last six knowledge enablers: Status assessment and decision making

Knowledge Enabler	Definition
Activity awareness	Knowing what others are doing now & the need for doing it
Understanding of the external situation	Knowing status of people, things, & events of the world outside of the team & projecting future changes
Current task assessment	Keeping tasks on track, knowing own & others' task progression, and when to offer help
Mutual understanding	Knowing what other team members understand now & knowing if they agree/disagree
Plan assessment	Predicting whether the plan will enable achievement of goals
Understanding of decision drivers	Judging & applying criteria for selecting an action

Similarly to the first stages in Tuckman and Jenson's [12] model the first six knowledge enablers revolve around team preparation and acquiring knowledge on the task at hand and the other members of the team. This knowledge will build slowly over time with interaction between team members. The last six knowledge enablers are "real time" understandings and can change in an instant. There is considerable overlap between the knowledge enablers proposed by Noble and the competencies required for teamwork identified by research (e.g., Salas and Bowers [17]; Smith-Jentsch et al. [18]; Cannon-Bowers et al. [19]; Salas et al. [20]). Salas and Bower [17] propose that teamwork is comprised of critical knowledge, attitudes and skills (KSA) which team members must demonstrate. Noble takes the KSA framework a step further by producing a generic framework which forms the basis for a diagnostic tool to identify where cognitive knowledge is lacking and provides suggestions for interventions, in order to improve teamwork. It is this diagnostic aspect that makes the Noble knowledge enablers attractive as the core of a simulation of team performance effects (Mistry et al [15]). The model would be implemented using an algorithmic representation, which would be employed in order to characterize the relationships between the knowledge variables, as they interact over the lifetime of the team (Waters, Mathieson & Mistry, [21]).

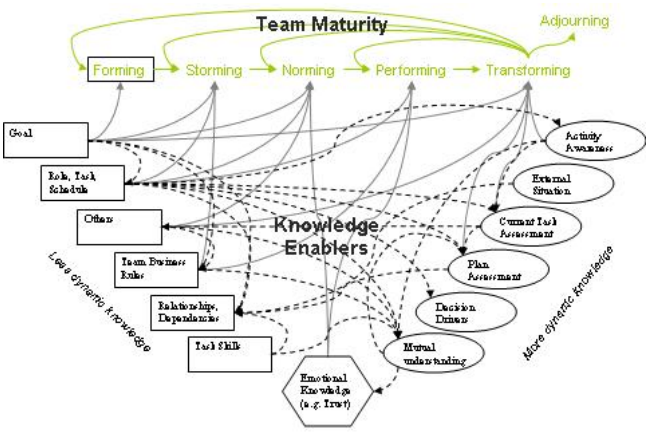
Combining Tuckman's stages of group development to Noble's knowledge enablers revealed the need to extend the enablers to include an affective component, which we call 'Emotional Knowledge', to cover issues of trust that impact upon team development and subsequently performance (Mistry et al. [15]). This additional enabler allows for a representation of various factors discussed in the literature under the general heading of 'Trust'.

Noble [13] identifies 4 basic premises as to why knowledge is essential in teamworking. The first principle is that knowledge is central to collaboration and a team working together on a task. If team members know everything they need to know, they can work effectively. A lack of knowledge in teams is recognised as a potential source of predictable errors (Liang, Moreland & Argote [22]).

The second premise is that should a team lack this essential knowledge they need to know how to obtain it. This is imperative for any work within the military domain, as it highlights and addresses a key challenge for NEC. NEC enables the delivery of a large amount of information and the key challenge is distinguishing the important information, and its timely delivery, in order to ascertain teams have the necessary information to perform the task at hand, without overloading them with irrelevant information. Recent anecdotal evidence from a US military trainer reported that with the introduction of Blue Force Tracker on land platforms, performance in training environments was initially hampered[1]. This was due to soldiers being overloaded with information and being too busy trying to identify the information that was key to fulfilling their mission (Mistry et al. [15]). It is also important to consider that information requirements and fidelity of that information will differ higher up the echelons.

Noble's third premise is that for effective taskwork, team members require knowledge for both teamwork and taskwork. This has further been emphasised within the military context when addressing issues of teamwork and shared situational awareness (Henderson, Mills and Lynam [16]). Similarly, Pascual [23] distinguished between mental models related to teamwork and taskwork. For example, he proposed that we require knowledge on teamwork, how to work with other people and norms of behaviour that governs these interactions. We also need knowledge on how to do the task, if you were a pilot you would need to know how to fly.

Finally, the fourth premise is that collaboration between team members is important to develop and build upon the knowledge and understanding of team members. It is, therefore, important to understand the process of teamwork and taskwork over time.



Emotional Knowledge

'Team preparation' knowledge enabler

Status assessment and decision making enabler

[1] Per

Figure 2: Outline of Conceptual model showing linkages between team maturity, knowledge enablers and structural processes

Team Performance

The final step of the model is the connection between the maturity stages through to the output, or team performance. The inclusion in STORM of both team behaviour and performance would be desirable, however, the empirical literature base upon which STORM was developed does not support a complete enough treatment of task work behaviours (e.g., content of plans or courses of action) (Mistry et al. [15]). Behaviours related to teamwork interactions are incorporated into the knowledge enabler relationships described above in terms of their effect on team maturity.

Information transfer

As has already been described team maturity is a reconstruction of the level of knowledge which the team possesses. In order to progress to the next level of maturity, there are thresholds within the knowledge enablers that must be reached. In other words for each knowledge enabler there will be a certain level of knowledge required to allow the team to progress through the maturity stages.

There are two ways in which knowledge can transferred between knowledge enablers. Firstly knowledge can directly transfer from one knowledge enabler to another. This is certainly the case where the 'team preparation' enablers update knowledge for the 'status assessment and decision making' enablers (Mistry et al. [15]).

To assume that knowledge leads to knowledge, however, is not always plausible. Task activities therefore provide another means through which information can be transferred. In order to gather knowledge, it is likely that individuals have to engage in activities. These activities provide feedback on 'teamwork preparation' enablers which, in turn, update the team maturity model (Mistry et al. [15]). For example, changes in knowledge of significant events in the external environment may trigger an action to change the short-term plan of the team, which will then generate knowledge of goals and schedules, etc. In a warfighting scenario, a team could have been tasked to carry out an air raid on the enemy. Subsequent intelligence received informs the team that the enemy location has changed. In light of this news, it may no longer be practical to carry out an air raid that the team had originally been tasked to do. This is due to the enemy moving to a more urban location where the potential civilian causalities will be high. This could lead to a re-assessment of the plan, changing the short-term goal of the team and subsequently the task.

Unlike the Organization-Oriented approach, which is a model representing organization/team formation and operational behaviour, STORM is a knowledge driven, maturity model. Whereas STORM is a performance driven model, not an actionable model capable of adaptation, the Organizations in the Organizational-Oriented approach include an organizational, behavioural model with the capability to change and adapt. These are a couple of ways in which they complement each other and a collaboration stands to provide a more comprehensive model of AMG than if they stand alone as individual models.

STORM represents the extent to which such knowledge is held rather than the knowledge itself. It provides a team model; however, as already described it belongs to an original model which comprised three other key elements: a task model, an organizational model and a social model. The Organization-Oriented approach would provide two of these additional elements: a task model and organizational model which is required by STORM to investigate the effects of team maturity.

3. MODELLING THE FORMAL AND INFORMAL IN AGILE ORGANIZATIONS

The Organization-Oriented Systems approach described above provides a comprehensive computational model of formal organizational behaviour embedded in a dynamic environment. However, it does not include aspects of the informal influences related to team behaviour. The Team Maturity model provides a comprehensive framework for determining the Maturity Level of an organization based on a range of internal and external influences. However, it does include the operational behaviour of the organization, the interaction with its environment, and the way it is influenced by its organizational structures.

In this work we describe the theoretical integration of the Organization-Oriented Systems approach and the Team Maturity model to allow for the development of models that capture the formal and informal aspects of agile organizations. The combined model includes two primary elements:

1. A specification of the Knowledge Enablers as function of the state and attributes of the organization; and
2. The influence of the Maturity Level on the organizational process.

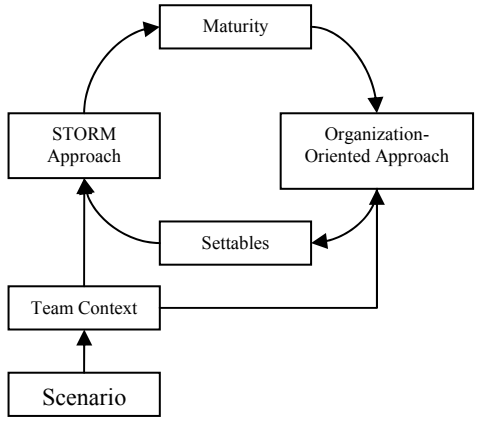


Figure 3: Information transfer around the combined approach

Enablers

Settables

A set of variables, which we refer to as settables, were introduced as a key part of the interface between STORM and the Organizational model. They are built based on a combination of anecdotal evidence gathered from the experiences of the military, particularly those from Op Telic where International collaboration has played a large role. This evidence was then consolidated using the Social Sciences literature (Lewis, [24]; Hofstede, [25]). These settables consist of 15 socio-cultural, organizational and task related variables which incorporate the informal processes in teamworking.

The settables provide a context within which the team performs and matures and they will be used to exchange information between the Organization and STORM about the team composition. Changes in the settables can alter the knowledge and maturity levels of an established team. This variable set is broken down into three main categories: personal/team coherency settables, organizational settables, situational settables, and task-specific settables. A premise of the settables is, however, that is not necessary to have the same, or even necessarily complimentary cultures (however, it could be argued this would be advantageous in initial team formation); understanding team mates' cultures, in order to predict their behaviour, would be sufficient to provide coherency for a team to perform. Below is a description and justification for its inclusion, for each settable. There is also a description as to the information which will be used to set or derive each variable within the model:

Personal/team coherency settables

These settables offer information on the informal social processes occurring within a team; they are primarily derived from experience and knowledge of different

cultures, based upon which the sub-teams are provided with a tag during the scenario set-up:

- **Socio-cultural coherence**: The coherence between the cultures of two different organizations required to work together. It would be necessary to develop some form of rating system for this likely to be based upon historical preconceptions/caricatures of different nations. This settable is an interpretation of the official doctrine which teams may or may not share as stated by the organisational coherence. This variable reflects the baseline coherence of a newly-formed team with no previous connections.

  The socio-cultural coherence of an organization provides information on the informal team processes. It is an important consideration for AMG because incoherent teams may hinder team performance, irrespective of their organizational tags. The socio-cultural coherence of an organization will be derived from tags provided to the sub-teams. For example, a sub-team may be given a tag of Western European, whilst another sub-team may have the tag of Middle Eastern. Using calculations set beforehand, the coherency of the overall organization would be established using these tags of the sub-teams.

- **Personal experience/coherence**: The personal experience, of the group, of working with the organisation in question. This is not based upon generalisation of experience from the larger organisation instead it is based upon records of groups of people who had previously worked with each other. This variable is the acme of coherence sources and is intended to allow representation of the difference between well established teams and new or ad hoc ones.

  Similarly to socio-cultural coherence, personal experience/coherence of team members is likely to affect how well teams work together and interact. The personal experience/coherence settable will be established similarly to that of socio-cultural coherence. Overall organizational coherency will be established through the tags given to the sub-teams during the scenario set-up.

- **Leadership**: This is the style as set by the elected team leader and provides an opportunity for mutual adaptation by the team and its leader. It provides more space for manoeuvre by the individual team than that provided by co-ordination style and offers an opportunity to reflect personal interpretation of doctrine. This settable will allow us to represent the effect of choosing appropriate styles for the nature of the problem and the nature of the team – i.e. the 'followship' styles, possibly derived from the organisational co-ordination style.

  Similarly to socio-cultural coherence, leadership style would be derived beforehand based on knowledge of the typical styles employed given the culture of the sub-teams. Within the model, the coherency of these styles would then be calculated to establish the coherency and leadership style of the overall organization.

Organisational settables

These settables are primarily derived by the official organizational tags of the sub-teams; they represent the formal structure within the teams:

- **Organisational coherence**: This incorporates the coherency between two organisations based primarily on official shared tags (e.g., NATO) or shared doctrine. This is irrespective of socio-cultural variables and captures the extent to which the team start with coherent ways of working together, compatible doctrines and common understandings of their business.

  The coherency of an organization will be derived using official tags. Beforehand the organizations to which the sub-teams belong will be set, and then in the model the coherency of these will be determined. Such calculations are likely to be based upon shared doctrines of the sub-teams, which is an important consideration of Agile Mission Grouping.

- **Co-ordination style**: This is the official style dictated by the organisation and provides little room for personal interpretation or adaptation. This variable is the nominated co-ordination style for the team. Pre-dispositions to different co-ordination styles are wrapped up in the Organisational Coherence above. Co-ordination style is likely to interact with organisation coherence in the sense that some co-ordination styles may work better with coherent or incoherent teams.

  Coordination style will be set in for the sub-teams beforehand based upon knowledge of the preferred styles typically used by the organizations. The model will then calculate the coherency of the styles to determine the coordination style employed by the overall organization.

- **Teamwork skills**: This settable is based upon the organisation's 'culture' regarding teamwork and the training provided to the team. Teamwork skills will reflect the extent to which the team members are skilled in teamwork and this will reflect the extent of training and the organisational approach to such training. This variable will likely interact with co-ordination style.

  The teamwork skills of the sub-teams will be derived beforehand. The coherency between the

sub-teams will then be calculated by the model to establish that of the wider team/organization. The teamwork skills will again be derived from tags and settings provided based upon knowledge and experience of the sub-teams.

Situational settables

These settables provide information of the setting within which the teams must perform. They are derived primarily from the scenario:

- **Situation brief**: This is defined as the extent to which the situation is briefed, conflating quality/depth and completeness. It provides the direct setting of team's initial knowledge.

  This will be derived from the scenario within which the organization is functioning. It is a contextual variable of the situation which the team are expected to perform and is derived from the mutual beliefs available to the organization as compared with that required by the joint plan.

- **On-task location**: Offers the team the opportunity to interact in a professional capacity. This will be a tag applied to a team who are co-located for the task. This settable provides the opportunity to develop interpersonal relations required for performance of the task.

  This will again be defined by the scenario. Whether or not the team are co-located or distributed is a contextual variable and an important consideration of AMG as distributed teams, who are expected to work over long distances and possibly having never met each other, are a common feature of NEC. This settable is situation dependent and stored as a belief, and may well alter as the scenario unfolds.

- **Off-task location**: This is a tag which will be applied for teams who live together but do not work together, for example a team co-located in the same barracks but have to travel to different locations for their tasks. This offers the chance for 'natural' teams of different nationalities to form in a personal but not necessarily professional capacity.

  Similarly to on-task location this is a contextual variable which will be defined by the scenario and stored as a belief, and may alter as the scenario develops.

- **Adversary environment**: This settable will provide information on the conditions in which the task is to be performed, for example, offering information on the potential dangers of the environment. Environment adversity is likely to influence willingness of the team to co-operate, especially if the environment faced is threatening. One may assume that there may be a positive relationship between increased risk of danger in environment and motivational willingness, as the completion of the task becomes more pressing in terms of survival.

  This is a contextual variable which will be defined for the organization as part of the scenario and computed based on the mutual beliefs of the organization.

Task specific settables:

These settables offer information on the context within which the team must perform. Similarly to the situational settables they are derived primarily from the scenario:

- **Task difficulty**: This is a task descriptor and is defined as how difficult the task is likely to be. This could be related to the skills required or conditions in which the task is to be performed. Task difficulty may affect co-operation of the team, as more complex tasks are likely to require more co-operation and motivation than simpler tasks.

  Task difficulty will be defined beforehand allocating each joint plan in the organizations with a task difficulty setting. These task difficulty settings will be then be transferred to the joint intention that was formed from the joint plan. The current task difficulty for the organization will be aggregated from the task difficulties of the top level intention structure as it changes.

- **Task richness**: This is another task descriptor and is defined as how complicated the task is. This will relate to the breadth of knowledge and skill required to complete the task, the number of components which make up the task and the team's ability to understand the task.

  Task richness will be defined beforehand allocating each joint plan in the organizations with a task richness setting. These task richness settings will be then be transferred to the joint intention that was formed from the joint plan. The current task richness for the organization will be aggregated from the task richness of the top level intention structure as it changes.

- **Goal brief**: This settable offers information on the extent to which the team briefed on the final, customer's goal.

  Goal brief is contextual information on the setting in which the organization is performing. This information can be provided by the delegating organization during the delegation process. Such a brief could include no information, only a

description of the parent joint goal, or a complete description of the parent joint intention.

- **Task novelty**: This settable provides input on the novelty of the task to the team based upon either actual, previous, experience or preparedness through rehearsal.

  This information will be derived by considering the experience parameter of the sub-organisations and then using that to determine the task experience/novelty of the organization as a whole.

- **Task skills**: This is defined as the ability of the team to do the task well based upon previous experience. It is the consistency between the skill set required by the task, and that which is provided by the team members. This consistency is what will be of particular interest when we use this; by comparing this task skill knowledge settable with task difficulty and richness as a requirement for maturity transition.

  This is a composite of training and experience within the context of the task being undertaken. This variable is pivotal in agile teamworking. It is based on the plan libraries of the organization and sub-organizations. The overall task skills for the organization will then be derived from the settings of the sub-organizations.

These settables are a means of information transfer from the Organization to the Team Maturity model. As can be seen from Figure 3, it provides contextual information on the conditions and situation within which the team must perform. A change in a settable could affect the knowledge available to the team which may stunt or negate progression through the maturity stages. For example, if a task becomes richer, the team may not have all of the information necessary to them, which could cause them to move down to an earlier stage of maturity, until they are able to obtain this information to proceed to the next stage of maturity.

3.2 Team Maturity and Organizational Processes

The Team maturity affects the following organizational processes:

- **Selecting an Organization**: Depending on its maturity level, an organization might have different selection functions available to it to determine which other organization, including sub-teams, should be tasked. More mature organizations might have more advanced methods of assessment and selection.[2] Furthermore, the time it takes to select an organization might depend on the maturity of the organization.

- **Selecting a Social Structure**: The applicable social structure for the situation might depend on the maturity level of the organization. For example, different levels of authority and communication would be required or feasible depending on the maturity level of the organization. Furthermore, the time it takes to select a social structure might depend on the maturity of the organization.

- **Selecting an Organizational Plan**: Similar to the selection of the social structure, the applicable organizational plan for the situation might depend on the maturity level with different levels of coordination and synchronization required or feasible depending on the maturity level of the organization. Furthermore, the time it takes to select an organizational plan might depend on the maturity of the organization.

- **Adopting a Social Structure**: The time it takes for all members of the organization to adopt a new social structure might depend on the maturity level.

- **Forming a Joint Intention**: The time it takes for all members of the organization to adopt a new joint intention might depend on the maturity level.

- **Adding a Joint Intention to Joint Intention Structure**: The time it takes for all members of the organization to adopt a new joint intention might depend on the maturity level.

- **Selecting a Set of Joint Intentions**: An organization might be a sub-team of multiple organizations. The selection of one set of joint intentions belonging to one organization over another might depend on the maturity level of these organizations. For example, an executing organization might favour acting on the intentions of a more mature organization as compared to a forming organization. Alternatively, an organization might be more committed to an organization that is forming as it might be more sensitive to failure.

The individual and combined impact of the maturity level on these processes will result in subtle, but possibly, significant change to the effectiveness of the organization. As the maturity level changes so will the operational behaviour of the organization.

3.3 Expected Limitations

The framework described here is a first attempt at modelling the formal and informal aspects of team behaviour. As such it provides an exciting opportunity but also exposes areas of uncertainty. The interplay between organizational behaviour and team maturity provides an extension to exiting modelling frameworks. However, this co-dependency introduces the potential for the behaviour to be either too complex or too difficult to specify. Furthermore, like any new complex framework, it requires field testing and fine tuning.

[2] A possible extension is to make the maturity level of organizations observable allowing for such knowledge to be used by other organizations in their selection process.

4. CONCLUSION AND FURTHER WORK

The approach described here presents a first attempt at combining theories of modelling formal organizations embedded in dynamic environments with a conceptual model of team maturity to determine performance. The knowledge, mental state, situation and operational modelling of an organization and its sub-teams provide input into determining the organization's maturity level. In turn, the maturity level influences the capacity of the organization to function in an effective and timely fashion.

The theoretical work described here is the foundation for the development of the DARNSTORMS modelling and simulation system. The outcome of this implementation will test the boundaries and limitations of the theory and will be used to validate the approach presented here.

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