Networked simulations: New paradigms for team performance research

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The prevalence of the use of teams in a variety of occupations and environments has increased the importance of investigating the processes involved in their performance. However, in the past, there have been few methodologies available for the investigation of team performance. The present manuscript attempts to contribute to this area of research by describing the rationale underlying the use of computer-based simulations in research on team performance. This is followed by a review of the networked simulations that are currently being used in team-performance research. This review emphasizes the capabilities provided by the networks and the types of research concerns for which they are effective. Finally, the application of this technology to the broader study of group performance is discussed.

Because teamwork is prevalent in a number of occupations (e.g., fire-fighting, aircrews, and medicine), the ability of teams to work effectively has become a vitally important issue. In fact, Watson (1990) states that the effective use of teams is "America's best hope" for competition in the worldwide marketplace. It has been noted that technological developments and global competition have placed added emphasis upon understanding the processes and performance of teams because many tasks are often beyond the mental and physical resources of one individual (Salas, Dickinson, Converse, & Tannenbaum, 1992). Cannon-Bowers, Oser, and Flanagan (1992) cite three reasons underlying the increased importance of using teams in industry. The first is that there are critical tasks that cannot be accomplished by one individual alone. The second is the belief that groups will together perform better than single individuals. Furthermore, certain critical tasks often benefit from the redundancy offered by the use of teams (e.g., nuclear power plant operators). The third is that group structures have developed in response to the humanistic movement in industry; that is, it is argued that the use of groups and work teams increases the source of significance and responsibility of individuals in relation to their occupations.

Cannon-Bowers et al. (1992) concluded, in their review of the literature on the use of work teams in industry, that "work groups are important and offer enough

potential to warrant creative, innovative theoretical and methodological approaches to the study of their design and effectiveness" (Cannon-Bowers et al., 1992, p. 370). Despite the critical role that teams play in industry, however, science has made woefully little progress in understanding the factors that contribute to effective team performance. In fact, reviewers in this area have severely criticized the available knowledge regarding team performance (i.e., Dyer, 1984; Modrick, 1986). In large part, the absence of a sufficient data base in team performance can be directly attributed to the lack of an appropriate methodology for the study of teams.

Research on team process and performance imposes a unique challenge to researchers. Because a team has been defined as "a distinguishable set of two or more individuals who interact dynamically, interdependently and adaptively to achieve specified, shared and valued objectives" (Morgan, Glickman, Woodard, Blaiwes, & Salas, 1986, p. 3), a "team task" must provide a situation in which multiple operators are required to interact in an interdependent manner. Yet, there have historically been relatively few laboratory paradigms that can be used as effective teamwork testbeds. Thus, researchers have been remanded to relatively contrived tasks that have questionable external validity (i.e., tower building). However, the advent of low-cost, configurable computer networks might provide a technology that allows for the development of much more realistic laboratory analogs of team tasks. Research paradigms using these tools have begun to appear, but are limited almost exclusively to the group decision-making literature. However, it is likely that the networked simulation approach will be equally useful for the study of other types of teams and issues in group process and performance.

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The present manuscript attempts to contribute to this area of research by describing the rationale underlying the use of computer-based simulations in research on team performance as related to team-performance theory and the networked simulations that are currently being used in team-performance research. This review emphasizes the capabilities provided by the networks and the types of research concerns for which they are effective. Finally, the application of this technology to the broader study of group performance is discussed.

LOW-FIDELITY SIMULATION AS A TESTBED FOR TEAM PERFORMANCE

Tasks used in previous investigations of team performance range from artificial and contrived laboratory ones to complex and expensive high-fidelity simulations (Bowers, Salas, Prince, & Brannick, 1992). The former have been criticized for their artificiality and the latter for their lack of experimental control. Furthermore, such simplistic laboratory tasks as tower building fail to capture the essence of team performance in that there is little need for interdependence and interaction among team members. Bowers et al. argue that an understanding of naturalistic team performance will be forthcoming only by investigating teamwork behaviors among interdependent operators performing different types of taskwork. Bowers and his colleagues further state that the increased requirement for coordination will probably improve the generalizability of team research to real-world environments.

In general, team researchers have delineated areas in need of further research and have called for the development of better methodologies with which to meet this need (Dyer, 1984). In fact, it has been argued that "the lack of empirical studies of team training is secondary to the absence of methodologies to capture the dynamic behaviors inherent in team activity, assess the nature and levels of complex team performance, or determine the relationships among the relevant set of variables" (Bowers, Morgan, & Salas, 1989, p. 10). Thus, while team researchers are aware of the areas that need research, they are likewise aware that effective research can result only when sound methodologies are discovered and made available. In large part, the lack of useful paradigms for team-performance research can be attributed to limitations in technology.

In the past, the study of coordinated behavior provided a formidable challenge for researchers because it was difficult to create the task or measure the resulting performance. However, researchers interested in investigating team performance have begun to employ low-fidelity networked simulations to gain an increased understanding of the various factors that might impact team performance, such as structure (Bowers, Urban, & Morgan, 1992; Kleinman & Serfaty, 1989), team training load (Morgan, Coates, Kirby, & Alluisi, 1984), and communication (Bowers, Kline, & Morgan, 1992). Low-fidelity simulations can be likened to computer games

that are then networked in order to provide a task usable by more than one individual. That is, a networked simulation can provide a task suitable for use by a team of individuals. More importantly, a task of this type provides a useful, low-cost method which answers the need of researchers for an interdependent and interactive approach with which to investigate team processes and performance. Although the pioneer use of low-fidelity simulation was undertaken within the Ohio State studies (Johnston & Briggs, 1968; Kidd, 1961; Naylor & Briggs, 1965), relatively few contemporary team/group researchers have adopted the methodology. Other researchers have also noted that the "rich, colorful, and challenging environments offered by computer games provide powerful tools with which the foundations of a new approach might be studied and tested" (Hart & Battiste, 1992, p. 1291).

TEAM EFFECTIVENESS MODEL

It has been noted that research is best directed in relation to a particular theoretical paradigm. That is, it has been argued in the past that there is "nothing more practical than a good theory" (Marrow, 1969). This section will describe one of the most recent and inclusive models of team performance which might serve as a useful guide to team research. This model is based on the team performance literature and describes a number of relevant factors for investigations of team performance in a variety of domains. The purpose of describing the model here is to present an inclusive conceptualization for the study of team performance in order to illustrate the vast number of factors that require investigation for the development of a thorough understanding of team processes and performance.

The team effectiveness model (Salas et al., 1992; Tannenbaum, Beard, & Salas, 1992) represents an integration of a number of models developed in an attempt to explain team (group) process and outcomes (see Salas et al., 1992, for a review of these models). Figure 1 depicts the model. The team effectiveness model (TEM) builds upon the classic input-throughput-output model. Team inputs are individual and team characteristics, task characteristics, and work structure; examples of these variables are task structure, team norms, attitudes, and team cohesion. Throughputs are the processes by which the team communicates, coordinates, and makes use of its resources to produce outputs over a period of time; the variables include problem solving, communication, and coordination. Outputs include the quantity and quality of work or products produced by the team and changes in the team and its members; the changes might be new norms, attitudes, and communication patterns. Tannenbaum et al. (1992) argue that these model components must be considered within the context of the organizational and situational environment.

The TEM provides a useful method for the conceptualization of team processes and performance and guidance for team research. Although research on the com-

Figure 1. The team effectiveness model (TEM). (From "Toward an Understanding of Team Performance and Training," by E. Salas, T. D. Dickinson, S. A. Converse, and S. I. Tannenbaum, 1992, in R. W. Swezey and E. Salas (Eds.) *Teams: Their training and performance*, 1992, pp. 3-30, New York: Ablex. Copyright 1992 by Ablex Publishing Corporation. Reprinted by permission.)

ponents defined within the model has been conducted to some extent, there is a need for researchers to systematically test the components of the model in order to determine their relative importance. The section that follows will review research conducted utilizing low-fidelity networked simulation technology and detailed explanations of the simulations with illustrations of their appearances. Each of these sections will conclude with discussion relating the variables studied to the TEM.

NETWORKED SIMULATIONS IN TEAM PERFORMANCE RESEARCH

Low-Fidelity Aviation Research Methodology

One area in which low-fidelity simulation has been applied is in aviation research. The methodology described by Bowers and his colleagues (1992) utilizes a commercially available simulation presented on a personal computer and two monitors (connected via a video splitter) which functions as a "poor man's" network. Figure 2 depicts this configuration. This approach allows for the creation of task interdependence between team members by permitting the task to be divided so that each

team member has both individual and overlapping tasks to perform. The operator serving as pilot inputs by utilizing the joystick, while the operator serving as copilot inputs by utilizing the keyboard. The "pilot" controls altitude and heading, while the "copilot" is responsible for weapon selection and aircraft stabilization.

Bowers and his colleagues delineate several advantages to using such low-fidelity simulations for the investigation of team performance. First, the methodology is available at a relatively low cost. Second, it possesses the characteristics needed for use in team research, such as 2 or more subjects and the requirement for coordination and task interdependency. Finally, low-fidelity simulation provides the requisite experimental control of independent variables. Although there is a need to further investigate the utility of this methodology, the results of past aircrew psychology investigations have converged to suggest its reliability and validity (Bowers et al., 1992). That is, past studies that have adopted this methodology have obtained similar results, thus demonstrating its consistency for investigating behaviors related to aircrew coordination (e.g., communication, assertiveness).

Figure 2. Schematic illustration of the low-fidelity research methodology (Bowers, Salas, Prince, & Brannick, 1992).

A number of researchers (Smith & Salas, 1991; Stout, Cannon-Bowers, Salas, & Morgan, 1990) have made effective use of this methodology in aviation psychology research. For example, Stout et al. (1990) made use of the low-fidelity simulation methodology for their investigation of the relationship between aircrew coordination behaviors and performance. That is, these researchers demonstrated the utility of the methodology for investigating coordination behaviors and their impact upon the performance of aircrews. This research is particularly critical given past reviews which have described the impact of ineffective aircrew performance (Cooper, White, & Lauber, 1979). Failure to communicate and coordinate effectively has been shown to lead to disastrous consequences. Driskell and Salas (1992) argue that research conducted within the laboratory provides a unique opportunity to derive general principles of team performance that can be applied to real-world situations in order to maximize team performance within operational settings. Consequently, low-fidelity flight simulations might provide a tool with which to gain an understanding of aircrew coordination in order to permit optimal performance in aviation settings.

This discussion illustrates the need for investigation of the dynamic nature of team process and performance. The low-fidelity network paradigm provides this capability by requiring team members to share functions. That is, this methodology appears amenable to the investigation of throughput factors, particularly such team processes as coordination and communication as portrayed by the TEM. The methodology also lends itself to the investigation of "individual characteristics" such as those described by the TEM (e.g., attitudes, assertiveness). However, one shortcoming of this methodology is the extent to which such input factors as "task characteristics" and "work structure" can be altered. For exam-

ple, it might prove difficult to provide a level of workload high enough to test its relationship to output factors, such as performance and team and individual changes, without bringing the task to an end (e.g., flights crashing). Finally, simulations of this type typically limit the number of team members to two. Therefore, "team characteristics" such as team size might be less amenable to investigation by this method. This methodology appears to be most effective for the derivation of general principles of team performance and for aviation-related research.

Team Performance Assessment Battery

The Team Performance Assessment Battery (TPAB) was developed as a tool to investigate team decision making (Bowers, Urban, & Morgan, 1992). However, because TPAB is somewhat generic, it appears to have utility for investigations of team performance outside of the tactical environment. The TPAB was developed on the basis of research from two other methodologies, synthetic work (Alluisi, 1967, 1969; Morgan & Alluisi, 1972) and resource management (Kleinman & Serfaty, 1989). The history of the synthetic work methodology is grounded in the work of Alluisi and his colleagues on the Multiple Task Performance Battery (MTPB; Alluisi, 1967). The synthetic work methodology has a number of advantages (Alluisi, 1969). The primary ones are (1) relatively low cost, (2) the ability to measure many variables concurrently over extended periods of time, (3) capability for individual and team performance measurement, (4) high face validity, (5) high degree of experimental control, and (6) simplicity of measurement.

The purpose of synthetic work is to present multiple tasks to operators in a manner that requires time-sharing and results in realistic workload levels (Alluisi, 1969). For example, TPAB utilizes three watchkeeping tasks—

warning-lights monitoring, blinking-lights monitoring, and probability monitoring—to provide the constant monitoring loads that are associated with many team tasks (Bowers et al., 1992). The monitoring of both warning lights and blinking lights requires operators to respond to “critical conditions,” or, in other words, deviations from their normal states. Reaction times of operators to correct critical conditions are recorded by the simulation. Response times are also recorded for the probability monitoring task. This task requires operators to detect the presence of a bias of pointer settings along two linear scales. Operator responses to “critical conditions” for all three tasks are made via mouse interface.

In addition to the presentation of the monitoring tasks borrowed from the synthetic work methodology, the TPAB presents a resource management task that is a modification of the distributed resource allocation and management (DREAM) task developed by Kleinman and his colleagues (Kleinman & Serfaty, 1989). Operators are required to utilize information from their computer displays in order to coordinate resources and actions to prosecute incoming targets (Bowers et al., 1992). Figure 3 depicts the display viewed by TPAB operators.

The simulated radar scope displays incoming targets that must be prosecuted. Team members are required to coordinate in order to allocate two types of renewable resources. Target and resource information are presented in a table containing current time, expected target penetration time, target identification number and type, target status, score, and resources to be returned. The team is required to coordinate the allocation of their resources in order to prosecute as many targets as possible.

The resource allocation task is presented simultaneously with the individual monitoring tasks. This approach is consistent with the synthetic work methodology, and it has been noted that this approach enhances generalizability because operators are required to time-share individual and team tasks (Alluisi, 1969). Furthermore, it has been noted that the created synthetic job places reasonable cognitive demands on operators while simultaneously providing effective performance measures (Bowers et al., 1989).

Bowers et al. (1992) provided an extension of the work of Kleinman and his colleagues (Kleinman & Serfaty, 1989; Kleinman, Serfaty, & Luh, 1984; Kohn, Kleinman, & Serfaty, 1987). That is, Bowers and his col-

Figure 3. Team Performance Assessment Battery (TPAB) operator screen display (Bowers, Urban, & Morgan, 1992).

leagues utilized the TPAB to investigate the relationship between team structure, or overlap of responsibility, and workload. However, this research goes beyond research previously conducted in that the synthetic work tasks add an additional and important element—that is, the degree that structure and workload relationships are impacted by the addition of individual tasks. In addition, Bowers et al. (1992) used 5- (rather than 2-) person teams.

Results indicated that teams with no overlap of responsibility outperformed teams with partial overlap regardless of workload conditions. These results contradict earlier findings (Kleinman & Serfaty, 1989) that partial overlap of responsibility results in better performance under high workload conditions than does total or no overlap. Kleinman and Serfaty also found that total overlap was associated with best performance under low and moderate workload conditions. Bowers and his colleagues (1992) hypothesized that tradeoff effects on the individual tasks might account for this contrary finding, because teams with overlapping responsibility outperformed no-overlap teams on the synthetic work or monitoring tasks. Thus, it appeared that the teams with overlapping responsibility on the team task focused more on their individual tasks.

These findings are indicative of the utility of TPAB for investigating team performance since most occupations require team members to perform individual tasks as well. Thus, TPAB provides a unique opportunity to investigate these circumstances. In terms of the TEM, the synthetic work methodology of TPAB provides an opportunity for the investigation of “task characteristics” such as workload and time pressure. The TPAB is also amenable to the investigation of “organization and situational characteristics” such as uncertainty. That is, TPAB provides a methodology for the investigation of work structure and task characteristics in a context that also necessitates performance of individual tasks. This should facilitate the generalizability of this task for the study of team processes and performance. Consequently, the TPAB should be useful for the study of groups in a variety of environments. Because TPAB simultaneously presents both resource allocation and synthetic work tasks, it is potentially very useful for study of the components discussed within Tannenbaum’s TEM.

Tactical Naval Decision Making System

The Tactical Naval Decision Making System (TANDEM) has just been recently developed and provides a low-fidelity simulation of a command, control, and communication environment similar to that of the TPAB (Dwyer, Hall, Volpe, Cannon-Bowers, & Salas, 1992; Weaver, Morgan, Hall, & Compton, 1993). However, the TANDEM system was developed to provide a closer approximation of an actual combat information center for the investigation of team decision making than does the TPAB.

The TANDEM task requires team members to query and share information in order to arrive at a decision about a target’s identities and intentions. The TANDEM is a highly configurable PC-based simulation that was developed to allow for the investigation of factors such as task interdependence, time pressure, task load, and ambiguity, using from 1 to 3 operators. Operators performing the TANDEM task are required to make decisions regarding unknown contacts by consulting and integrating pieces of information regarding contact characteristics. That is, operators are required to make decisions regarding the type, threat, and intent of contacts on the basis of a total of 15 information pieces which sometimes can be ambiguous or conflicting. Each of the determinations (i.e., type, threat, and intent) is made by integrating five information pieces. For example, a target can be a submarine, surface, or air type of craft. Targets also are civilian or military, having either peaceful or hostile intentions toward the team’s own ship. On the basis of determination of intent, targets are either cleared or shot. Thus, the TANDEM requires accurate decisions to be made regarding the true characteristics of incoming targets. Figure 4 illustrates the display viewed by TANDEM operators.

The TANDEM system is particularly effective because of the degree of flexibility it offers. That is, TANDEM scenarios are created with number of targets, type of targets, information ambiguity, information organization, and magnitude of penalties determined by the experimenter through the use of the TANDEM authoring system. This authoring system allows a great deal of flexibility in investigating team decision making.

The TANDEM system is particularly well suited for the investigation of conditions that characterize stressful environments. For example, it has apparent utility for the investigation of ambiguity and time pressure (Weaver et al., 1993) which are “task characteristics” within the TEM of Tannenbaum and his colleagues. In addition, this task would also be an effective tool for the investigation of other task-related factors such as the weighting of information and redundancy. Although these four factors are task characteristics according to Tannenbaum’s model, it should be noted that this decision-making task has utility for investigating these characteristics in relation to “team processes” and “team performance.” According to the model, such “team process” variables might be coordination, communication, and problem solving, while “team performance” variables could include quality, time, and errors. Additionally, the configurability of the TANDEM system permits the investigation of other input factors which might impact team performance such as “work structure.” Although TANDEM would allow for the investigation of numerous factors of interest to team researchers, the task is only moderately dynamic in that the items of information to be integrated remain constant throughout as programmed within the authoring system. That is, team

Figure 4. TANDEM operator display (Weaver, Morgan, Hall, & Compton, 1993).

members possess the same information throughout a scenario. Thus, the largest potential shortcoming of TANDEM is its failure to require the integration of dynamic information over time.

Team Interactive Decision Exercise for Teams Incorporating Distributed Expertise

Another system developed for the investigation of team decision making is the Team Interactive Decision Exercise for Teams Incorporating Distributed Expertise (TIDE²; Hollenbeck, Sego, Ilgen, & Major, 1991). This low-fidelity networked simulation was developed at Michigan State University for use in the study of team decision making and includes the task itself and subprograms for the collection, sorting, and analysis of data. In particular, TIDE² was developed to provide a methodology for investigating team decision making in environments characterized by complexity, uncertainty, and ambiguity.

Although TIDE² is a networked program developed for investigating team decision making in command and control, its scenarios can be changed for other uses as well. For example, the authors note that "one can move from a naval command and control scenario to an investment banking scenario, or a scenario involving a personnel selection decision" (Hollenbeck et al., 1991, p. 9). The command and control scenario requires 4 team members to query nine attributes in order to determine the intent of incoming targets. These attributes must be considered in addition to five rules which describe how the attributes combine to indicate the level of

threat. Each team member has a different area of expertise manipulated through (1) the ability to measure target attributes, (2) knowledge of rules, and (3) the capability to translate raw target-attribute data into judgments regarding the target's threat level per attribute. Figure 5 depicts the display viewed by operators of the task. Each team member has individual responsibilities hierarchically related to the team task, and there is a designated leader responsible for determination of the team's decision and the decision can be rendered at any time with or without the recommendations of other team members. The leader is also free to disregard the input of subordinates. Team members communicate with one another by sending information via the simulation.

Because decision making is so often conducted within contexts in which team members are hierarchically organized (e.g., organizations, fire-fighting teams), it is imperative that researchers gain an understanding of its processes in order to optimize decision-making performance. Because TIDE² was designed to be a flexible system easily adaptable to many different types of decision-making contexts, it is particularly amenable to these types of investigations. For example, it is possible to manipulate group conflict and "task characteristics" such as ambiguity, time pressure, and task complexity.

Because the task is useful in different circumstances, the physical appearance of the task is somewhat less dynamic than that of other simulations discussed in this report. However, this element does not necessarily jeopardize the task's utility and might actually contribute to its effectiveness as a research tool for the investigation of

Figure 5. TIDE² operator display (Adapted from Hollenbeck, Sego, Ilgen, & Major, 1991).

team performance, because a greater number of researchers can employ it within their research investigations. Hollenbeck, Sego, Ilgen, and Major (1992) investigated the relationship between stress, uncertainty, team-member conflict, coordination, and team performance. Their past research regarding these “environmental” and “team process” variables indicates that this task is useful for these research applications, and particularly for the investigation of distributed decision-making team tasks in which there is an identified leader or decision maker.

C³ Interactive Task for Identifying Emerging Situations

Wellens and Ergener (1988) have also developed a team decision-making task of particular utility for the investigation of situations characterized by distributed information, ambiguity, and time pressure. Although the C³ Interactive Task for Identifying Emerging Situations (CITIES) was developed to simulate aspects of a metropolitan crisis control center, the authors note that their primary purpose was to develop a “plausible context within which to create a pattern of rapidly changing events that required continuous assessment to optimally allocate a limited number of resources” (Wellens & Ergener, 1988, p. 307) and to investigate information dissemination and fusion.

The CITIES simulation allows the manipulation of a number of independent variables such as event severity, timing, information richness, and resource availability. Two teams of 2 persons each, performing as police-tow and fire-rescue teams, perform the CITIES task in response to computer-generated emergency events. Each of the teams has a number of resources (predetermined by the experimenter) which must be allocated to emer-

gency situations that vary in location and intensity (also predetermined by the experimenter).

Wellens and Ergener (1988) note that the CITIES task has utility for the investigation of team-to-team communication under a variety of circumstances. In particular, such communication methods as computer conferencing, audio conferencing, and two-way television can be investigated with the CITIES task. As the frequency of these types of interactions increases with improved communication technology, it becomes increasingly important to investigate team decision making in these contexts. Furthermore, investigations of team decision making within these situations is necessary to determine how decision-making processes differ from face-to-face interactions.

Another benefit of the CITIES task is that the experimenter can create scenarios that vary in the number, severity, positioning, variety, and sequencing of events. In addition, most of the dependent measures are automatically documented by the game computer. The CITIES game uses electronic “city maps” that display emergency events as they occur. The video monitors that display the maps have transparent touch screens which enable the teams to interact with the displays as team members are presented with descriptive icons. Figure 6 illustrates these maps. The icons also provide access to extensive situational information for use by team members if desired.

Because of the technology involved, the CITIES task might be more costly than some other simulations. However, the scope of the task and the environments to which it might generalize as a research tool would appear to justify its cost. With additional equipment, the game computer can also sample microphones to determine who is speaking, whether there is communication be-

Figure 6. CITIES emergency maps and icons. (From "The C.I.T.I.E.S. game: A computer-based situation assessment task for studying distributed decision making," by A. R. Wellens and D. Ergener, 1988, *Simulation & Games*, 19, 304-327. Copyright 1988 by Sage Publications. Adapted by permission.)

tween teams, and operator heart rate via finger-mounted photoplethysmographic probes. Thus, the CITIES task appears to offer an excellent approach to the investigation of team processes and decision-making performance under a variety of circumstances which are readily translatable to the "real world." In other words, this simulation appears effective for the investigation of the "environmental factors" described by the TEM, that is, situations that are characterized by environmental conditions of time urgency, criticality, need for situation assessment, and, often, teams of persons separated by distance. As noted by Wellens and Ergener (1988), it is often necessary for public health officials, weather forecasters, multinational corporations, and military commands to link "widely dispersed teams so that a common big picture emerges" (Wellens & Ergener, 1988, p. 306). The CITIES simulation is probably the best of those reviewed here for approximating these types of environmental demands.

Computer-Supported Cooperative Work

Although the majority of the research-application examples discussed here have been networked team *tasks* as opposed to *tools*, Computer Supported Cooperative Work (CSCW) deserves mention as an additional research methodology which might be a useful aid in improving our understanding of team performance. CSCW

consists of computer technology used to support work groups in such activities as decision making, planning, project management, and communication (Olson, Olson, & Kraut, 1992). Olson and his colleagues note that CSCW can be used for distributed and face-to-face groups, working either simultaneously or asynchronously.

One type of CSCW that has been used for research purposes is GroupSystems, an electronic meeting systems environment developed at the University of Arizona (Valacich, Dennis, & Nunamaker, 1991). The group activities supported by GroupSystems are idea generation, communication, decision making, and systems analysis, among other things. The primary theoretical underpinnings of GroupSystems are related to process losses and gains (Steiner, 1966). That is, the primary purpose of GroupSystems, according to Valacich and his colleagues, is to eliminate process loss by minimizing dysfunctional group interactions and thus maximizing process gains and productivity.

The GroupSystems facilities consist of individual work stations, each containing a networked, hard-disk-based color graphics microcomputer. The work stations are arranged to provide a point of focus at the front of the room. A large-screen video display serves as an electronic blackboard, with other audio-visual support, such as overhead projectors, available when needed. The GroupSystems software focuses on "supporting generic

activities (e.g., idea generation) and not specific tasks (e.g., strategic planning)" (Valacich et al., 1991, p. 278). The authors note that this toolkit approach allows for flexibility, thus allowing for the support of a greater variety of tasks and groups. Valacich and his colleagues give several recommendations for researchers interested in developing CSCW facilities. The facilities should be able to accommodate groups of all sizes, each group member should have his/her own workstation situated so as to allow for the viewing of a central public display, and the public display should support media such as slides and transparencies in addition to computer-generated information.

One of the primary research uses of GroupSystems has been as a method for investigating group decision making and idea generation (Valacich et al., 1991). Valacich and his colleagues note that variables such as anonymity, group size and type, and proximity have also been investigated in a GroupSystems environment. As previously noted, the CSCW method is a tool that is being used more frequently in business environments as technology advances. Therefore, much of the CSCW research being conducted attempts to investigate the impact of this technology on such various process and outcome factors as strategy and task outcomes (see McLeod, 1992, for a review of this literature). Figure 7 depicts a screen from one of the GroupSystems tools called Idea Organizer.

The CSCW methodology appears to be particularly suitable for the investigation of "team-process" factors as depicted by the TEM. For example, the TEM offers communication, coordination, conflict resolution, decision making, and problem solving as illustrative of "team process." It is these types of factors for which Valacich et al. (1991) suggest the use of such technology as GroupSystems. These factors might be investigated in relation to the "output" factors described by Tannenbaum et al. (1992) (e.g., "team changes, team performance, and individual changes"). Thus, the CSCW methodology, like several of the tasks previously discussed, might allow researchers to gain additional knowledge regarding team decision making in an organizational context.

DISCUSSION

This manuscript has presented the argument that the use of simulation provides a particularly effective method for team-performance research. Indeed, it has been noted that an understanding of the processes that determine the effectiveness of teams will be gained only when researchers are equipped with useful tools for their investigation. Table 1 lists a number of factors related to team performance and suggests simulations appropriate for their investigation. Low-fidelity simulation is an ideal method for team research because (1) it is available at a

IDEA ORGANIZER

Topic Category
3. Measurement of Effectiveness
Supporting Information
<p>7.2 We must determine those conditions for which GDSS is suitable, or desirable, and those for which it is not.</p> <p style="text-align: center;">F2 = SEARCH F5 = PASTE</p>
Prior Comments
<p>7.1 Users believing that it is worth their time and effort to change the way they now work and then invest in these technologies.</p> <div style="border: 1px solid black; padding: 5px; margin: 5px 0;"> <p>7.2 We must determine those conditions for which GDSS is suitable, or desirable, and those for which it is not.</p> </div> <p>7.3 I agree with 7.2, we need to create a harmonious marriage of both technical and behavioral considerations.</p> <p style="text-align: center;">F1 = HELP F9 = CHANGE WINDOW F10 = SUBMIT CATEGORY</p>

Figure 7. GroupSystems (CSCW) tool: Idea organizer screen. (From "Electronic meeting support: The GroupSystems Concept," by J. S. Valacich, A. R. Dennis, & J. F. Nunamaker, Jr., 1991, *International Journal of Man-Machine Studies*, 34, 267. Copyright 1991 by Academic Press. Reprinted by permission.)

Table 1
Team Simulations and Possible Research Applications

Simulation	Team Performance Variables
Low-Fidelity Flight Simulators	coordination behaviors, leadership, assertiveness
Team Performance Assessment Battery (TPAB)	hierarchical structure, uncertainty, workload, time pressure
Tactical Naval Decision Making System (TANDEM)	time pressure, stress, information ambiguity, redundancy, leadership, information overlap
Team Interactive Decision Exercise for Teams Incorporating Distributed Expertise (TIDE ²)	hierarchical decision making, uncertainty, ambiguity, leadership, assertiveness
C ³ Interactive Task for Identifying Emerging Situations (CITIES)	team communication, distributed information, event severity, resource availability
Computer Supported Cooperative Work—Group Systems (CSCW)	idea generation, decision making, conflict resolution, communication

relatively low cost, (2) it is portable and convenient, (3) it can present tasks that are interdependent with sufficient workload, (4) it provides sufficient experimental control, (5) it provides a method for the generation and testing of team-performance theory, and (6) additional equipment (e.g., cameras, headsets, physiological recording methods) is easily added to optimize the dependent measures obtained.

It should be noted that many past team-performance investigations that have utilized the simulation methodology have been within the aviation and/or military domain. However, one purpose of this manuscript has been to indicate the utility of such simulations for team/group research outside the military domain. It is imperative that researchers interested in other team-research applications become familiar with simulation and its utility. By increasing the use of simulation, team researchers will be able to optimize our understanding of team principles and performance. Driskell and Salas (1992) note that one of the primary reasons for conducting research in the laboratory is to test team-performance theory. Low-fidelity simulation provides a particularly effective method for furthering empirical knowledge of theory related to team performance and processes. By testing relationships such as those proposed within the TEM, researchers and practitioners might gain the best understanding of team process and performance. The low-fidelity network methodology provides a convenient, low-cost technique for optimizing our understanding of team performance by empirically testing theoretical propositions.

The methodologies and research discussed have described a number of factors associated with team performance and depicted in the TEM proposed by Tannenbaum et al. (1992). For example, teams are characterized by differing degrees of responsibility, overlap, and structure (input variables). Similarly, many teams are more or less hierarchical in nature. That is, teams can differ in relation to their "input" factors, to their processes or throughput, and to the "output" factors of interest. Consequently, it is imperative that researchers be equipped with methods for the investigation of these factors. Teams are also confronted with a large variety of situa-

tions which demand optimal performance. In addition to their team-task responsibilities, team members must often perform individual tasks simultaneously. Therefore, it is crucial that research be continued in order to determine methods for the optimization of team performance under these various conditions.

Many team decision-making contexts are critical in terms of human life and welfare, while many organizational contexts are important in terms of profit. Although the former is more overtly vital, businesses are obviously interested in maximizing the profitability of their organizations. Thus, there is a great deal to be gained in a large number of circumstances by investigating and understanding the processes and performance of teams. Although the military was the first to make effective use of simulation as a methodology, increased technological development has improved its availability so that cost is no longer prohibitive. Consequently, researchers in other fields should benefit from the past experience of those who have developed and refined the use of simulation in other contexts. Indeed, although the developers of CITIES (Wellens & Ergener, 1988) acknowledged that they had no particular interest in specifically investigating the area of crisis control, they realized the benefit of simulating a context for which team performance was both relevant and important in order to gain an increased understanding of factors related to team decision making.

Although the simulations reviewed here have varying degrees of utility for the investigation of factors that might impact teams, there are areas in which they might be less than optimal for all researchers' needs. Because situations in which teams and groups function are often dynamic, there is a need for the development of methodologies which allow the conduct of team research utilizing tasks that are more dynamic than those reviewed here. Most of the tasks discussed within this manuscript are fairly static in nature. That is, although the *appearance* of the simulations is dynamic, the actions required on the part of the team's members are often repetitive with fairly well-defined roles for its members and little opportunity to "step in" and help fellow team members if they become overloaded. This is a potential advantage

of the CSCW methodology and a difficult criticism of low-fidelity simulations, since it is just this experimental control touted as an advantage of low over high fidelity. That is, the control afforded by low-fidelity simulation has associated costs, one of which is its invariance. However, an optimum tradeoff between experimental control and task variability should be sought.

Another shortcoming of these simulations is their ability to address situations more like those found in different types of organizations. For instance, it is often necessary for teams of individuals within organizations to work together on tasks that have delayed feedback regarding the consequences of members' actions. Because of the nature of the tasks reviewed here, feedback is typically given fairly quickly. Organizational settings also often work toward task outcomes that are confounded across group members. Most of the simulations reviewed here address this fairly effectively although their ability to investigate multiple teams interacting together is limited. An example of an organizational scenario with all of these characteristics might be an organization that works to sell a product. Because various individuals (and teams) work on different aspects of this task, advertising, production, sales, marketing, and so forth, the final outcome (e.g., sales) is confounded but dependent on the efforts of all these individuals. Furthermore, feedback (sales figures) is most often delayed. Thus, it would appear that there is a need for simulations that approximate this type of "organizational/environmental" situation characterized by true interdependence of function and delayed feedback.

Two other characteristics that might differentiate organizations from the task simulations presented here are the existence of a "right" answer versus an optimization of a task situation and the ongoing nature of training in organizational contexts. The simulations discussed within this report present tasks to which there is a "right" answer. Although strategies can be developed among team members, most often they are working toward a discernible goal (e.g., identification and prosecution of targets). The CITIES task is one which probably most closely approximates an organization in that it is difficult to assess one's progress while managing one's resources. A related issue is that of training in organizations. The simulations reviewed here are often for a relatively short period of time, whereas the performance and interactions of teams within organizations wax and wane over time. Thus, there is a need for the study of teams over longer periods of time, ideally utilizing tasks that require strategizing toward a solution that is less apparent and therefore requires *optimization*. It is suggested that the tasks reviewed here be utilized to investigate basic concepts related to team functions. However, the CSCW methodology might provide a mechanism for the investigation of teams in an "optimization" situation (e.g., brainstorming about a problem's solution or designing a system). The simulated tasks described here should serve as models of low-fidelity simulation tasks

to be developed in order to address factors such as those illustrated within the TEM. An understanding of these factors is integral to the development of an understanding of groups in organizational/operational settings.

Because the use of teams has become so prevalent, it is imperative for researchers and practitioners to understand the factors and processes related to effective team performance. However, adequate methodologies must first be discovered and/or developed in order to provide a mechanism for the determination of these factors. Consequently, researchers should maximize their efforts by adopting the simulation methodology, which has already proven effective in some domains. The team-performance literature has frequently contended that little team research has been conducted since "the Ohio State studies." Networked simulations provide a means to facilitate the breadth and depth of research in this area.

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