Behavior Research Methods, Instruments, & Computers
1995, 27 (1), 12–24

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-

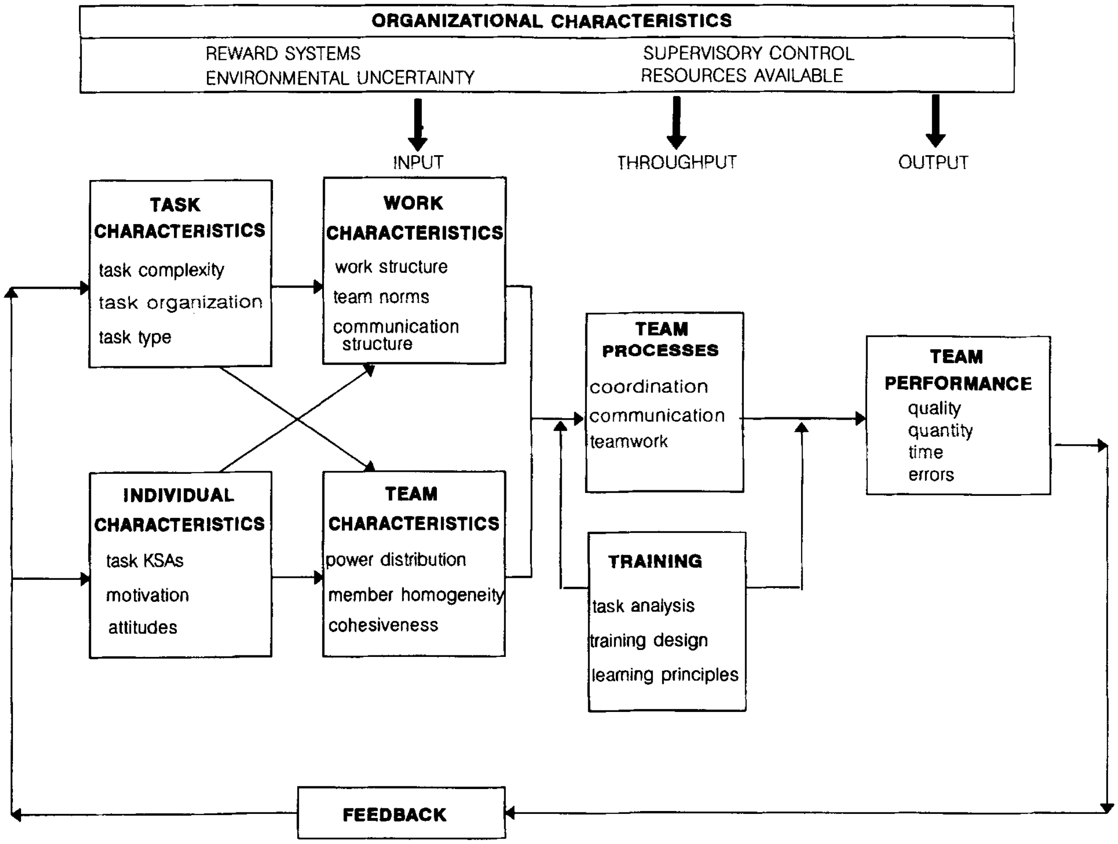

Figure 1. The team effectiveness model (TEM). (From "Toward an Understanding of Team Performance and Training," by E. Salas, T. D. Dickinson, S. A. Converse, and S. I. Tannenbaum, 1992, in R. W. Swezey and E. Salas (Eds.) *Teams: Their training and performance*, 1992, pp. 3–30, New York: Ablex. Copyright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

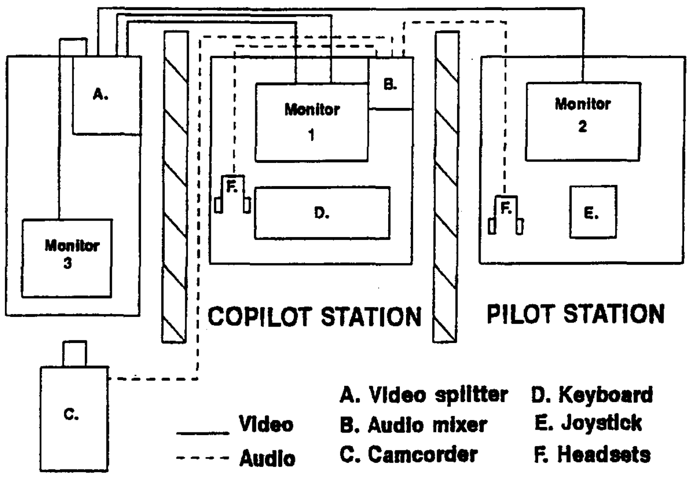

Figure 2. Schematic illustration of the low-fidelity research methodology (Bowers, Salas, Prince, & Brannick, 1992).

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 example, 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-

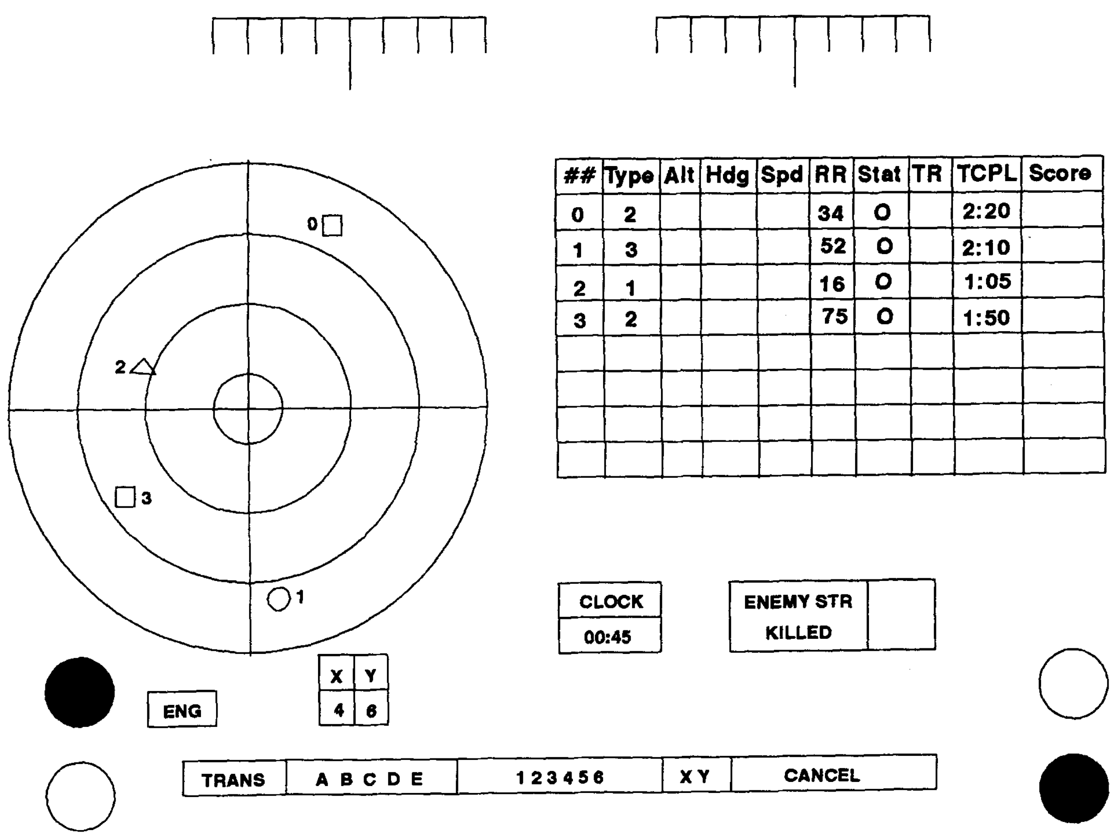

Figure 3. Team Performance Assessment Battery (TPAB) operator screen display (Bowers, Urban, & Morgan, 1992).

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