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A Context-Sensitive Functional Model of Teamwork Processes

Topic 3: Information Sharing and Collaboration Processes and Behaviors

Daniel Lafond (DRDC Valcartier)
Hengameh Irandoust (DRDC Valcartier)
Sébastien Tremblay (Université Laval)
Wilson Price (Université Laval)
Abder Rezak Benaskeur (DRDC Valcartier)

Point of Contact: Hengameh Irandoust
Defence Research and Development Canada – Valcartier
2459 Pie-XI North, Quebec, QC, G3J 1X5, CANADA
Tel.: (418) 844-4000 #4193

Hengameh.Irandoust@drdc-rddc.gc.ca

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Abstract

A great deal of effort in research on team functioning has been devoted to identifying the relevant cognitive and social processes (the building blocks of collaboration) and measuring their impact on team effectiveness. This body of research has shown how those processes mutually support each other and together determine the efficiency of teams and multiteam systems. Furthermore, there is evidence that the collaboration context and the characteristics of the task at hand can have a profound impact on teamwork requirements and mediate the relationship between team processes and team effectiveness. Here we consolidate these findings by organizing the key features of collaboration into a functional classification. We then develop a metric of the degree of collaborative interaction based on three key functions (team formation/adaptation, sharing awareness, and coordination) mediated by social factors such as trust, group motivation and cohesion. The proposed framework weighs the importance of each factor according to the characteristics of the context in order to derive context-specific models using a same generic structure.

Keywords: collaboration, team, multiteam system, command & control, team cognition, teamwork, teamwork modeling.

1. Introduction

1.1 Teams and multiteam systems

Teamwork involves two or more people (within or across organizations) interacting dynamically, adaptively, and interdependently toward a shared objective/goal/mission (Salas et al., 1992). Devine (2002) defines a team as "a collection of individuals who share a common goal, whose actions and outcomes are interdependent, who are perceived by themselves and others as a social entity, and who are embedded in an organizational context". Inter-team collaboration occurs when existing teams are called upon to work together to meet some emergent situation that no single team can effectively deal with (see Caldwell, 2005; Marks, DeChurch, Mathieu, Panzer, & Alonso, 2005; Endsley, & Jones, 2001). Inter-team collaboration can take place within a single agency, as in joint operations involving the army, navy and air force. Multi-agency teamwork also occurs when a number of emergency measures organizations, such as various police and fire-fighting forces, collaborate to deal with a particular situation.

1.2 Building blocks of collaboration

Salas and Fiore (2004) describe teamwork as being achieved when members of a team interact interdependently and work towards shared goals. They add that teamwork involves group orientation towards reaching these goals and adaptation of coordination strategies through communication. Accordingly teamwork is more than work accomplished by a group of individuals. Salas and Fiore suggest that teamwork can be viewed as the result of a collective cognitive, behavioral and attitudinal activity, which, as the following statement emphasises, is difficult to measure and analyse.

> "There are a multitude of individual attitudes, behaviors, decisions, and actions—all potentially measurable—that may contribute to successful outcomes for the entire organization. This complexity creates a major challenge for understanding and measuring organizational performance. Without a strong theory to guide the measurement and analysis, a mountain of seemingly unrelated and uninterpretable data can quickly overwhelm the analyst" (MacMillan et al., 2005, p. 253).

As MacMillan et al. (2005) pointed out, attempting to take into account the extensive number of potentially relevant factors of team effectiveness may result in more confusion than enlightenment unless this knowledge is organized and synthesized. It is therefore important to identify the primary determinants and requirements of collaborative interaction. Indeed, among the wide range of concepts identified in the scientific literature, a number of those can be highlighted as being the most important for successful collaboration. We came up with a list of eighteen distinct *building blocks of collaboration*:

Adaptability	Monitoring progress toward goals
Conflict management	Mutual monitoring and support
Communication	Planning and synchronization
Division of labor	Resource sharing
Goal specification	Shared knowledge, representations and intentions
Group cohesion and team identity	Systems interoperability
Group motivation and commitment	Systems monitoring
Leadership	Training & education
Mission analysis	Trust

This list essentially summarizes the key features of collaboration identified in a range of review articles (e.g., MacMillan et al., 2005; Rousseau, Aubé, & Savoie, 2006; Salas, Sims and Burke, 2005; Sartori, Waldherr, & Adams, 2006). It distinguishes different features of collaboration as best as possible without producing an overly lengthy list of redundant concepts. Nonetheless, it is clear that these concepts – while minimally redundant – are not independent. They are related to one another and jointly determine the degree and quality of interactions, which determines the potential capabilities of the group.

1.3 The role of the operational context

Several researchers have made a case for the importance of contextual factors and identified key dimensions along which the work settings may vary (e.g., Arrow, McGrath & Berdahl, 2000; Devine, 2002; Driskell & Salas, 2006; Leedom, 2001; Salas et al., 2005; Sartori et al., 2006; Stewart & Barrick, 2000). In order to better understand military C2 in teams and multiteam systems, it is important to consider research findings from other contexts while keeping in mind that not all the trends observed in one context necessarily generalize to another, mainly because the task requirements and constraints are not the same. For instance, Driskell, Salas and Hogan (1987) developed a taxonomy of task environments because they suggest that these taxonomies will help make predictions for studies that examine similar tasks: “The demands on an effective Explosive Ordnance Disposal (EOD) team are not necessarily the same as those on a Combat Information Center (CIC) or weapons fire team.” (Driskell et al., 1987, p. 2).

In a key review article on team performance modeling, Salas et al. (2005) call attention to the importance of context and list the environmental factors of *time pressure* and *task load* as being essential elements to include in any modeling exercise. Driskell and Salas (2006) also raised the issue of context and identified six contextual factors that they suggest will affect the performance of teams. These factors are: *type of distributed environment* (geographical distribution), *type of task* (physical requirements), *temporal context* (team history), *team size*, *status structure* (team structure) and *high stress/high demand* (time pressure and workload).

Devine’s (2002) taxonomy of workgroups also emphasizes the importance of context. His taxonomy is based on an important two-part conjecture: the critical determinants of team effectiveness vary, at least to some extent, as a function of team type; the characteristics of the team context are responsible for this variation. Devine (2002) therefore not only takes context explicitly into account by enumerating a number of workgroups of contrasting types, he also describes context through seven specific characteristics: *fundamental work cycle*, *physical ability requirements*, *temporal duration*, *task structure*, *active resistance*, *hardware dependence*, and *health risk.*

2. Functional classification of the building blocks

2.1 Types of collaborative interaction

Specific teamwork activities may be classified into a few basic types of interaction on the basis of their distinct *functions*. This suggests that the building blocks could be categorized along their function in order to characterize collaboration using a minimal number of constructs. Identifying these functions may also provide insights as to the relationship between team processes and outcomes. In the following analysis we identify three types of interaction that correspond to three key functions underlying collaboration. This synthesis classifies the features of collaboration into three distinct interaction types: 1) Sharing awareness; 2) Coordinating; and 3) Team/group formation and adaptation.

The first type of interaction is **sharing awareness**. This function includes processes aimed at achieving shared mental models of the workgroup/task/situation, including its goals and plans. It builds a common ground and shared understanding. Teamwork relies heavily on the concept of mutual awareness (Ioerger, 2003). It involves sharing *static information* such as knowledge of the team structure, of the mission objective and the plans for achieving it, as well as *transient information*, such as current task assignments, status of intermediate goals, resource availability, and other aspects defining the current situation.

The second type of interaction is **coordinating**. Espinosa, Lerch and Kraut (2004) define coordination as the effective management of dependencies among subtasks, resources (including equipment and tools), and people. If the group can carry out the task in an entirely independent manner, then there is nothing to coordinate. Dependencies arise when several individuals, subtasks, and resources need to interact in a synchronized way to complete a joint task. Coordination activities may occur either beforehand (planning, scheduling, etc.) or during task execution. Teams may coordinate by means of task programming mechanisms, such as schedules, plans and procedures, or by various forms of communication. March and Simon (1958) proposed that teams can rely on task programming mechanisms (or task organization) for the regular aspects of a task since they are more predictable and can be managed in a programmed way. They propose that teams resort to communication (i.e., coordination by feedback) during changing situations or when the task has very few predictable or routine elements.

The third type of interaction is **team formation and adaptation**. This function refers to the process of organizing and re-organizing the group/team in face of an initial context and subsequent changes in the situation. It also encompasses preventive measures such as mutual performance monitoring and the recovery process when unexpected events/errors occur. Teams flexibly respond to changes in the environment by adjusting their internal activities. Adaptation includes load-balancing, re-allocation of resources, and re-configuration of the team structure. It also includes shifting among strategies (or re-planning) and redefining roles. Adaptiveness is often taken as a characteristic of the most effective teams (Ioerger, 2003).

In summary, team processes can be classified as: 1) oriented toward sharing awareness (serving the function of comprehension); 2) oriented toward forming the team and adapting its structure and roles as a function of personal needs and external demands (goal-orientation); and 3) oriented toward accomplishing the actual taskwork *together*, as a team (which requires planning and coordination). This conceptual framework is thus aligned to a set of three prototypical features of behaviour (see Figure 1).

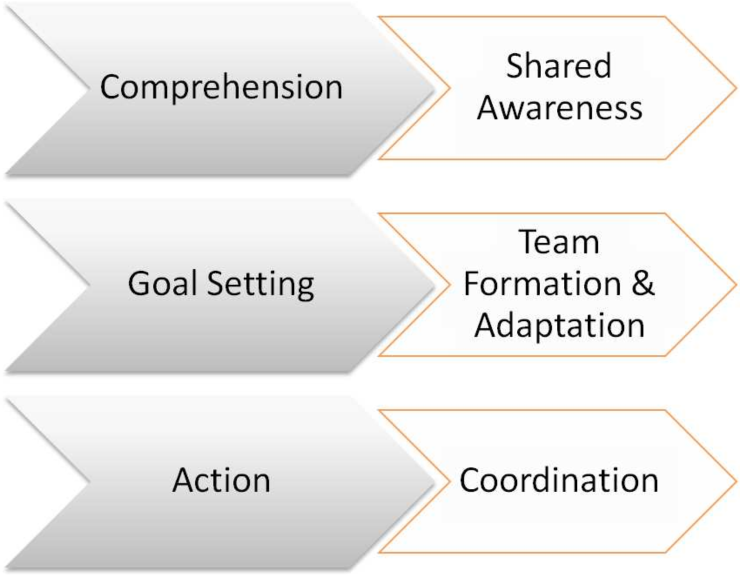

Figure 1: Aspects of behaviour associated with team functions

Practically all group processes involve communication: It can be seen as an integral part of each feature of collaboration, since interacting necessarily implies communicating. Communication is not classified into a specific teamwork function because it is ubiquitous in virtually all group interactions: “Team members must communicate to distribute or assign tasks, update status, seek help, and maintain coordination. Furthermore, communication is needed to exchange information and make decisions” (Ioerger, 2003).

Figure 2 summarizes the three functions of collaboration. Note that we placed “central” or “supporting” factors at the center. These elements, such as communication and systems interoperability, are considered requirements for the effective accomplishment of all three types of interaction. Indeed, the three essential functions we identified and the central role of communication for each of these functions fall in line with the purposes generally attributed to communication by researchers and practitioners. For instance, Ioerger (2003) lists three key purposes of communication that correspond to our functional classification, namely the coordination function, the information sharing function, and the team adaptation function:

> "Communication among team members can serve a number of different purposes, including coordination of team activities (synchronization), information exchange (especially building situation awareness), and to support other teamwork processes (load-balancing, requests for help, decision-making, feedback/ monitoring/self-correction, etc.)"

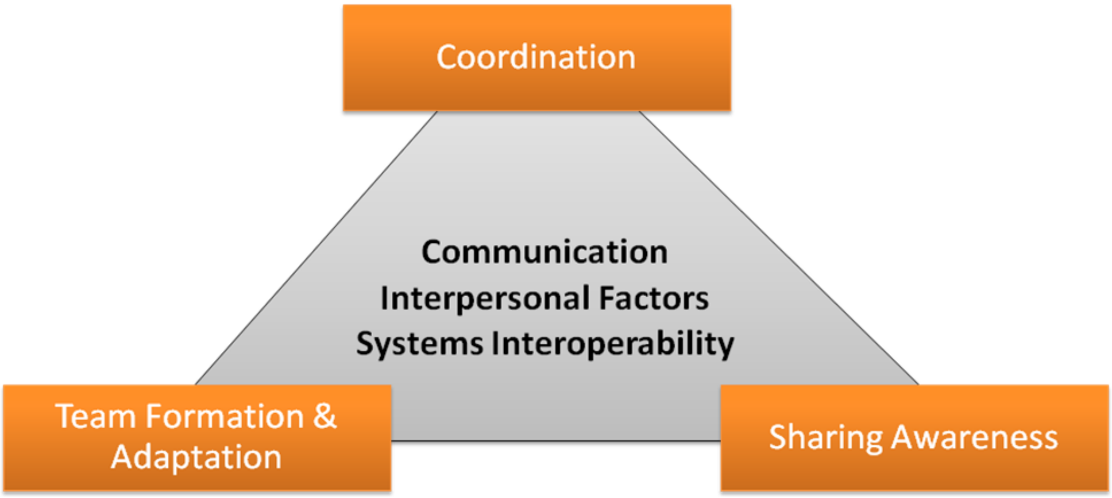

Figure 2: Functions of collaborative interaction

2.2 Teamwork requirements

Coordinating, sharing awareness, and team formation and adaptation are viewed as the three primary factors of collaboration effectiveness. The concepts at the center of Figure 2 are teamwork requirements, meaning that they moderate the quality of the three types of interactions. These factors affect collaboration effectiveness only through their impact on the three types of interaction. For instance, systems interoperability is related to all three types of interactions because various tools and systems can be used to support each one of them. Building blocks such as trust, cohesion, and motivation are conceptualized as indirect factors that influence the three basic types of interactions. We placed them at the center of Figure 2 under the heading *interpersonal factors* (a type of factor also found in Marks, Mathieu, & Zaccaro, 2001). We propose that these factors are better seen as team states rather than processes. Many researchers present constructs as processes while they are not really processes at all, but emergent cognitive or affective states. Emergent states develop throughout the existence of the team and have an impact on team outcomes (Marks et al., 2001). In line with this interpretation of interpersonal factors as emergent states, Marks et al. (2001) note that:

> "Emergent states do not represent team interaction or team actions that lead toward outcomes. Rather, they are products of team experiences (including team processes) and become new inputs to subsequent processes and outcomes. The point is that emergent states are not processes in and of themselves."

The taxonomy proposed here is both inclusive of the wide variety of processes identified in the teamwork literature, and parsimonious, owing to its classification of team processes into a simple set of functions. The factors identified here are not the only ones that affect group performance. There are also intra-personal factors (individual characteristics), and contextual factors. The features and functions of collaboration discussed here focus on the properties of the *interaction* itself rather than on the properties of the individuals or the features of the operational environment.

2.3 Process-function mapping

Table 1 presents the functional classification of the eighteen building blocks of collaboration. The classification is organized around three types of collaborative interaction and teamwork requirements that support these functions.

Table 1: Functional classification of the building blocks of collaboration

Team formation & adaptation	Coordinating	Sharing awareness	Teamwork requirements
Adaptability	Leadership	Shared knowledge, representations & intentions	Communication
Division of labour	Planning & synchronization	Systems monitoring	Group cohesion & team identity
Goal specification	Conflict management	Monitoring progress toward goals	Group motivation & commitment
Mission analysis	Resource sharing		Systems interoperability
Mutual monitoring & support			Trust
Training & education			

A possible implication of this classification is that the exact processes used to accomplish a function may be less important than the actual achievement of that function.

This may be particularly relevant for developing models of collaboration effectiveness and metrics for assessing the quality of team interactions (e.g., Essens et al., 2005).

3. An integrative modeling framework

3.1 Purpose of the model

Arrow, McGrath and Berdahl (2000) criticized the fact that most group research has been limited to examining only a subset of potentially relevant variables at a time. They explain that this is a consequence of relying on a "positivist-analytic-reductionist" research methodology. Group research and theory have mainly attempted to decompose the individual effects of team processes, rather than treating groups as holistic-emergent systems. The traditional experimental strategy limits progress on team research in two ways:

1) It can only consider a limited number of variables at a time, since an increase in the number of independent variables necessarily reduces an experiment's statistical power.
2) It deals inadequately with higher-order interactions between factors. This approach can only be successful if the key factors of group effectiveness have a unidirectional, linear and additive effect.

Furthermore, a general limitation of existing teamwork models is that they fail to account for the variability of teamwork requirements and their different effects depending on the work context:

> "[Group research, in general] not only fails to study the interactions between group and embedding context but takes great pains to strip away "irrelevant" contextual factors. […] We believe that attempts to strip context from groups are both limiting and doomed to fail. What is most successfully stripped away is the researcher's attention to context." (Arrow et al., 2000, p. 27-28).

Our modeling efforts seek to address the above challenges by proposing an integrative conceptualization of team interactions capable of explicitly representing the combined effects of collaborative *processes* and collaboration *context* on team functioning. A first objective was to integrate the key concepts of collaboration identified in the scientific literature. We called these concepts the "building blocks" of collaboration. We proposed a list of building blocks that is both minimally redundant and that covers the range of collaborative interactions relevant to teams and multiteam systems. A second goal here is to model an aspect of collaborative behaviour that has been overlooked in this field of research, namely the *degree of collaborative interaction* in a group. This idea basically distinguishes groups along a *continuum of collaboration* that spans from very low to very high levels of collaborative behaviour.

The concept of *degree of collaborative interaction* will rely on a multidimensional measure of the degree to which a group collaborates effectively, based on an assessment of each building block of collaboration. This may provide a very useful predictor of team effectiveness, one that is more useful than individual factors taken separately. This proposition is far from trivial: Rather than considering team processes individually, it is their *combination* that best determines the global outcome. Moreover the effects of these factors are assumed to be more than simply additive: they mutually reinforce each other (i.e., process synergy). The degree of collaboration is proposed as a *systemic* indicator of team functioning which is *embedded* in an operational context. Below, we describe the logic of the continuum of collaboration as a holistic conceptualization of team functioning that is both generic and context sensitive. We then describe the formal strategy employed to represent the degree of collaboration and the effects of changes in context.

3.2 Continuum of collaboration

Having identified a set of 18 basic building blocks of collaboration in the growing literature on teamwork, our next objective is to determine how they might be assembled to define various levels of collaboration and how they are affected by the context.

We suggest that teamwork is the set of interactions that—taken together—explain capacity gains compared to individual work. The continuum serves to illustrate that, *all else being equal*, a group or organization's capacity/effectiveness increases according to the level of collaboration achieved. The core concept of this continuum is that capacity/effectiveness is in linear relation with the degree of collaboration. Here, we prefer the notion of capacity over the term effectiveness mainly because it emphasizes that there is a qualitative leap in what the group can accomplish and not merely an increase in accuracy or speed. Each of the building blocks contributes in defining the degree of collaborative interaction. These attributes of collaboration are considered universal dimensions of collaborative behaviour, regardless of context. The dependent variable associated to the continuum (i.e., the output of the model) is defined as the group's capacity and can be used to refer to various types of outcomes depending on the context.

The notion of capacity proposed here can be related to a conceptualization of system capability described by Beer (1981). Beer actually described three dimensions of an organization's behaviour:

- Actuality: "What the group is managing to do now, with existing resources, under existing constraints."
- Capability: "What the group could be doing (still right now) with existing resources, under existing constraints, if it really worked at it."
- Potentiality: "What the group ought to be doing by developing its resources and removing constraints, although still operating within the bounds of what is already known to be feasible."

According to Beer (1981), *productivity* is the ratio of actuality and capability, *latency* is the ratio of capability and potentiality, and *performance* is the ratio of actuality and potentiality, and also the product of latency and productivity (both operations yield the same result). While these measures are all very relevant, for the sake of simplicity, we define the dependent variable of the continuum of collaboration using only the central measure proposed by Beer: the *capability*.

Our goal here is to combine the building blocks of collaboration within a model that quantifies the degree of collaboration and linearly relates it to organizational performance capabilities using a mathematical function. Of course, other factors such as group size, collective resources, and individual ability can affect the potential capability of the group, but they do not describe the quality of team *interactions* and therefore will not be considered in the present framework.

The role of context. Building blocks are variables that provide an indication of the level of collaborative activity achieved by different teams, or by a same team at different points in time. We suggest that some building blocks will be more important for accomplishing one task type and less important for accomplishing another type of task. Each building block's intrinsic *weight* (or importance in predicting the outcome) is thus expected to change in various contexts (i.e., according to task type, time pressure, team structure, etc.). Below, we propose a more formal characterisation of this framework and specify how the building blocks are integrated to define the degree of collaboration.

3.3 Generic model with context-sensitive parameters

Approach: A basic model. The continuum of collaboration is intended as a general model of collaboration that identifies a unique set of key attributes regardless of context. However the relative weight of each construct can vary from one context to another (e.g., team type, task features, etc.). We then assemble these building blocks into a model that estimates group capacity depending on the degree of collaborative interaction, each building block being weighted by its contextual relevance. The group's capacity is a number defined by combining the value of each building block according to a mathematical function. Let us refer to the building blocks as *features of collaboration* (F_1, F_2, etc.). Here are two possible ways to combine these values in order to define the degree of collaboration (DC):

Additive/linear perspective on team factors:

$$DC = F_1 + F_2 + F_3 + F_4 + F_5 \ldots + F_{18}$$

Multiplicative/mutually reinforcing perspective on team factors:

$$DC = F_1 \cdot F_2 \cdot F_3 \cdot F_4 \cdot F_5 \ldots \cdot F_{18}$$

Note that this approach requires selecting an appropriate assessment technique for each building block. For this initial framework, let us assume a multiplicative relationship between factors. Furthermore, suppose that when evaluating a specific team, each building block can be assigned a discrete value on a scale from 0 (poor interaction) to 10 (optimal interaction). Since the continuum of collaboration comprises eighteen building blocks, the degree of collaboration corresponds to a value between 0 and 180. Next, each feature value can be weighted by a parameter (w_i) estimating the relative importance of each feature in a given context:

$$\text{Predicted capacity}_{(\text{Context } x)} = (F_1 \cdot w_1)\,(F_2 \cdot w_2)\,(F_3 \cdot w_3) \ldots (F_{18} \cdot w_{18})$$

A group's *predicted capacity* thus corresponds to the degree of collaboration after weighting each factor for a specific context. This basic framework could be extended in various ways. Different metrics could be tested and different types of attributes could be combined (e.g. moderating or negative attributes). An important aspect in developing this framework would be to compare various possible relations between building blocks and select one that best fits empirical data. Another important aspect would be to compare the predictive accuracy of these different models, not just their ability to describe the data.

Estimating model parameters. The equaliser shown in Figure 3 illustrates that the building blocks of collaboration can have different weights relative to one another. In this figure, weights can be thought of as varying between -1 and 1. A positive value (i.e., between *zero* and *one*) indicates that this interaction increases a team's capacity in that context. A negative value (i.e., between *zero* and *minus one*) would indicate that in this context, this feature reduces the group's capacity (in some contexts, some interaction types may turn out to be more costly than beneficial to the group). The analogy of the equaliser also shows how each knob (feature of collaboration) is a *dimension* of the output (degree of collaboration).

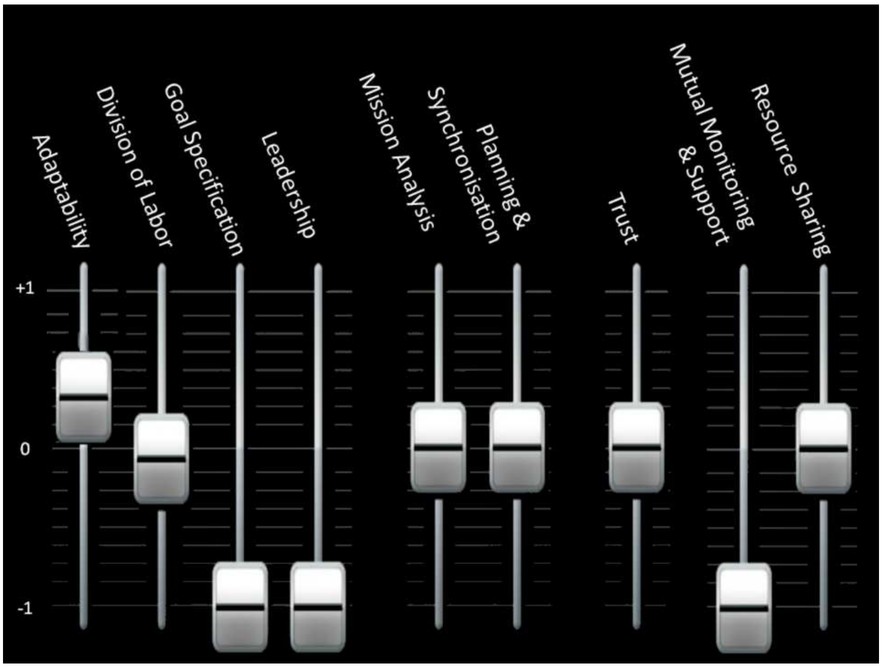

Figure 3: The equalizer as an analogy of the relative weights of the building blocks

The core concept illustrated by the continuum is that *everything else being equal*, capacity/effectiveness is in linear relation with the (weighted) degree of collaboration. Weight parameters are estimated (using statistics software) when fitting the model to actual data (either experimental or simulated results). Model fitting consists in a search for model parameters that allows it to explain as much variance as possible in the data. These parameter values can be very informative by indicating the relative importance of each attribute in explaining the observed performance in various experimental conditions (e.g., the effects of leadership, mutual support, etc., on observed performance).

The continuum of collaboration proposes a metric that assumes a multiplicative relationship between the building blocks. This approach contrasts with the standard assumption of the General Linear Model (underlying the statistical tests commonly used in team experimental research). The General Linear Model assumes that factors have an additive effect on the dependant variable. In the proposed modeling framework we hypothesise that these effects are mutually dependent. The degree of collaboration is expected to provide a powerful predictive factor of team and multiteam effectiveness because it considers all the key factors of collaboration at once. The formal model adds to this framework by assigning relative weights to each factor through statistical modeling techniques and allowing these weights to vary from one context to another.

One of the possible implications of the *functional classification* of team factors proposed earlier is that rather than making an assessment of collaborative behaviour for each of the 18 building blocks, it may be more efficient to determine the degree of collaboration with metrics directly based on the four functional categories (the four column headers in Table 1). In other words, the exact processes used to accomplish a function may be less important than the actual achievement of that function. The formal description of the degree of collaboration could thus be redefined using only the four variables identified in our functional classification. Furthermore, only four unknown parameters (rather than 18) would have to be estimated using experimental (or simulated) data. This could make the model more tractable both for research and evaluation purposes. One possible way to test this model would be through computational simulation, using a multi-agent system and manipulating the ways in which the artificial agents may collaborate. The more they engage in collaborative processes, the better their performance should be. By presenting two different task environments, one could also test how the relative weights of the building blocks change according to context. This framework could also be tested using questionnaires during the course of field studies. Finally, this approach could be used in laboratory settings by manipulating the task environment and creating conditions that promote or inhibit different interaction types. Rather than using statistical procedures that attempt to isolate the effects and interactions of different variables (which tend to lack statistical power when there are many variables), the present modeling approach attempts to explain the observed variability in group effectiveness using a systemic characterisation of team functioning.

3.4 Modeling a dynamically changing context

A key challenge for designing teams and multiteam systems is that even though an organization can be tailored to be more effective in a specific context, history has shown that the operating context can dramatically change during the course of an operation. Organizations can either take a static approach that aims to be robust in a wide range of situations, or an adaptive approach that implies adjusting the organizational structure and processes if the operational context has changed. The static approach favours stability and robustness. One benefit of stability is that organizations avoid the possible cost of making significant changes (in plans, role and resource allocations, etc.) during an operation. However, balancing the effectiveness of an organization for various contexts in order to make it robust is a challenge in itself and it comes with a cost. Adopting such a static approach will necessarily lead to a suboptimal effectiveness in each possible context. In contrast, an agile organization can restructure itself to adapt to changing circumstances to maintain an optimal efficiency, and thus can be more effective than a static organization, of course, provided that the adaptation process is seamless.

Let us assume that a context can be characterized using Devine's seven dimensions (fundamental work cycle, physical ability requirements, temporal duration, task structure, active resistance, hardware dependence, and health risk). It seems clear that as each of these variables changes over time, so should the collaborative process. The modeling approach that we propose may provide the means to create a mapping between the importance of collaboration processes (the model's weight parameters) and contextual requirements. This context-sensitive collaboration model may thus characterize the changing demands as a situation evolves. This approach could therefore provide a dynamic model of collaboration requirements. The key requirement for such a quantitative model is a rich set of constraints for model calibration, which can be obtained through expert assessments, multi-agent simulations or experimental research. Basically, this framework lays down the foundation for a research program on adaptive collaboration processes for agile C2. Future work will start with multi-agent simulations that systematically vary the agents' collaboration processes and the key dimensions of the context in order to rapidly obtain all the data needed to calibrate the model and generate predictions for an upcoming validation.

4. Concluding remarks

We proposed a list of key building blocks of collaboration and classified them according to a set of three functions of collaboration (coordinating, sharing awareness, team formation and adaptation) mediated by teamwork requirements. We developed a formal framework for modeling collective capacity using a generic model with context-sensitive parameters. Agile C2 requires teams and multiteam systems to adapt their collaborative processes as a function of contextual changes. For instance, a change in the situation during the course of a military operation may require unit commanders to invoke a different set of standing operating procedures, make new plans and reallocate roles. A better capability to read into a situation according to specific dimensions would help commanders respond to such changes more rapidly and appropriately. A better capability to figure out the requirements of the situation would provide support for adaptive C2 and result in more effective teamwork. A fundamental limitation of the present framework is that because it requires knowledge of the situation, it can't provide a priori predictions for a situation that has not yet occurred. Nevertheless, the approach could help guide the adaptation process following a change in context and possibly provide the basis for an analytical tool to generate feedback following training exercises.

Our approach takes a step toward a characterisation of teams and multiteam systems as dynamic, goal-oriented systems. While the continuum of collaboration provides a useful framework for modeling team capacity/effectiveness both as a global outcome and as key dimensions of the situation change, it remains, like most current models of collaboration, an essentially static representation of team interactions (it does not model the evolution of trust, cohesion, leadership, etc). In dynamically changing environments, key phenomena may be better described by dynamic models, that is, models whose processes adjust to feedback. While most models of team effectiveness rely on a basic "input → process → output" (I-P-O) approach (e.g., Hackman, 1987; McGrath, 1964), only a few incorporate feedback loops (e.g., Essens et al. 2005; Warner et al., 2005). Rousseau et al. (2006) specify that *inputs* are conditions that exist prior to a performance episode. They may include three types of characteristics: 1) Individual-member characteristics; 2) Team characteristics; or 3) Organizational characteristics (i.e., contextual parameters). The present framework explicitly takes into account the context but makes abstraction of individual (specific expertise) or team characteristics (team composition). *Processes* describe how teams "transform" inputs into outputs. Processes include behavioural, cognitive, and affective phenomena. *Outputs* resulting from team activity can be different variables "*valued by one or more constituencies, such as managers, customers, and team members*" (Rousseau et al., 2006). Rousseau et al.'s generic description of I-P-O models is highly similar to the information processing approach dominant in contemporary cognitive psychology. The notion of "transforming" inputs into outputs also bears a resemblance to control models in engineering applications. For this analogy to be complete, the outputs should be able to become inputs for the next "performance episode" (through feedback loops). For instance, we propose that emergent states could be conceptualized as dynamic team outputs, which then become factors that influence subsequent team behaviours. Marks et al. (2001) argue that emergent states are cognitive, motivational, and affective states of teams, rather than collaboration processes. They suggest that emergent states can be considered both as team inputs and proximal outcomes. While I-P-O models with feedback loops represent a promising step forward, they still provide a relatively static representation of collaboration, until they can be implemented in a simulation. We suggest that another important challenge is to find an architecture that departs from the linearity of modular I-P-O models so as to better represent systemic notions such as goal-orientation, emergence, control and regulation. Arrow et al. (2000) argued that most group behaviours function in a nonlinear, recursive and systemic manner, three hallmark properties of *complex systems*. They explain that:

> "Group research seems to be approaching the limits of what can be learned about groups using the currently dominant methodological paradigm, the data-gathering and analysis methods that are its main tools, and the theoretical conceptions that arise from it. If we want to achieve major progress in our understanding of groups and their activities, we need a major paradigm transition. We need to borrow and invent new ways of thinking about groups and new tools for doing research on them that allow us to conceptualize and study groups as complex, adaptive, dynamic systems." (Arrow et al., 2000, p. 30)

Arrow et al. (2000) suggest that team research should make use of the concepts and methods from General systems theory, Dynamical systems theory and Complex systems theory—three fields that currently deal with complex, adaptive, and dynamic systems. The modeling approach proposed herein was motivated by this recognition that a better understanding of social and cognitive factors of collaboration effectiveness in teams and multiteam systems requires a systemic approach. The complexity of the socio-technical systems that characterize civil and military organizations makes it increasingly clear that no simple model will confer truly powerful leverage to researchers or decision-makers. A multiteam, coordinated multidisciplinary research effort may be what it takes to make the most important breakthroughs to come.

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