Knowledge Systems for Coalition Operations 2017

The Role of Transactive Memory (TM) in Proactive Decision Support (PDS) (Position Paper)

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Abstract

Advances in technology have exponentially increased the information and data at our fingertips. While there are many benefits of such access, a tradeoff is that information seekers can be overwhelmed by the vast sea of information at their disposal. Challenges multiply when information seekers operate as part of a team where there are differences in knowledge, information access, and decision-making responsibilities. Coalition operations are examples of such situations, involving decisions that impact a complicated network of different countries and actors. Proactive decision support (PDS) tools have the potential to make more manageable the tasks of selecting, verifying, compiling, and analyzing relevant information, so that good decisions can be made more efficiently. Effective PDS requires a system that "understands" and adapts to the context in which information seeking and decision-making occur. Context includes aspects of the physical environment within which the technology and user are embedded, and the cognitive or mission objectives of users. We argue that for teams, PDS context must also include a collection of team member and team dynamic variables such as shared and differential tasks, requirements, knowledge, and expertise. Collectively, these variables can be conceptualized as transactive memory (TM). We describe how PDS that incorporates TM variables as a form of context can facilitate and streamline validation and communication of information among team members, which is crucial for realizing the potential benefits of PDS for coalition operations. We discuss considerations for implementing TM variables into PDS tools and key research and development questions to be addressed.

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A Case for Proactive Decision Support

Dateline: July 2017

A large, distributed, multinational team works against the clock to provide aid to a disaster-stricken region. Despite their best intentions and efforts, priceless time is lost in the team's attempts to coordinate with each other, to share relevant information, and to sift through irrelevant information and numerous unintentional "red herrings." As a result, they fail to make decisions in a timely and efficient manner, countless lives are lost, and much suffering ensues. The world resolves to do better next time…

Dateline: July 2027

A massive earthquake, volcanic eruption, and resultant tsunami cause mass destruction in Southeast Asia. Teams from across the globe mobilize to provide humanitarian assistance and disaster relief to the stricken local population. Despite the unprecedented scope and complexity of the operation, response teams can provide effective care and relief by using new proactive decision support (PDS) tools developed by the US Navy's Office of Naval Research (ONR). Sophisticated artificial intelligence-based PDS tools automatically recognize key decision events, gather decision-relevant information, and distribute it to those personnel responsible for making decisions. When specific expertise is needed, or new information becomes available, the PDS system automatically routes the information or requests to the correct people. When decisions are made, the system accurately predicts follow-on events and decisions, and prepares for them as well. Using the new PDS tools, the world relief organizations can take control of the disaster in an organized fashion, and effectively and efficiently provide aid when and where it is needed the most. Despite the massive scale of the disaster, the casualties are kept to a minimum, and the survivors can quickly rebuild their lives and prosper. In after action discussions about the response, the teams agree that their PDS tools were invaluable for the rapid, effective communication of information and sound decision-making that directly contributed to the success of their missions. Moving forward, smart PDS systems will be a core component of coalition operations…

How to Make PDS a Reality: Introduction

Advances in technology have exponentially increased the amount of information and data at our fingertips. While there are many benefits of such easy access, a tradeoff is that information seekers can be easily overwhelmed by the vast sea of information at their disposal. It can be difficult and time-consuming to sift through available information and to select, verify, compile, and analyze the information that is relevant. The consequences of these tradeoffs can be especially significant for those who seek information to make rapid, high-stakes decisions in complex environments. Further, the challenges multiply when information seekers are operating as part of a team when there are differences in knowledge, access to information, and responsibilities in the decision-making process. Coalition operations such as the humanitarian assistance and disaster relief efforts described above, are examples of such situations, involving decisions that may impact a complicated network of different countries and actors.

Proactive decision support (PDS) tools can improve the efficiency of the decision-making process, for example by automatically monitoring information feeds, recognizing and alerting users to decision events, and gathering and presenting critical information. Effective PDS requires a system that "understands" and adapts to the context in which information seeking and decision making occur. This decision context includes various aspects of the physical environment within which the technology and user are embedded [1] and the cognitive or mission objectives of users [2]. Overall (environmental or mission) context may also interact with information provided by various sources, including decision cues and other types of context, to influence the decision-making process, as shown in the notional *decision support structure* in Figure 1. The effect of context on the outcome of the decision(s) may be determined by the *decision factors* (type, timeliness, priority, consequences, etc.). Further, decisions made may influence other decisions and/or impact context.

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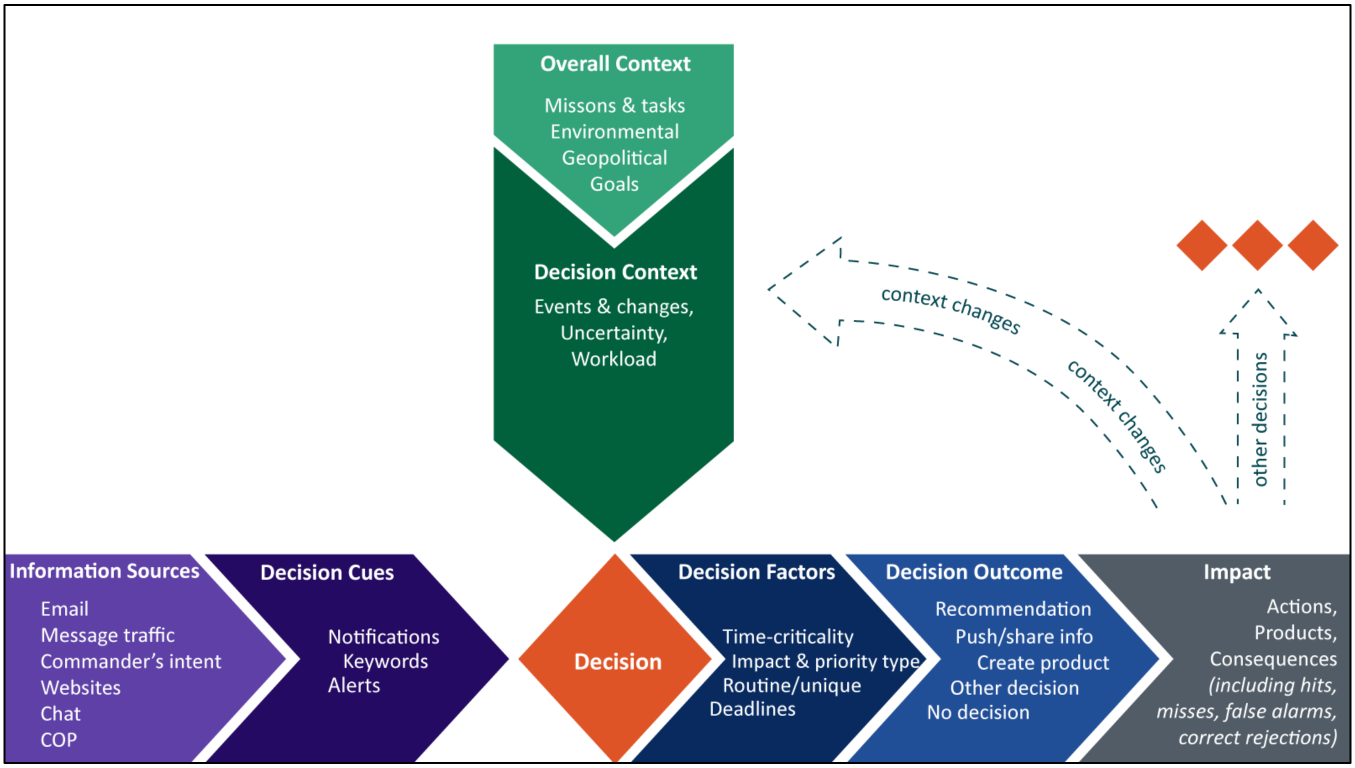

Figure 1. Decision support structure with example details.

In this position paper, we argue that for teams, PDS must also be responsive to context relevant to team member and team dynamic variables such as shared and differential tasks, requirements, knowledge, and expertise [3]. Collectively, these variables can be conceptualized as a form of transactive memory (TM) – the concept of collective knowledge possessed by individual group members, and the shared awareness within the group of who knows what. We maintain that considering TM as a form of context and providing a mechanism to foster TM in PDS tools will facilitate and streamline communication of information among team members. We suggest that addressing TM variables can increase the potential performance and workload benefits of a PDS tool for complex, time-sensitive, coordinated team missions. The paper will discuss the following:

- The concept of TM and its relevance to coalition operations
- Considerations for a TM-supportive PDS tool
- Research and development challenges for TM in PDS

The paper concludes with a high-level summary of the potential value of a TM-supportive PDS system to coalition operations.

Transactive Memory

As noted, an effective PDS system must be *context-aware,* incorporating contextual elements such as the environment and mission, a user's available information sources, and factors specific to the decision at hand. For teams, an often-overlooked aspect of context is TM. Moreland defines TM as the sum of "knowledge possessed by individual group members with a shared awareness of who knows what" ([4], p.5). With accurate shared awareness, team members can better evaluate how and to whom to distribute new information, and from whom to request information. Shared awareness and differentiated knowledge (unique knowledge and expertise contributed by individual team members) form the *structure* of TM; there are also transactive *processes* by which team members cooperatively store, retrieve, and communicate information (cf., [5]). A *transactive memory system* (TMS) is characterized by the dynamic interaction of team members' individual TM to draw on and integrate knowledge to achieve a team task [6]. Performance benefits of a strong TMS include reduction in errors and better recall of task procedures (see [7]). TM research originally focused on two-person teams, but it has been extended to

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larger groups and teams[1] with similar results [6]. PDS tools need the ability to represent, evaluate, and "perceive" TM context and supporting decision processes by adaptively facilitating effective TMS development and function.

TM in Coalition Operations. Coalition operations present a special type of team environment, one in which a robust TMS has the potential to provide immense benefits. Specific characteristics and requirements of coalition operations that research suggests are supported by TM include:

- The need to understand expertise and differentiated knowledge across distributed, cross-culture teams [4]
- The need for trust across unfamiliar team members (note that TM has been found to be both an antecedent to and an outcome of trust [8])
- Substantial involvement of transactive processes, such as collaboration, communication, and feedback [9]
- The need to understand team member culture and leadership styles [10]

At the same time, coalition operational environments are intrinsically suboptimal for the *development* of TM. Coalition teams are frequently ad hoc, and rarely involve the amount of group training required to form strong TMSs. In the humanitarian assistance and disaster relief scenario described above for example, teams from around the world who may never have worked together must rapidly coordinate and execute a set of missions with a complexity and scope that can never be fully trained. Further, with an effort this massive the amount of information and number of information sources would be completely overwhelming. Yet to make sound decisions, the credibility and relevance of every piece of information must be established, and the right information must get to the right people at the right time. In other words, a strong TMS is critical for efficient, effective decision-making. The coexistence of the need for and likely absence of TM provides a unique opportunity to leverage a TM-supportive PDS system.

Considerations for a TM-supportive PDS Tool

There is evidence that technologies such as information directories and repositories can help to build TMS within teams (e.g., [11]), but that these technologies fall short of producing expected performance benefits. Lewis & Herndon [9] argue that such technologies do not allow full development of a successful TMS because while they provide TM *structure*, they fail to support the transactive *processes* that are crucial to a TMS. A PDS tool offers additional capabilities beyond information directories and repositories in that it can be designed to model context, including transactive processes. This section discusses considerations for a PDS tool designed to facilitate strong TMS and improve performance of team tasks that require identification, selection, verification, compilation, analysis, and communication of information.

Transactive Memory Information Requirements for PDS. The specific information requirements of a TM-supportive PDS tool will be partially dependent upon the application for which it is being developed. However, there are some overarching considerations that will be relevant to the TM aspects of decision support in most any application. Because TMS is being conceptualized as a set of context variables that shape the decision-making process, there will be representations of TMS that are not communicated explicitly to users, but rather work "under the hood" to support the user and to help the PDS tool evolve and improve over time. However, there will be occasions in which there is explicit communication of TM information between the system and the user. For example, a new team member not familiar with the expertise of other team members may ask "Who would know local resources in small Southeast Asian villages that might have access to baby food for the families displaced by the tsunami?" Explicit communication between users and with the PDS tool will naturally be more frequent when the tool is in its initial stages and the underlying decision structures haven't had an opportunity to "learn". There will also be more instances of explicit communication of TM information when there are one or more new team members, as the baseline states for the new member(s) become instantiated in the PDS tool. Broadly speaking, the explicit communications will either *push* information to a team member, or *pull* information from a team member. When explicit communication is required, the design of the PDS tool interface should ensure that the communication happens as unobtrusively as possible. The goal is to allow the PDS tool to develop a TMS (an internal representation of who knows what) so that the tool can get the right information to the right people at the right time with minimal burden on the user. The information to be captured, understood, and represented in a TM-supportive PDS tool can be categorized in terms of the "five Ws", as summarized in Table 1.

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[1] A distinction can be made between 'groups' and 'teams', with teams typically having more clearly specified roles, tasks, and relationships, such as in military command and control domains. The terms are used together here because although the TM literature frequently addresses groups, many aspects of the work apply readily to teams (see [15]).

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Table 1. Summary of general information requirements for development of a TM-supportive PDS tool.

TM Information	
Who	Which team member(s), if any, possess a specific piece of knowledge? Which team member(s), if any, need that knowledge?
What	What information category/categories are relevant to the current decision process? What specific piece(s) of knowledge are relevant to the current decision process?
Where	Where does a specific piece of knowledge reside? • In the expertise of a team member? • In an external repository such as a directory or database? • As tacit knowledge within the TMS?
When	At what time in the decision-making process should a specific piece of knowledge be communicated to a team member for *proactive* decision support?
Why	What is the relevance of a specific piece of knowledge to the current decision process?

Task Selection. There are certain types of tasks that stand to benefit the most from a strong TMS, and these tasks should be given special weight in the development of TM-supportive PDS tools. Lewis & Herndon [9] provide a useful discussion of relationships between TMS and task types. They characterize tasks based on processes and structural qualities. Task processes include "produce" (generate ideas), "choose" (select a solution to a problem), and "execute" (perform a set of actions to achieve a goal). Task structural qualities relate to whether the associated responsibilities are unitary or divisible among team members, whether the task goals are cooperative or competing across team members, and the degree to which there is a single, demonstrably correct task outcome. To summarize, they conclude that while TMS is important for these task types, the ones that stand to benefit most from a strong TMS are "execute" tasks with divisible responsibilities, cooperative goals, and a demonstrably correct solution. More so than other task types, efficient and effective team performance on tasks with these characteristics relies upon (a) a solid TM structure with diverse and specialized knowledge that is readily accessible from known, credible sources, and (b) well-developed transactive processes that facilitate communication, coordination, and integration of this knowledge.

For example, in the tsunami scenario above, an operationally-appropriate *execute* task may be "Provide medical aid to local villages that require it." While each coalition member may be able to perform this task to some degree on their own, coordinating to divide the task to take advantage of each nation's strengths/expertise would provide a more optimal solution. One nation may be able to provide the best medical staff and supplies, another may have the closest transport resources available, another may know the location of the most appropriate linguist to help the medical staff, and yet another may have knowledge from previous events related to the most efficient and safe route to use to get to local villages. A TMS-enabled PDS system would provide a mechanism to support this coordination and, thus efficient execution, of the task.

Representing TM Variables in a PDS Tool. Palazzolo et al. [12] discuss the utility of considering TM from a network perspective. Palazzolo et al. [12] developed and tested a network model of TM that illustrates how TMS could be instantiated as a form of context in a PDS tool. The model was based on a conceptual framework that specifies three interrelated transactive processes by which a TMS develops. These processes are directory updating (each team member's dynamic understanding of who knows what within the team), communication to allocate information, and communication to retrieve information. The team's initial attributes and the success of these transactive processes result in two measures of TMS development: accuracy in expertise recognition and differentiation of knowledge [12]. The starting attributes of the team that are captured in their model are initial knowledge, initial accuracy of expertise recognition, and network (team) size.

This network perspective allows not just individuals, but also the connections between them to be modeled and measured. As Stanton et al. [13] note in their related discussion of distributed situation awareness, the focus in a network is on *links* (interactions and transactions between team members) rather than on *nodes* (the information processing of individual team members). In the tsunami scenario, these links may be transactions between members as they share information to coordinate each step of the task (move resources using assets, coordinate with translators, plan safe land route, …).

Research and Development Challenges for TM in PDS

Two important research and development considerations for a TM-supportive PDS tool are (a) validating the representation (capture, learning, and updating) of TM variables within the other decision structures of the tool, and (b) testing to determine whether the inclusion of TMS context does in fact add value to the PDS tool. The validation and testing process both require

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measures of TMS. Traditionally, measurement of TMS has consisted primarily of inferences generated from team members' recall of information in task performance, observation and evaluation of team members' behaviors and communications during task performance, and team members' post hoc self-reports about the credibility of other team members' knowledge [6]. While these measures may be suitable for experimental settings, there are multiple constraints that limit their utility for measurement of TMS in field settings (see [6] for a discussion).

In an effort to overcome the limitations of the traditional TMS measures, Lewis [6] developed and validated a TMS scale that would be appropriate for field use. The results of the testing reported by Lewis [6] indicated that his fifteen-item scale is a valid measure of TMS that can be applied across tasks and teams. Another candidate measure could be derived from the Event Analysis of Systemic Teamwork (EAST) methodology described by Stanton et al. [13]. While designed for analysis of distributed situation awareness, the methodology should be adaptable for TMS constructs as well. While there is further testing to be done, Lewis's [6] scale and the EAST methodology [13] provide candidate field-appropriate TMS metrics that could be used as part of a suite of measures to evaluate TMS networks for PDS.

Additional measures could include automated data collection built into PDS tool prototypes, and surveys administered during coalition training exercises. In simulations using a TM-supportive PDS tool where the information available to a network can be controlled, the pieces of information that are propagated through the TMS network to and from each agent can be extracted and evaluated. Thus, additional candidate measures of TMS can be gleaned from using a signal detection framework [14] to conceptualize the TMS-dependent information collection, validation, and communication aspects of the decision-making process. Within the signal detection framework, TM performance could be captured by analyzing the relative frequency of "hits" (valid, relevant information is communicated to the right people), "misses" (valid, relevant information is NOT communicated), "correct rejections" (invalid, irrelevant information is NOT being propagated), and "false alarms" (invalid, irrelevant information is propagated). Once a TM-supportive PDS tool has had an opportunity to learn, it should maximize hits and correct rejections, and minimize misses and false alarms. If the tool was not learning as expected, the signal detection analysis would provide diagnostic information by allowing the identification and localization of the issue(s) (e.g., invalid information propagating between specific nodes).

Taken together, the resultant data would inform the design of next-generation PDS tools and the associated human computer interfaces. Further, the outputs of several of these measures can be used to help diagnose the source of shortcomings in under-performing teams, which may have implications for improvements to team composition and system design. For example, the relative scores across the three constructs that comprise Lewis's [6] scale can reveal weaknesses in team members' knowledge, their coordination of knowledge, and/or their perceptions of each other's expertise. Depending on the score profile, the weaknesses might be mitigated by a change in team composition or a change in training practices to improve TMS development.

While the test and validation process required for a TM-supportive PDS tool will be extensive, the extant body of work has established a strong conceptual framework and promising network architectures that can readily be integrated with other PDS decision structures [12]. Further, there is a set of candidate measures available that can provide converging data to help refine and validate TMS components of a PDS tool. There is a clear need for PDS in team tasks that require complex decision making, such as those commonly encountered in coalition operations. Because the differentiated knowledge and transactive processes among team members are such crucial drivers of decision making performance, TMS must be considered as an essential element of a PDS tool that will be successful in improving performance and reducing workload.

Discussion and Conclusions

At a time when vast amounts of information are available from myriad sources, PDS tools have the potential to make the task of selecting, verifying, compiling, and analyzing information more manageable so that decisions can be made more efficiently and effectively. A PDS tool that incorporates TM as a form of context can increase the value of a PDS tool for team tasks by also representing the distribution of knowledge across team members, team members' meta-knowledge about where information resides, and information about the credibility of information sources.

The benefits of TM to coalition operations can be illustrated by returning to the decision support structure discussed above in Figure 1. The fact that the mission is being conducted by a coalition team might be considered a type of overall context, and the team variables that stem from this, such as understanding/uncertainty about the distribution of knowledge, the need for collaboration, etc. might be representative of decision context. Figure 2 adds to the decision support structure several TM variables (shown in yellow and with bolded text) that can inform and improve decision-making in a coalition team context. The variables relate to the specific requirements of coalition teams discussed above that include support for 1) differentiated

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knowledge understanding in distributed teams [4], 2) trust in unfamiliar team members [8]), 3) collaboration, communication, and feedback [9] and 4) team member culture and leadership styles [10]. Also shown in Figure 2 is the update and increase in TM as an outcome (impact) of the decision-making process.

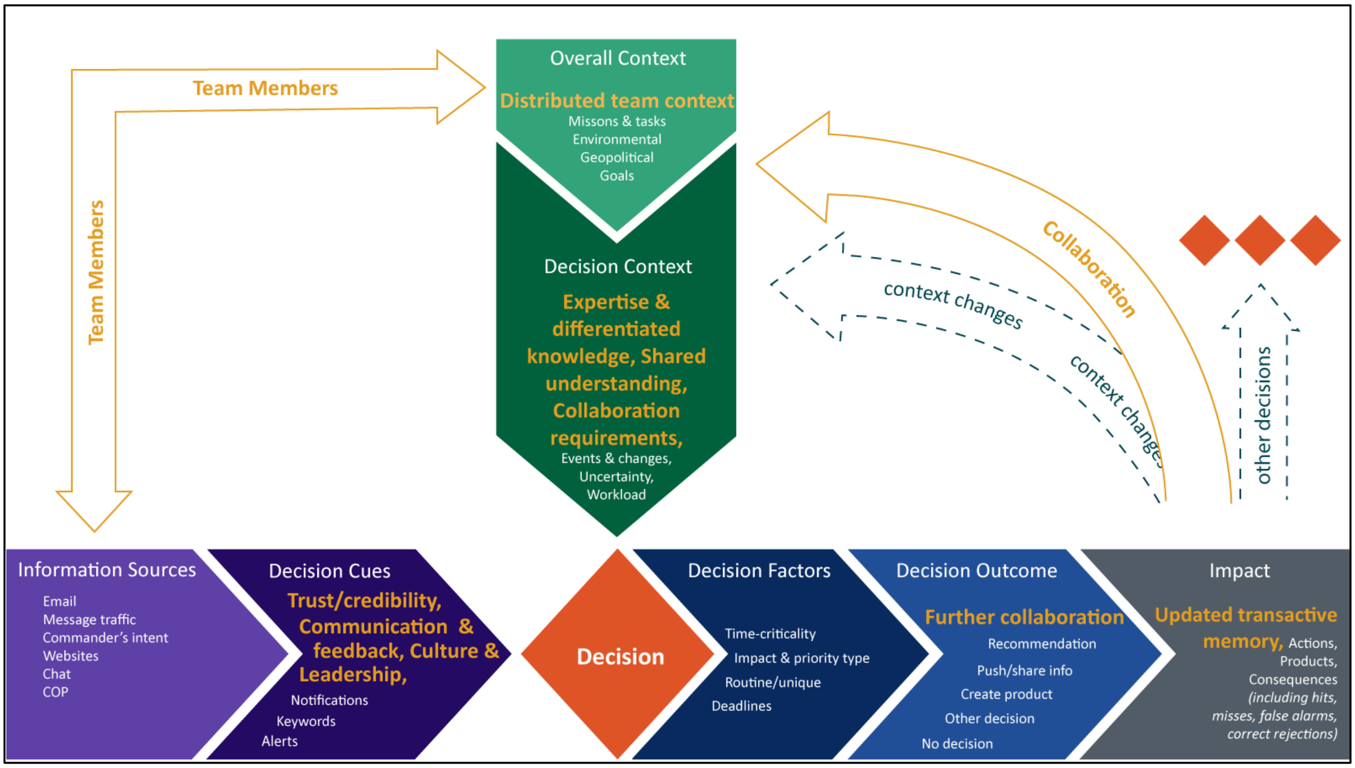

Figure 2. Decision support structure for coalition operations, with TM variables (shown in red).

If properly designed and implemented, a PDS system that supports TM should improve operations by facilitating the sharing of relevant information among team members, thus reducing workload, increasing the efficiency of information gathering, verification, compilation, and analysis, and, ultimately, supporting optimal effective decision making. Thus, consideration of TM variables is crucial for the development of a PDS tool that will maximally support the complex, high-consequence decisions and large, disparate teams that characterize so many coalition operations.

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References

[1] A. K. Dey, G. D. Abowd and D. Salber, "A conceptual framework and a toolkit for supporting the rapid prototyping of context-aware applications," *Human-Computer Interaction,* vol. 16, pp. 97-166, 2001.

[2] J. Hong, E. Suh and S. Kim, "Context-aware systems: A literature review and classification," *Expert Systems with Applications,* vol. 36, pp. 8509-8522, 2009.

[3] Pester-Dewan, M. R. A. J. and H. M. Oonk, "Knowledge flow in command & control: Developing intelligent aided communication. (Technical Report)," Pacific Science & Engineering Group, San Diego, CA, 2005.

[4] R. L. Moreland, "Transactive memory: Learning who knows what in work groups and organizations," in *Shared Cognition in Organizations: The Management of Knowledge.*, L. L. Thompson, J. M. Levine and D. M. Messick, Eds., Mahwah, NJ, Lawrence Erlbaum Associates, 1999, pp. 3-32.

[5] D. M. Wegner, T. Giuliano and P. Hertel, "Compatible and Incompatible Relationships," in *Cognitive interdependence in close relationships.*, W. Ickes, Ed., New York, Springer-Verlag, 1985, p. 253–276.

[6] K. Lewis, "Measuring transactive memory systems in the field: scale development and validation," *Journal of Applied Psychology,* vol. 88, pp. 587-604, 2003.

[7] R. Moreland and L. Myaskovsky, "Exploring the performance benefits of group training: transactive memory or improved communication?," *Organizational Behavior and Human Decision Processes,* vol. 82, pp. 117-133, 2000.

[8] M. Ashleigh and J. Prichard, "An integrative model of the role of trust in transactive memory development," *Group & Organization Management,* vol. 37, pp. 5-35, 2012.

[9] K. Lewis and B. Herndon, " Transactive memory systems: Current issues and future research directions," *Organization Science,* vol. 22, pp. 1254-1265, 2011.

[10] A. M. Phebus, B. Gitlin, M. L. Shuffler and J. L. Wildman, "Leading Global Virtual Teams: The Supporting Role of Trust and Team Cognition," in *Cross-Cultural Interaction: Concepts, Methodologies, Tools, and Applications*, E. Khosrow-Pour, Ed., Information Resources Management Association, 2014, pp. 362-384.

[11] S. Y. Choi, H. Lee and Y. Yoo, "The impact of information technology and transactive memory systems on knowledge sharing, application, and team performance: A field study," *Management Information Systems Quarterly,* vol. 34, p. 855–870, 2010.

[12] E. Palazzolo, D. Serb, Y. S. C. She and N. S. Contractor, " Coevolution of communication and knowledge networks in transactive memory systems: using computational models for theoretical development," *Communication Theory,* vol. 16, pp. 223-250, 2006.

[13] N. Stanton, P. Salmon and G. Walker, "Let the reader decide: a paradigm shift for situation awareness in sociotechnical systems," *Journal of Cognitive Engineering and Decision Making,* vol. 9, pp. 44-50, 2015.

[14] J. A. Swets, "Detection theory and psychophysics: A review," *Psychometrika,* vol. 26, pp. 49-63, 1961.

[15] S. Mohammed and B. Dumville, "Team mental models in a team knowledge framework: expanding theory and measurement across disciplinary boundaries," *Journal of Organizational Behavior,* vol. 22, pp. 89-106, 2001.

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