

# Variety versus speed: how variety in competence within teams may affect performance in a dynamic decision-making task

Ulrik Spak  
Swedish defence university  
ulrik.spak@fhs.se

Isabell Andersson  
Swedish defence university  
isabell.andersson@fhs.se

## Abstract

Command and control (C2) activities are conducted in various domains such as defence, emergency response, police and crises management. The problems in these domains are often characterized by complexity, i.e. having a high degree of variety. According to cybernetic theory, the variety of the controller (the C2 system) must equal or exceed that of the controlled system in the operational environment. The degree of variety sufficient to control a particular system is defined as requisite variety.

In this paper we aim to operationalize both external and internal variety, closing the gap between high level abstract descriptions and concrete solutions, in order to suggest practical propositions when designing C2 systems. C2 systems are composed by methods, technology, personnel and organization. In this work we focus on the aspects of personnel and organization. A particular interest is dedicated to the competence variable within the personnel component. We discuss, based on previous research on e.g. diversity, what dimensions of the competence variable may be of most importance when performing C2 activities to cope with complexity.

However, a substantial amount of C2 research, also suggests that making fast decisions is important to cope with problems stemming from an adversary. We elaborate on the potential cost of high internal variety in that it may delay decisions in the C2 team because of a raised need for team communication. We conclude by presenting an investigative method, which includes simulated external complexity requiring dynamic decision-making that is handled by C2 teams with different types of competence (internal variety).

## 1 EXTERNAL AND INTERNAL VARIETY AND THE NEED FOR SPEED

The notion of a general demand to match the features and potential problems in the endeavor space (the outer environment) with requisite variety and solutions in the C2 approach space (inner environment) have endured for several years in the C2 community and research [1]. The ideas regarding requisite variety originates from cybernetics and were developed by Ashby [2]. The basics of requisite variety can be presented as a so called “pay-off matrix” where a set of disturbances D (rows in the matrix) can be met by, or controlled by, a regulator with a set of responses R (columns in the matrix). The intersections between disturbances and responses constitute the possible outcomes O.

Table 1. The pay-off-matrix. Adapted from [3, p. 2].

D \ R	R	r 1	r 2	r 3
d 1		O 11	O 12	O 13
d 2		O 21	O 22	O 23
d 3		O 31	O 32	O 33

The denotation of this matrix is expressed in Ashby’s famous law of requisite variety that states: “the latter [R] cannot be less than the quotient of the number of rows divided by the number of columns” [3, pp. 2-4] or put in another way: “an effective controller must have variety greater than or equal to the system it seeks to control” as perceptively described by Niven and Capewell in a C2 context [4, p. 6].

This matching is also closely related to the view on design as proposed by Simon [5] that implies the inner environment designs an interface (an artefact) to handle the properties of the outer environment, and also to the

viable systems model (VSM) as proposed by Beer [6].

In this paper, we will start by presenting a general description of the operational environment or endeavor space with its characteristic features and the typical demands related to those features. The variety found among features and potential problems will be termed *external variety*.

Our perspective on C2 consists of a systemic view which implies that a mission respondent system consists of a C2-system and an execution system (see figure 1). Our definition of C2 is: C2 is a human activity or system that strives to solve (military) problems in order to achieve goals. The key products stemming from the C2-process are direction and coordination [7].

influence the potential variety in the controlling C2 system as a whole.

However, the personnel component is not obvious in the C2-approach space. We have chosen to focus our efforts on the personnel component for two main reasons. First, it is probably the least investigated part of the C2 system within C2 research. One recent and noteworthy exception though is Valaker et al. [9]. Second, it is in our perspective, the most influential factor in a C2 system, not least because C2 is so closely connected to decision making. Making decisions is, despite the radical development in artificial intelligence (AI), chiefly a human activity.

Naturally, the personnel component can be further broken down into several distinct sub-components such

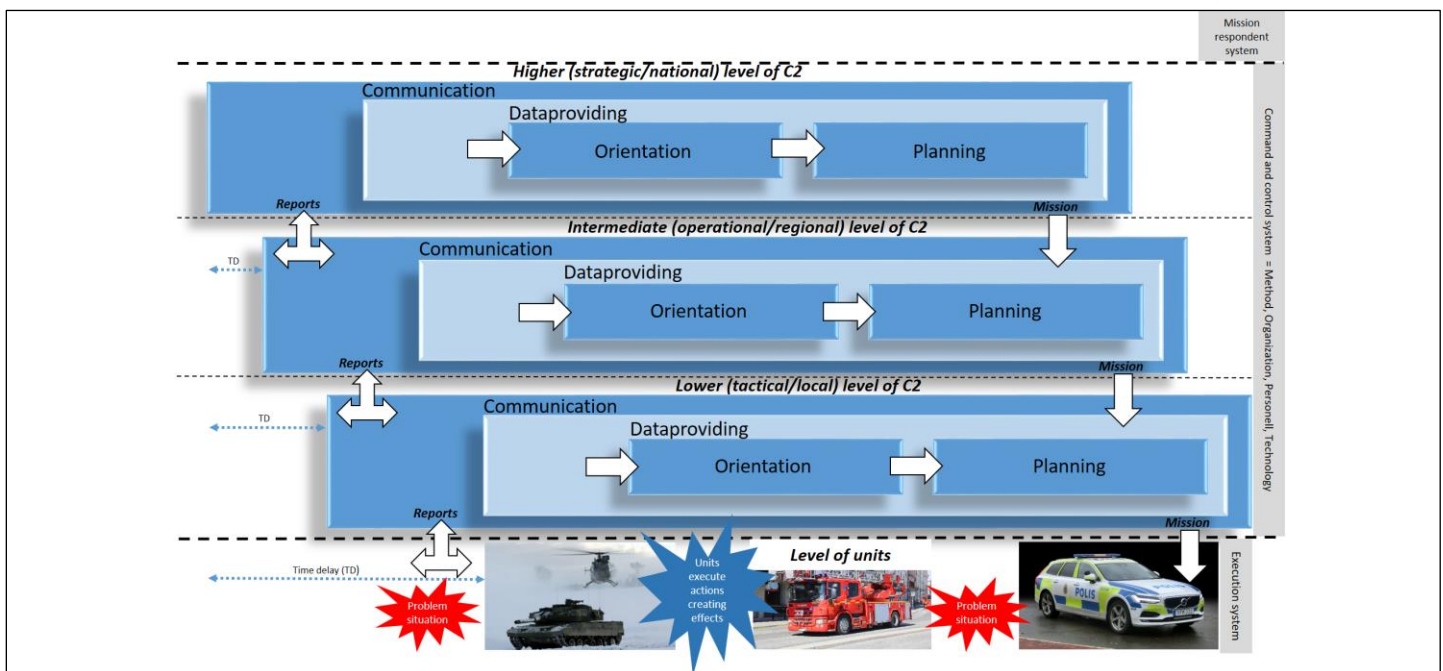


Figure 1. A mission respondent system consists of a C2-system and an execution system (grey entities to the far right in the picture). The C2-system is presented with three levels of command, which in turn include the recursive and generic activities of communication, data-providing, orientation and planning [7, p. 3].

The C2-approach space can be regarded as the abstract or theoretical description of critical aspects of a real C2 system. The C2-approach space is constituted by three inter-dependent dimensions: a) distribution of information, b) patterns of interaction, and c) allocation of decision rights [8]. One way of representing a concrete C2 system is by listing its components: methods, organization, personnel and technology [7, p. 14]. There are linkages between the dimensions in the C2-approach space and the categories of organization, methods and technology in a C2 system. The potential variety within each, and in combination between, these categories

as individuals demographic characteristics (e.g. gender, age, ethnicity), and functional or task-related diversity aspects (e.g. knowledge, skills, and expertise/competence). In this paper we will primarily address the competence factor and more specifically task/mission competence [10, pp. 105-182]. Accordingly, the competence factor will be our main interest when describing the *internal variety* within the C2 system.

The level of analysis will be on teams and how they solve problems within a typical C2 process, e.g. making mission analysis and performing estimations about what to do [11], in a context characterized by execution and dynamic

decision making. In this paper, we adopt the definition of a team as suggested by [12, p. 5]:

(a) are composed of two or more individuals, (b) who exist to perform organizationally relevant tasks, (c) share one or more common goals, (d) exhibit task interdependencies (i.e., workflow, goals, knowledge, and outcomes), (e) interact socially (face-to-face or, increasingly, virtually), (f) maintain and manage boundaries, and (g) are embedded in an organizational context that sets boundaries, constrains the team, and influences exchanges with other units in the broader entity.

Further, our interest in the team-level of analysis has a direct relation to increased possibilities concerning variety that the team level has in comparison to an individual. Ashby [3, p. 10] also noticed this possibility:

[T]he limitation on “the capacity of Man” is grossly ambiguous, according to whether we refer to a single person, to a team, or to the whole of organized society. Obviously, that one man has a limited capacity does not impose a limitation on a team of  $n$  men, if  $n$  may be increased without limit. Thus the limitation that holds over a team of  $n$  men may be much higher, possibly  $n$  times as high, as that holding over the individual man.

In C2 in general and in C2 decision-making in particular, the generic need for performing fast, or at least faster in relation to a adversary, is a long-lived and well established principle. This principle is prominent in for example the work of Boyd (the Orient-Observe-Decide-Act-loop) [13], the writings of Klein (Recognition Primed Decision-making) [14] and the theoretical framework developed by Endsley (Situation Awareness) [15].

These three areas of research all highlight the relation between experience, expertise and the possibility to perform rapid decision making. However, we consider that there is a probable trade-off between making fast decisions (in teams) and coping with certain important aspects of complexity in the operational environment. One particular aspect of interest is the ability to manage unexpected events [16], [17].

We hypothesize that a team with a low level of variety (regarding for example a specific class of mission- or task competence) may be relatively fast to make decisions, yet simultaneously less likely to notice and effectively handle unexpected events. On the other hand, we also hypothesize that a team with high level of variety (varying mission- or task competencies) may be relatively slower

to make decisions, yet simultaneously more likely to notice and effectively manage unexpected events.

In this paper, we therefore develop a method of investigating the more precise nature of the balance between variety and speed and how it affects performance. The costs of not having enough or requisite variety in one’s mission respondent system can be catastrophic as shown clearly by historic events. One well-known example was the battle of Agincourt in the year 1415 when the French armored knights made a cavalry attack against the English longbowmen and were effectively stopped. The battle result was a complete disaster for the French side and marks the end of the knight era [18]. A typical example of not having enough speed (regarding transient maneuvers) is described in the experiences provided by Boyd when, due to superior transient maneuver speed, the US F-86 fighter jets had a kill rate against the Russian Mig-15 of 10:1 [19, p. 41] in the Korean war.

### 1.1 THE OPERATIONAL ENVIRONMENT - EXTERNAL VARIETY

In domains such as defence, emergency response and crises management, the operational environment including potential specific situations or problems, can be described by a set of constituent factors. One example of such a set is proposed by Brehmer [20, pp. 41-48]. He suggests that these factors are regarded as constraints that build up a possibility-space in which all possible courses of action can be found/discovered. These factors are: time, task/mission, resources, legal framework (e.g., rules of engagement), terrain, doctrine, and enemy/accident.

The factors listed above can be further broken down and the resulting components can be regarded as parts of the operational environment or the outer environment/endeavor space. These parts are of course numerous and they are also interrelated with each other. The relations between the components may change over time. This web of many interacting components that change over time is often characterized as being complex [21, pp. 47-60]. Further, we consider the relation between complexity and variety in a similar way as suggested by [4, p. 2]: “We equate ‘variety’ with the range of underlying relationships and interactions that combine to create the emergent properties of a complex operating situation.”

Before going into some examples of how to define the level of complexity, we need to state our stance that the operational environment is an objective, real, and existing

part of the world. It can to a certain extent be observed. In parallel there are corresponding subjective operational environments, i.e. how we interpret what we observe in the world.

There are several attempts to classify the level of complexity in the operational environment. One prominent path in C2 research is the ongoing strive for matching the C2 approach space with the endeavor space: “For any given location in the Endeavor Space, there is a corresponding region in the C2 Approach Space that contains the C2 Approaches best suited for this type of mission under a specific set of circumstances (situation)” [22, p. 4]. The suggested dimensions are: a) coupling/causality, b) dynamics and c) complexity/tractability. Both a) and b) correspond to the features mentioned above about complexity regarding “many interacting components that change over time”. The dimension c) however is of a different sort, more related to the level of perceived difficulty by an observer or “self”.

Another concept closely related to complexity is “wicked problems” [23, pp. 161-166] as described by for example Kalloniatis et al. [24]. The characteristics of a wicked problem include there is “no definitive formulation”, they lack a “stopping rule”, and solutions are not “true-or-false”. Solutions are difficult to test because each trial generates effects that last for long times and each trial also alters the environment, thus “every trial counts”. Wicked problems have an unknown number of potential solutions and they are all “essentially unique”. Finally, every wicked problem is linked to, or is a symptom of, another wicked problem at a higher level. The context of wicked problems is social planning. Military operations are probably a similar context.

The cynefin framework [25] is used in several relevant applications such as in the Swedish military handbook for planning and C2 on the strategic and operational levels of command [26], and also in the European field guide: Managing complexity (and chaos) in times of crisis [27, p. 63]. This framework presents four different problem domains: clear, complicated, complex and chaotic as presented in figure 2.

We conclude this section by noting that descriptions of complexity in the operational environment often are a mix of objective features and how these features may be perceived by an observer.

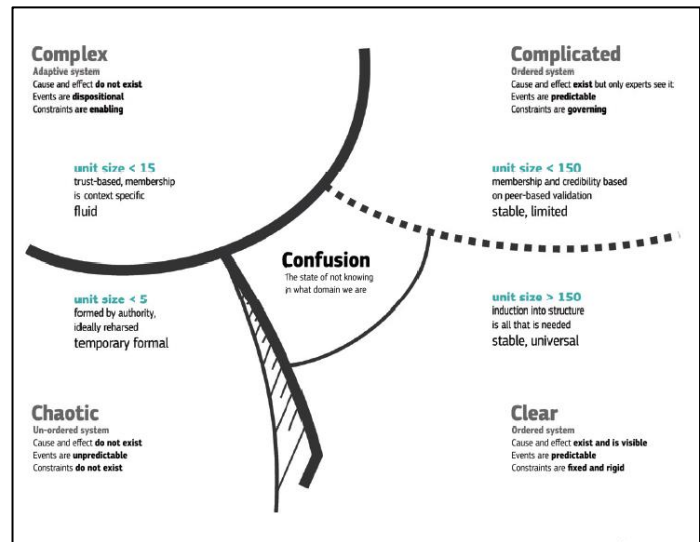


Figure 2. The Cynefin domains and their characteristics [27, p. 63].

#### THE C2 SYSTEM – INTERNAL VARIETY

Internal variety in the C2 system may originate from all components in the C2 system. In this section, we focus on the personnel component. As mentioned above we have chosen to focus on variety in team members competence when performing certain steps of the C2-process. This approach resembles the work presented by Valaker et al. [9] in that both focus on the competence variable. However, Valaker et al. primarily investigate competence to coordinate in a multiteam context *between* teams, while we focus on competence *within* teams to direct and coordinate resources (cf. the C2-system and the execution system in figure 1). Further, the former work also include the potential relation between multiteam competence to coordinate and organizational structure, and how these factors could influence the shift between coordination forms. In this paper, even though we find the relation between competence and organizational structure natural and well worth a research emphasis in it's own right, we chose to delimit our effort to the relation between competence variety within a C2-team and the variety/complexity regarding the situation/problem in the operational environment.

In research on teamwork, the composition of teams is seen as one of the central antecedent factors that drive team processes and contributes to team performance [28], [29], [30], [31], [32], [33]. Team member characteristics affect both team processes such as cognitive, verbal and behavioral activities [34], and affective or cognitive states within the team [29], both

which are assumed to affect team outcomes.

In order to understand variety in terms of (C2) teams, we have to address a synonymous term widely used in e.g. applied psychology, namely diversity. Teamwork and team composition, or diversity among team members, has a rich research background as presented in e.g. [35], [36], [31].

Diversity in teams has been defined as “the distribution of differences among the members of a unit with respect to a common attribute” [37, p. 1200]. What attributes would be of relevance in our case? There are two broad categories of attributes; bio-demographic characteristics such as gender, age, and ethnicity; and task-related characteristics, which concerns attributes such as team members’ functional expertise, education, and organizational tenure [38].

There are mixed results regarding the relationship between team diversity and performance of the team (see e.g., [33], [31], [39], [40]). There is a general tendency however that task-related diversity is positively related to output of the team, whereas the effects of bio-demographic diversity are more weak or negative. For instance, in a meta-analysis Horowitz and Horovitz [38] examined effects of team diversity on decision making, creativity/innovation and problem solving. Results showed a positive relationship between task-related diversity and quality and quantity of team performance, whereas there was no significant relationship between bio-demographic variety and performance. Other meta-analyses have found small negative effects of bio-demographic diversity and positive effects of task-related diversity [41].

Findings of negative effects of demographic differences are usually attributed to social categorization processes within the team. In contrast, findings of positive effects of task-related diversity is attributed to team information elaboration, such as exchange of information and perspectives, the process of feeding back the results of individual-level processing into the group, and discussion and integration of information [33]. Teams composed by team members with different knowledge, perspectives and functional experiences would provide a broader knowledge base [42], which in turn could lead to more creative solutions, e.g. [43]. Processing of this rich information among team members may be more time consuming however [33].

Moreover, the effect of task-related diversity seems to be moderated by task complexity. The more complex the

task, the stronger positive relationship between task-related diversity and performance, e.g. [40], [44].

In sum, there are mixed results regarding effects of team composition, however a diverse team in terms of task-related attributes seems to benefit team performance, particularly in complex tasks. There might be a downside, though, in that information processing requires more time in such a team.

## 1.2 THE NEED FOR SPEED

The thinking and writing of air force colonel Boyd is perhaps the clearest example of prioritization of the speed factor in military affairs. He proposed that [45, p. 5]: “[I]n order to win, we should operate at a faster tempo or rhythm than our adversaries—or, better yet, get inside adversary’s Observation-Orientation-Decision-Action time cycle or loop.” (Underlining in original.) By acting this way, we will appear as unpredictable, and the adversary would be confused and disordered according to Boyd. Even though the original ideas on the need for speed were developed in a single individual (i.e. pilot) context, Boyd also extended his thoughts to a broader meaning. Inspired by the tactics used by the Germans in World War II (“Blitzkrieg”), he suggested that a “common outlook” has the implication of “a unifying theme that can be used to simultaneously encourage subordinates initiative yet realize superior intent” [45, p. 74]. A common outlook is in turn developed in conditions where officers have the same training, tactical education, way of thinking and speech. It is difficult not noticing the proposed link between a high level of similarity or a low variety/diversity regarding certain variables among officers, and the capability to act fast on the tactical level of command. Boyd’s reasoning has had a significant impact on military education and doctrine, e.g. [19, p. 4].

Klein developed the Recognition Primed Decision-making model (RPD), which to a large extent is based on the recognition of goals, critical cues and expectancies in dynamic situations. Thus, the decision maker’s experiences and expertise in a specific domain is of great importance [14], [46]. The theoretical underpinnings from RPD has been used to develop military planning manuals with the purpose of managing time-constrained situations more effectively [47], [48].

Endsley’s model of situation awareness (SA) also highlights the importance of experience and training when conducting the hierarchical situation assessment process [15]. The first level is about perception of

elements in a current situation. The second level concerns the comprehension of current situation and the third level regards the projection of future status. Endsley emphasizes the importance of time in gaining SA in general, and specifically highlight the advantages of developed mental models through experiences in relation to decision-making [49, p. 24]: “A direct, single-step link between recognized situation classifications and typical actions, enabling very rapid decisions to be made”. The SA concept is applied in military handbooks such as [11].

Situations in dynamic environments demand dynamic decision-making (DDM). This field of decision-making research focus, among other things, on the problems related to the time factor [50]. Time delays (TD) occur within the C2-system between the structural levels of command, and between the C2-system and the execution system as presented in figure 1. In the mission respondent system as a whole, TD occur both in the feed-forward part (command) of the C2-process as missions or tasks, and in the feedback part (control) of the C2-process as for example reports.

## 2 HOW MUCH VARIETY AND SPEED?

The exposé above regarding external and internal variety accentuate the need to match internal capabilities in terms of for example specific mission competences in C2-teams, with the given type of situation or problem in the operational environment (level of complexity). Hence, we propose this overall research question:

*How does the variety of task/mission competences within C2-teams affect performance in dynamic decision-making tasks with varying levels of complexity?*

We further suggest this set of hypothesis in order to investigate the overall research question:

H1a: Teams with high variety regarding mission competencies will perform relatively less effective than teams with low variety in tasks characterized with low complexity.

H1b: Teams with high variety regarding mission competencies will perform relatively more effective than teams with low variety in tasks characterized with high complexity.

H2: Teams with high variety regarding mission competencies will communicate more and make relatively slower decisions than teams with low variety in both low and high complexity tasks.

*Table 1. Variables and performance*

	High level of complexity in task/environment	Low level of complexity in task/environment
High variety teams	More effective	Less effective
Low variety teams	Less effective	More effective

### 2.1 HOW CAN THE BALANCE BETWEEN INTERNAL AND EXTERNAL VARIETY BE INVESTIGATED – THE USAGE OF MICROWORLDS

The word “performance” is mentioned in the research question and in the following hypothesis. A key question is of course how performance should be operationalized? We stated in the introduction that the main result or products from the C2-process are direction and coordination. So if we want to relate performance to C2, we need to find a way to measure direction and coordination. In this paper however, we want to study the relation between the C2-system (i.e. the C2-team) and the operational environment. Since the C2-system in itself does not create any effects in the environment, but is dependent on the execution system to carry out concrete actions, we need a method that can control the potential effects stemming from the execution system, thereby isolating effects from manipulation of the C2-system (such as team composition/variety in mission competences).

One conceptual way of doing just that, is to use microworlds [51]. In a microworld, the experiment-designer has the possibility to connect the actions by a C2 team with the effects in the operational environment, without the potentially confounding interactions by the execution system, since it is controlled by the simulation.

In the C3Fire microworld (see figure 4) the overall task is to control forest fires in the environment by extinguishing them with resources in terms of e.g. firefighting units, fire break units, water logistics and UAV-units [52], [53]. The overall task implies that the external variety/complexity relates to the behavior of the fire which in turn interacts with the properties/features of the terrain/substrate (including wind direction and strength) and the fire fighting units (types and number).

The internal variety depends on the chosen organization for the C2-team such as the number of roles (correlates with the types of fire-fighting units in the external environment) and the number of participants (one participant can sometimes occupy more than one role).

Further, the allocation of decision rights can be varied among participants and communication can also be regulated, permitting for example architectures, which are either networked or hierarchical based. Indeed, several previous studies used C3Fire to investigate the effects of different architectures under varying levels of complexity [54].

To our knowledge, the mission competence variable within C2-teams has not been specifically investigated in previous C3Fire studies. Factors related to the personnel component within the C2-system has to a limited degree been the focus of earlier experiment. The personality factor was the focus in one pilot study [55] and cultural differences was investigated in [56]. One study that touched upon the mission competence perspective inquired the effect of organizational structure in the execution system. This approach implied that participants managed either a set of resources of the same sort (functional) or a set of diverse resources (divisional) under three levels of complexity. Participants consisted of battle tank teams that had extended training together. Participants worked in teams of four people without a designated commander in a networked communication setting. Results displayed no significant differences between functional and divisional structure [57].

## 2.2 EXTERNAL VARIETY IN THE MICROWORLD

We propose that external variety in our forthcoming experimental investigation is tuned in, i.e. avoiding a too easy or too difficult task, using the vast experience from previous C3Fire experiments. Typical variations consider the number of simultaneous fires, the speed of fire, the number and speed of participating fire-fighting units and terrain features including wind direction and speed. We will use these possible variations to define our levels of complexity, i.e. high or low (see table 1).

In addition, we suggest that during each experimental session (not during training sessions) a number of unexpected events will occur. We consider this class of events important because of the assumed relation to the level of competence or expertise. Thus, we assume participants with high levels of mission competence or expertise are more likely not noticing and handling these sort of events. This assumption is based on that experts/specialists are more likely to focus their attention on a more narrow part of the operational environment, i.e. on sub-tasks related to their field of competence/expertise. In the context of C3Fire these fields of competence/expertise are connected to the

various types of fire-fighting units. Perhaps paradoxical, these assumptions regarding the individual participants, also implies on the analytical level of teams, that a team with all sorts of competence/expertise, is more likely to notice and handle unexpected events, i.e. the high variety team. Unexpected events could for example be a 180° shift in wind-direction complemented with a distinct increase of wind speed, or a fire-fighting unit might temporarily disappear from the display. It's noteworthy that the unexpected events in this context will still have a connection to the various fields of expertise, i.e. there will not be for example any gorillas in the screen (e.g., see [17, p. 8] regarding the phenomenon of inattentive blindness).

## 2.3 INTERNAL VARIETY IN THE MICROWORLD

The description of unexpected events leads to our suggestions regarding internal variety. We consider two types of teams. One with low variety (LV) regarding mission competence/expertise and one with high variety (HV). The variety variable is thus our independent variable. We define mission competence, within the context of the C3Fire application, to be the amount of training received on a specific type of fire-fighting resource. In the LV team, the participants undergo training directed towards managing a diverse set of resources, i.e. one fire-fighting unit of each type in a total of four units (A, B, C, D). Hence, all members of the LV team will have the same training and the same mission competence in managing a diverse set of resources/units. It is notable though that individual members of the LV team will only have one quarter (¼) of training/competence regarding each type of competence in comparison to individual members in the HV team.

In the HV team, the participants undergo training directed towards managing a specific type of resources, i.e. four fire-fighting units of the same type (e.g. A, A, A, A). Hence, all members of the HV team will have different/specialist training and thus varying mission competence in managing a unified set of resources/units. Both groups will receive the same total amount of training on the team level of analysis. The resulting mission competence profile for each team will be either specialists (HV) or generalists (LV) as presented in table three and four below.

The actual number of team members is not given. As mentioned above in section 1.2 there are no fixed number of individuals in a team. The general rule of thumb is that the number of members must match with the required skills to manage a specific task. In the case of C3Fire, the



task often requires four different types of skills, hence each team will have to possess requisite skills and competences on a team level. The question is how to organize or structure these skills and competences?

We will probably not include a specific commander to each team. Instead, each team will work in a self-synchronizing manner with networked possibilities to communicate and make decisions. This does not imply though that a C2-system is lacking. The participating team members have the role of local commanders (i.e. the C2-system), and the resources in the simulation constitute the execution system.

*Table 3. The high variety team (specialists).*

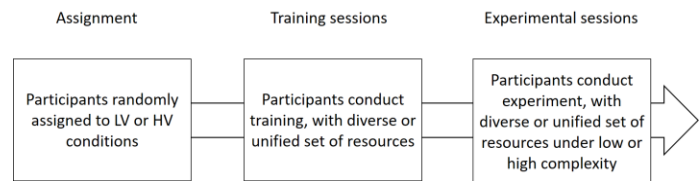
Competencies (A,B,C,D) Individual team member (TM)				
TM 1, specialist competence	A	A	A	A
TM 2, specialist competence	B	B	B	B
TM 3, specialist competence	C	C	C	C
TM 4, specialist competence	D	D	D	D

*Table 4. The low variety team (generalists).*

Competencies (A,B,C,D) Individual team member (TM)				
TM 1, generalist competence	A	B	C	D
TM 2, generalist competence	A	B	C	D
TM 3, generalist competence	A	B	C	D
TM 4, generalist competence	A	B	C	D

The following experimental sessions must probably include a balancing design in that all teams of both types (LV and HV) carry out both types of resource distribution.

This means that both the LV and HV teams fulfill an equal amount of sessions with diverse set of resources and unified set of resources. The reason for this balancing design is to control for the potential effects of organization/structure of the execution system. Our aim here is instead to focus on the potential effects of internal or team variety regarding the mission competence/expertise. A possible outline for the experimental design is presented in figure 3 below.



*Figure 3. Experiment procedure displaying random assignment, training- and experiment sessions.*

## 2.4 PERFORMANCE IN THE MICROWORLD

Usually, performance or the dependent variable in C3Fire, is the amount/number of burned out cells in the terrain. In some experiments, a variant of this measure has been used.

In the same way as the speed-factor is evident when entities in the external environment are considered, the speed of decisions and corresponding actions are important to study in the C2-teams (see supporting hypothesis H2). This interest in tempo of decision-making triggers the question: what does decision-making imply in the context of C3Fire? One possible line of thought is that all responses (actions) created by the team as a whole correlates/responds with decision-making tempo. The problem with that assumption is the non-decisions, i.e. those that does not generate any actions – those that are concealed from observation. Another more indirect measure is to focus on communication. Communication is necessary to coordinate resources in order to solve the overall fire-fighting task. The communication of messages will inform team members of the situation/problem at hand, and thus form the basis for decisions and actions. To communicate takes time and therefore it is likely to assume a correlation between amount of communication and decision-making tempo.

It is important to define communication since the function of communication may be fulfilled by different means. Messages could be sent and received as text messages with the built-in chat function in the application. On the other hand, communication could also be achieved by



observing the graphical map interface (cf. operational picture). In turn, which parts of the map interface that is available will depend on both the general settings in the simulation, and how information-gathering units (e.g. UAV) are managed by the team. Hence, how the function of communication is fulfilled (text-messages and or via the graphical interface) is significant when the internal aspects of decision (and action) speed, as a function of communication, is considered.

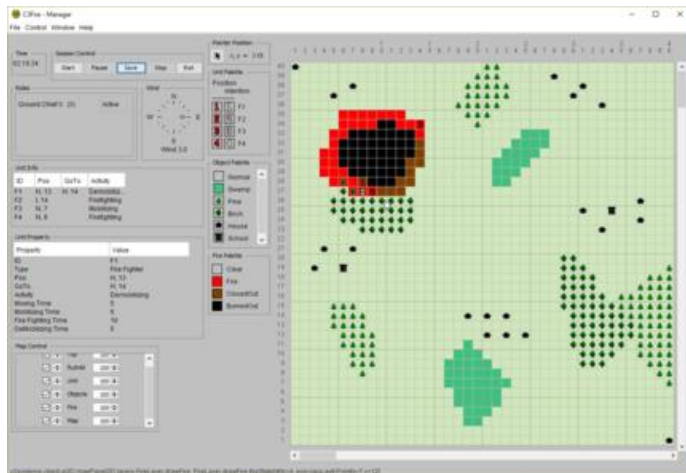


Figure 4: C3Fire interface displaying a wildfire in the terrain to the right and information about units and wind to the left.

### 3 DISCUSSION

Above we posed the research question:

*How does the variety of task/mission competences within C2-teams affect performance in dynamic decision-making tasks with varying levels of complexity?*

We also suggested a set of hypothesis regarding the relation between the teams levels of mission competence (high/low) and the level of complexity (high/low). A supportive hypothesis (H2) was developed to investigate the relation between the teams levels of mission competence variety and amount of communication/decision tempo. In the following section we discuss some methodological issues with potential implications to the research question and the hypothesis.

### 3.1 METHODOLOGICAL ISSUES

The general task conducted in the microworld C3Fire is a good example of a dynamic decision-making task. However, one may challenge the task being a sufficiently valid example of a C2-task/mission since there is not an obvious need to develop a concept, a course of action (COA) or a plan for the C2-team before the experimental sessions start. One possible way of reinforcing the C2 aspects of the task may be to instruct the team to make a very simple concept or COA before the experiment starts. Then, in-between the experimental sessions, the team could be instructed to update and correct their concept/COA. Eventual updates/corrections should be documented via a prepared template. The replay functionality in C3Fire could possibly also be used for this purpose.

There will be a need to develop a special measure regarding the unexpected events. This follows from the fact that there can only be a limited amount/number of unexpected events in the simulation, otherwise the events would not be unexpected. Hence, there will be few data-points to measure and therefore probably not possible to calculate statistics for this class of events. However, there are other ways to document participants managing of these events. One direct way is to ask participants specifically about these events afterwards.

Our proposed method relies heavily on the assumptions that the training sessions develop the types of task competencies we judged (LV and HV), and that the four types of resources are different enough to generate different competencies. A way to validate these assumptions before setting up the experiment would be desirable.

We have also argued that task/mission competence is more important to focus on than competencies connected to teamwork per se. One particular team-work skill/competence is communication which we also aim to measure (relates to the supporting hypothesis) in the experiment. Will the attributes related to teamwork be sufficiently controlled for by our randomized assignment of participants to each condition, so that effects regarding communication will be adequately related to our manipulation of the LV-HV-variable?

Are the external properties of the microworld adequate in relation to other elaborated descriptions of the operational/outer environment/endeavor space such as the constraining factors in possibility space as presented by [20]? Will the microworld satisfy our expectations about providing controllable variables for us as

experimenters, and at the same time present a sufficiently complex task, with aspects of a wicked problem and perhaps also a touch of confusion, to the participants in our C2 teams (cf. objective and subjective complexity above)?

We propose to measure performance in the C3Fire microworld by observing the number of burned-down cells in combination with a questionnaire. We need to harmonize these measures with an operationalization of “requisite” in the suggested experiment. What is requisite performance in this particular task? Our results will hopefully indicate what sort of organization/composition of competence (VH or HV) that is relatively more effective than the other – but will the results be requisite effective?

A complementary approach for a following experiment could be to compare the effects of on what level in the organization the variety of task/mission competencies is most effective? Would there be similar or different effects if variety instead was implemented in either the execution system or on a higher level of command in the C2-system?

### 3.2 CONCLUSION

In this paper, we have described why it is important to find out how the complexity in the external operational environment can be managed by a C2 team within a C2 system. Naturally, variety emerge from all the components in the C2 system. However, in the present work we focus on the personnel component. We therefore propose a method to investigate the relative influences of variety regarding task/mission competencies in C2-teams under different levels of complexity.

### REFERENCES

- [1] North Atlantic Treaty Organization (NATO), "C2 Agility: Task Group SAS-085 Final Report," NATO, 2014.
- [2] R. W. Ashby, An introduction to cybernetics, London, United Kingdom: Chapman & Hall Ltd., 1957.
- [3] R. W. Ashby, "Requisite variety and its implications for the control of complex systems," *Cybernetica*, vol. 1, no. 2, pp. 83-99, 1958.
- [4] G. Niven and D. Capewell, "The Variety Calculus – an alternative proposition for command & control in a complex world," in *International Command and Control Research and Technology Symposium (ICCRTS)*, Laurel, MD, 2019.
- [5] H. A. Simon, *The Sciences of the Artificial*, Cambridge: The MIT Press, 1969/1996.
- [6] S. Beer, *Diagnosing the system for organizations*, Chichester, New York: Wiley, 1985.
- [7] U. Spak, "Time aspects of command and control," in *25th International Command and Control Research and Technology Symposium (ICCRTS)*, Southamton, UK, 2020.
- [8] North Atlantic Treaty Organization (NATO), "SAS 050 Exploring New Command and Control Concepts and Capabilities," NATO, 2006.
- [9] S. Valaker, R. Stensrud, A.-C. Jenssen, W. Åsen, A. M. Ravnå Nyaas and T. Andersen, "Shifting between coordination forms: The role of competencies and organizational structure," in *International Command and Control Research and Technology Symposium (ICCRTS)*, Quebec city, Canada, 2022.
- [10] A. Lantz, D. Ulber and P. Friedrich, *Problemen med teamarbete och hur du löser dem*, Lund: Studentlitteratur, 2020.
- [11] North Atlantic Treaty Organisation (NATO), "Comprehensive operations planning directive version 3.0," NATO, 2021.
- [12] S. W. J. Kozlowski and B. S. Bell, "Work groups and teams in organizations: Review update".
- [13] J. Boyd, *The essence of winning and losing*, <http://www.danford.net/boyd/index.htm>, Unpublished presentation, 1995.
- [14] C. C.-C. Klein, "Rapid decision on the fireground," in *Proceedings of the Human Factors and Ergonomics Society 30th Annual Meeting*, 1986.
- [15] M. Endsley, "Toward a Theory of Situation Awareness in Dynamic Systems," *Human factors*, vol. 1, no. 37, pp. 32-64, 1995.
- [16] U. Spak and I. Andersson, "Modelling command and control: potential negative effects of transferring features of the individual to the organization," in *International Command and Control Research and Technology Symposium (ICCRTS)*, Quebec city, 2022.
- [17] U. Spak and E. Nygren, "Enhancing change detection of the unexpected in monitoring tasks – guiding visual attention in command and control assessment," in *21st International Command and Control Research and Technology Symposium (ICCRTS)*, London, United Kingdom, 2016.

- [18] "Wikipedia: the free encyklopedia," [Online]. Available: [https://en.wikipedia.org/wiki/Battle\\_of\\_Agincourt](https://en.wikipedia.org/wiki/Battle_of_Agincourt). [Accessed 10 06 2023].
- [19] F. Osinga, Science, strategy and war: The strategic theory of John Boyd, Delft, Netherlands: Eburon Academic Publishers, 2005.
- [20] B. Brehmer, Insatsledning: Ledningsvetenskap hjälper dig att peka åt rätt håll, Stockholm: Försvarshögskolan, 2013.
- [21] D. S. Alberts, The agility advantage: A survival guide for complex enterprises and endeavors, DoD Command and Control Research Program (CCRP), CCRP Publication series, 2011.
- [22] B. Johansson, M. Carlerby and D. Alberts, "A Suggestion for Endeavour Space Dimensions," in *23rd International Command and Control Research and Technology Symposium (ICCRTS)*, Pensacola, FL, 2018.
- [23] H. W. J. Rittel and M. M. Webber, "Dilemmas in a general Theory of planning," *Policy Sciences*, vol. 4, pp. 155-169, 1973.
- [24] A. Kalloniatis, I. Macleod and P. La, "Bounding Wicked Problems: The C2 of Military Planning," in *International Command and Control Research and Technology Symposium (ICCRTS)*, Washington, 2009.
- [25] D. J. Snowden and M. E. Boone, "A Leader's Framework for Decision Making," *Harvard Business Review*, vol. 85, no. 11, pp. 68-76, 2007.
- [26] "Svensk planerings- och ledningsmetod (SPL)," Försvarsmakten, 2017.
- [27] D. Snowden and A. Rancati, Managing complexity (and chaos) in times of crisis, Luxembourg: European Union, 2021.
- [28] S. J. Bunderson and K. M. Sutcliffe, "Comparing alternative conceptualizations of functional diversity in management teams: Process and performance effects," *Academy of management journal*, vol. 45, no. 5, pp. 875-893, 2002.
- [29] D. R. Ilgen, J. R. Hollenbeck, M. Johnson and D. Jundt, "Teams in organizations: From input-process-output models to IMOI models," *Annu. Rev. Psychol.*, vol. 56, pp. 517-543, 2005.
- [30] J. Mathieu, T. M. Maynard, T. Rapp and L. Gilson, "Team Effectiveness 1997-2007: A Review of Recent Advancements and a Glimpse Into the Future," *Journal of Management*, vol. 34, no. 3, pp. 410-476, 2008.
- [31] J. E. Mathieu, P. T. Gallagher, M. A. Domingo and E. A. Klock, "Embracing Complexity: Reviewing the Past Decade of Team Effectiveness Research," *Annual Review of Organizational Psychology and Organizational Behavior*, vol. 6, pp. 17-46, 2019.
- [32] B. Meyer, "Team Diversity," in *The Wiley Blackwell handbook of the psychology of teamwork and collaborative processes.*, Chichester, UK, Wiley-Blackwell, 2017, pp. 151-175.
- [33] D. van Knippenberg, C. K. W. De Dreu and A. C. Homan, "Work Group Diversity and Group Performance: An Integrative Model and Research Agenda," *Journal of Applied Psychology*, vol. 89, no. 6, pp. 1008-1022, 2004.
- [34] M. A. Marks, J. E. Mathieu and S. J. Zaccaro, "A temporally based framework and taxonomy of team processes," *Academy of Management Review*, vol. 26, no. 3, pp. 356-376, 2001.
- [35] J. E. Mathieu, J. R. Hollenbeck, D. van Knippenberg and D. R. Ilgen, "A century of work teams in the journal of Applied Psychology," *Journal of Applied Psychology*, vol. 102, no. 3, pp. 452-467, 2017.
- [36] Q. Robertsson, A. M. Ryan and B. R. Ragins, "The evolution and future of diversity at work," *Journal of Applied Psychology*, vol. 102, no. 3, pp. 483-499, 2017.
- [37] D. A. Harrison and K. J. Klein, "What's the difference? Diversity constructs as separation, variety, or disparity in organizations," *Academy of Management Review*, vol. 32, no. 4, pp. 1199-1228, 2007.
- [38] S. K. Horwitz and I. B. Horwitz, "The effects of team diversity on team outcomes: A meta-analytic review of team demography," *Journal of management*, vol. 33, no. 6, pp. 987-1015, 2007.
- [39] K. Y. Williams and C. A. O'Reilly, III, "Demography and diversity in organizations: A review of 40 years of research," *Research in Organizational Behavior*, vol. 20, pp. 77-140, 1998.
- [40] H. van Dijk, M. L. van Engen and D. Van Knippenberg, "Defying conventional wisdom: A meta-analytical examination of the differences between demographic and job-related diversity relationships with performance," *Organizational Behavior and Human Decision Processes*, vol. 119, pp. 38-53, 2012.
- [41] A. Joshi and H. Roh, "The Role of Context in Work

- Team Diversity Research: A Meta-Analytic Review," *The Academy of Management Journal*, vol. 52, no. 3, pp. 599-627, 2009.
- [42] K. B. Dahlin, L. R. Weingart and P. J. Hinds, "Team diversity and information use," *Academy of Management Journal*, vol. 48, no. 6, pp. 1107-1123, 2005.
- [43] C. K. W. De Dreu and M. A. West, "Minority Dissent and Team Innovation: The Importance of Participation in Decision Making," *Journal of Applied Psychology*, vol. 86, no. 6, pp. 1191-1201, 2001.
- [44] K. A. Jehn, G. B. Northcraft and M. A. Neale, "Why differences make a difference: A field study of diversity, conflict, and performance in workgroups," *Administrative Science Quarterly*, vol. 44, no. 4, pp. 741-763, 1999.
- [45] J. Boyd, *Patterns of conflict*, <http://www.danford.net/boyd/index.htm>, Unpublished presentation, 1986.
- [46] G. Klein, *Sources of power: How people make decisions*, 1998.
- [47] P. Thunholm, "The state of the art and the state of the practice. A new model for tactical planning for the Swedish Armed Forces," in *Command and Control Research and Technology Symposium (ICCRTS)*, San Diego, 2006.
- [48] J. Schmitt and G. Klein, "A Recognition Planning Model," Defense Technical Information Center (DTIC), Fort Belvoir; VA, 1999.
- [49] M. R. Endsley and D. G. Jones, *Designing for Situation Awareness: An Approach to User-Centered Design*, Second Edition, Boca Raton, FL: CRC Press, Taylor & Francis Group, 2012.
- [50] B. Brehmer, "Dynamic decision making in command and control," in *The human in command: exploring the modern military experience*, New York, Kluwer Academic/Plenum Publishers, 2000, pp. 233-248.
- [51] B. Brehmer and D. Dörner, "Experiments with computer-simulated microworlds: Escaping both the narrow straits of the laboratory and the deep blue sea of the field study," *Computers in Human Behavior*, vol. 9, pp. 171-184, 1993.
- [52] R. Granlund, "C3 Learning Labs," [Online]. Available: [http://www.c3learninglabs.com/w/index.php/Main\\_Page](http://www.c3learninglabs.com/w/index.php/Main_Page). [Accessed 29 05 2023].
- [53] B. J. E. Johansson, R. Granlund and P. Berggren, "Studying team cognition in the C3Fire microworld," in *Contemporary research: Models, methodologies, and measures in distributed team cognition*, Boca Raton, CRC Press, 2020, p. Chapter 2.
- [54] M. Persson and G. Rigas, "Complexity: the dark side of network-centric warfare," *Cognition Technology and Work*, vol. 16, pp. 103-115, 2014.
- [55] B. Gustasson and C. Bäckman, "Team-personality: How to use relevant measurements to predict team-performance," in *47th International Military Testing Association (IMTA)*, Singapore, 2005.
- [56] K. Smith, I. Lindgren and R. Granlund, "Bridging cultural barriers to collaborative decision making in on-site operations coordination centers," Linköpings universitet, Linköping, 2007.
- [57] G. Rigas, M. Persson and B. Brehmer, "Organisationsformer för självsynkronisering: funktionell vs divisionsorganisation," Försvarshögskolan, Stockholm, 2005.