TECHNICAL PERFORMANCE MEASURES AND DISTRIBUTED-SIMULATION TRAINING SYSTEMS

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Simulation systems are being increasingly used as a cheaper alternative to field training, and as the Services put such systems into place, acquisition managers must add new methods to the traditional technical performance measures to assess the effectiveness of these training systems.

Today each Service has acquisition programs under way to provide distributed-simulation systems for the collective training needs of military organizational units. Because budgets for collective training are tight, one common objective is to maintain or raise unit performance by acquiring comparatively less expensive distributed-simulation training systems to lessen the need for more expensive field training.

Trading field training for distributed-simulation training systems puts pressure on the acquisition community to ensure that the acquired systems are successfully fielded and achieve technical performance objectives. Assessing those objectives may require newly developed measures of performance that mean the same to the acquisition, supporting, and using communities.

The research detailed here examines technical performance measures for distributed-simulation training system acquisitions used for collective training of military units. We discuss the importance of these systems to the acquisition community, using the Army's Close Combat Tactical Trainer (CCTT) as an example. We identify potentially relevant technical performance measures. And finally, we analyze the applicability of the identified technical performance measures during an actual distributed-simulation training system exercise. Findings are generalized to other such systems used for collective training of military organizational units.

THE CLOSE COMBAT TACTICAL TRAINER

Historically, to avoid poor unit performance in combat, military units have focused on training unit tasks through field exercises. With declining budgets, the Services are acquiring distributed-simulation systems that are perceived to be able to train units more cheaply than do field exercises.

All the Services and many joint organizations are acquiring these systems. Under the direction of the Under Secretary of Defense for Acquisition, the Defense Science Board (Foster, 1993) began to define some of the terms applicable to these systems. The Board used the term "distributed" to refer to a "shared battlefield entered from geographically separated sites via communication networks." The Board also defines simulation as a "mix and match of ... simulation methods." Since then the Defense Modeling and Simulation Office (1995) has promoted the simulation "mix and match" concept through "a general purpose architecture for simulation reuse and interoperability" called the high-level architecture (HLA).

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The Defense Modeling and Simulation Office is developing an HLA that will enable multiple simulation federations (groups of simulations) to exist within and between all the Services, joint commands, and others. Many future distributed-simulation federations and systems are planned for training use (Hammond and Edwards, 1998).

The Advanced Research Projects Agency has composed a joint simulation federation used for collective training—containing air, naval, and army simulated elements within the Synthetic Theater of War initiative (Meier, 1999). Another system, the "distributed mission trainer" (DMT), is a priority for the Air Combat Command (Hawley, 1998). When fielded in 1999, DMT will add integrated and distributed manner simulator systems at Eglin, Langley, Shaw, and Tinker Air Force Bases (AFBs) to simulation systems already in the Air Force (Kuhn, 1998). The integration will provide a complete spectrum of aircraft and facilities for Air Force unit training and mission rehearsal.

An illustrative example of a distributed-simulation training system acquisition is the Army's CCTT, currently being fielded. As do field training exercises, the CCTT "will train Armor, Cavalry, and Mechanized Infantry Platoons through Battalion/Task Force on their doctrinal Mission Training Plan collective tasks" (Hammond and Edwards, 1998).

But unlike field training exercises, "the CCTT-system ... consists of networked vehicle simulator manned-modules ... in combination with Semi-Automated Forces, Combat Support workstations, computer networks and protocols, and After-Action Review systems" (Hammond and Edwards, 1998). Actual military systems like tanks are not used in the CCTT distributed-simulation training system. The CCTT may be considered a distributed, synthetic battlefield with various simulators that enable virtual and other synthetic players to interact in simulated battles.

As in field training exercises, senior evaluators and unit leaders discuss unit task and mission accomplishments and failures with unit members after the CCTT training. This forum is referred to as an "after-action-review." After-action-reviews also provide instruction on process improvements that are aimed at improving overall unit performance.

A simple analogy for this review session might be the discussion that a high school basketball team coach has with his team immediately after a team scrimmage. The emphasis in practice is on processes like individual dribbling and shooting, and team plays like setting up a clear three-point shot or a fast break. The coach does not focus so much on the score (outcome measure) run up against the scrimmage squad, but rather uses those failures and successes as points to correct specific task errors or reinforce successes. In combination with personal and other team tasks and plays, their ability to perform these tasks affects their ability to put points on the scoreboard in the real game.

Unlike most field training exercises, with the exception of some live simulation sites, sophisticated after-action-review systems permit replay of portions of the unit actions that occurred during a CCTT exercise. These after-action review systems enhance unit discussion and further enable unit performance improvements.

As in field training, U.S. Army mechanized and armored units (platoons, companies, and battalions) use mission training plans in the CCTT. These plans identify general and specific tasks with conditions and standards for measuring unit performance against these missions.

Units tend to build ever-higher levels of competence through exposure to ever greater challenges in training (CCTT, 1998). In the dynamics of human and unit growth, the learning environment evolves. From learning basic unit tasks, moving on to learn advanced unit tasks, reinforcement of previously learned tasks, and, finally, integration of various combinations of tasks (typically a mission or set of missions), individuals learn through some combination of instruction, discussion, and exercises.

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Just as in a field or live simulation exercise, the distributed-simulation training exercise integrates tasks in the form of unit mission scenarios. The training goal is to learn and perfect unit integrated processes like unit tactics, techniques, and procedures that are transferable to many different missions. The focus is typically not exclusively about the resulting outcome for a particular mission. Similar to the basketball scrimmage example, the emphasis is not on the outcome of the scrimmage, but on the processes that can put points on the board during the real game.

RELATIONSHIP OF SYSTEMS TO THE ACQUISITION MANAGER

As these distributed-simulation training systems emerge and move toward fielding, the need becomes apparent for metrics to help communicate meaning between dissimilar communities and to evaluate them appropriately. As an example of the importance of metrics, consider the Williams and Keaton (1998) comprehensive evaluation of the CCTT 1997–1998 initial operational test (IOT) and 1997 limited user test (LUT) conducted by the Test and Experimentation Command (TEXCOM).

During IOT fixed-site simulator training in the CCTT, Williams and Keaton report (based on their aggregate task measures) only a "range of modest to insignificant gains observed during the CCTT training." Specifically, "simulator training during the third through seventh weeks of the IOT indicates that few performance gains were achieved by the units undergoing training."

Despite this recorded lack of performance gains in the CCTT, Williams and Keaton report that "At the aggregate level across all subtasks, the CCTT [-trained] units performed significantly better at NTC" (National Training Center field exercise) than other baseline task forces (Figure 1) (Williams and Keaton, 1998). Specifically, aggregating company team performance within each observed task force, "Task Force 4 [TF4], the CCTT test unit, clearly outperformed the three baseline task forces."

There may be many different explanations for these starkly different observations of performance. One would hope that CCTT training was the primary contributor to success at the NTC. But Williams and Keaton conclude, "The IOT in-simulator performance data was insufficient to demonstrate a linkage between CCTT training and performance attained in the field."

One alternative conclusion is that additional measures and measurement instruments, or a different approach, are needed to capture unit performance improvement that may have actually

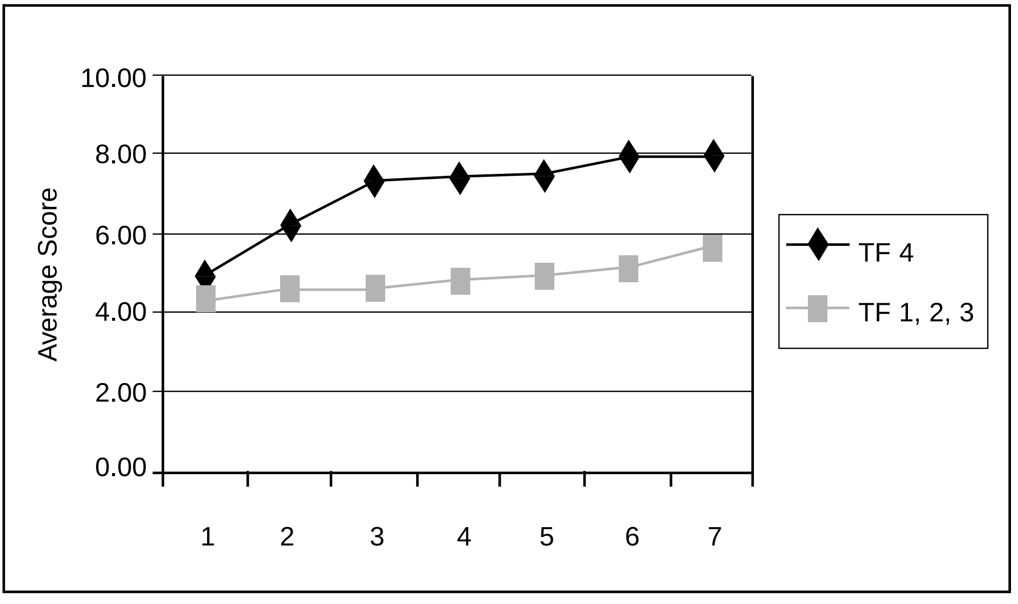

Figure 1. Pure CCTT Company Teams (TF4) versus All Baseline Company Teams (TF 1,2,3)

occurred while training in distributed-simulation systems. Supporting this alternative conclusion is the fact that these systems focus on improving the processes that make a unit function and not so much on the outcome of a particular training scenario.

Since distributed-simulation training systems are acquisitions, both the acquisition community and the training community could benefit from a shared lexicon of technical performance measures to provide a clearer indication of overall potential to achieve ultimate technical objectives.

In 1998 Maj Kenneth Delano published a survey of program managers showing that meeting "technical performance objectives" is ranked first as an indicator of program success. His survey also revealed that program managers ranked their own "ability to communicate" as the most important factor in program success (Delano, 1998). (The article did not define either of these terms more definitively.)

Aiding both evaluation and communications, *The Systems Acquisition Manager's Guide for the Use of Models and Simulations,* published by the Defense Systems Management College (Piplani, Mercer, and Roop, 1994), identifies numerous outcome-oriented, technical performance measures for use by acquisition managers of combat systems.

By contrast, reports on technical performance measures for unit collective training systems are scant if at all present in the acquisition literature. Further, technical performance measures for evaluation of individual training systems have traditionally been submerged within the related combat system acquisition. Typically, training systems were justified as trainers for a specific aircraft, weapon system, etc. Consequently, technical performance measures for individual and crew-training systems have been system specific and oriented to system performance.

TEAMWORK AND TASK PERFORMANCE

The most applicable traditional technical measure identified in the Piplani et al. (1994) publication is an aggregate outcome measure referred to as loss exchange ratio (LER). The LER can be used to judge individual or crew performance improvements. The LER is an outcome measure that compares enemy losses to friendly losses. Using an air warfare analogy, a loss exchange ratio might compare the number of enemy aircraft shot down to the number of friendly aircraft shot down. The more enemy aircraft shot down for every friendly aircraft shot down, the better your system. A difficulty in this approach is that it is limited in scope to comparative systems/ units and, in a peacetime environment without actual adversaries, the LER becomes suspect.

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Further, Johnston, Smith-Jentsch, and Cannon-Bowers (1997), Smith-Jentsch, Johnston, and Payne (in press-a) and Brannick, Prince, Prince, and Salas (1995) indicate that "free play" training exercises produce inconsistent outcomes in the LER when measuring unit performance change from training period to training period, whereas the alternative to "free play"—a structured exercise—was expensive to build and maintain.

As possible supplemental measures, Glickman et al. (1987), McIntyre and Salas (1995), and others discussed the influence of teamwork—a collection of critical behaviors and interpersonal skills—on unit or collective task performance. These two technical performance measures—teamwork and unit task performance—are not widely discussed in the system acquisition literature. As measures they represent analysis of the process as opposed to the aggregate outcome of those processes.

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Johnston et al. (1997) refined these teamwork dimensions and in a second review, Smith-Jentsch et al. (in press-a and -b) refined the four teamwork dimensions—discussed below—into more reliable and independent dimensions containing sets of specific interpersonal behaviors. Qualitative assessment for each dimension and behavior can be done using behaviorally anchored rating scales (Johnston et al., 1997).

The use of both process measures to supplement outcome measures allows for a more complete assessment of system contribution (Brannick et al., 1995; Johnston et al., 1997; Smith-Jentsch et al., in press-a; Stout, Cannon-Bowers, and Salas, 1997). This is significantly different from the more familiar and traditional emphasis on outcome measures identified by Piplani et al. (1994).

Collective Training in a Distributed-Simulation Training System

So what research could better illuminate the contribution of process measures as a supplement to outcome measures with respect to the discussion and evaluation of distributed simulations used for training?

During our research we observed collective training in the CCTT distributed-simulation training system to gain insight into what teamwork and task performance measures might provide.

Johnson and Noble (1994) indicate that distributed interactive simulation has the potential to effectively train the following primary tasks: command, control and communications (C3); maneuver and navigation; teamwork, and leadership.

For this study, the research team investigated measures for two of these tasks—teamwork and C3 task performance—by observing the normal training of two active-duty U.S. Army battalion task forces within the CCTT facility at Fort Hood, TX. Each battalion task force reported to the CCTT facility to conduct training. The battalion task force received familiarization training on the CCTT and then practiced operating and maneuvering manned module vehicles and units within the CCTT.

In the recorded training exercise, the task force received a "movement to contact" mission and entered its tactical operations planning process. A tactical plan was devised, rehearsed, and then executed in the CCTT.

Next, each battalion task force conducted an after-action-review feedback session on unit tactical performance at both the company level and the battalion level. After that, the units repeated the movement-to-contact mission. Upon completion of the second trial, another feedback session was conducted to assess tactical performance.

Participants in the study served in duty positions that included company commander, executive officer, and platoon leaders. For the purpose of this study, this team of leaders was referred to as the tactical command and control team, since these individuals provide the leadership to command and control their units while executing their mission.

For control purposes the same movement-to-contact scenario was used between the first and second simulation run. The selected tasks to be performed were identical between simulation runs. The scenario in each run presented the same mission, enemy force, terrain, time frame, environmental conditions, and semiautomated entities' coded behavior. The opposing force consisted entirely of semiautomated forces under the control of an experienced operator.

The semiautomated-force operators used their "free play" prerogative in the second run. Specifically, units typically train against a lesser able opposing force in their initial training. In accordance with the learning objectives of the commanding officer, the semiautomated-force operators typically increase the degree of difficulty by increasing the quality of semiautomated-force tactical operations in subsequent runs (CCTT, 1998).

As indicated above, this common training approach with increasing difficulty in subsequent training exercises was suspected to influence LER relationships. Since the research was aimed at supplementing the LER as a technical measure, the research team collected LER data.

We wanted to evaluate the use of process measures in light of aggregate outcome measures. To facilitate the evaluation, we used an event-based approach to focus on teamwork dimensions and unit task performance of each company's tactical command and control team during each movement-to-contact mission.

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Each event contains a unique tactical situation that requires team members to coordinate and exchange information at each step in order to assess the situation, make the appropriate decisions, and execute the correct actions. We selected three specific events that were likely to require the execution of team behaviors. Hence the mission was broken up into three events. The events selected were:

- perform tactical movement (17-2-0301);
- perform actions on contact (17-2-0304); and
- perform an attack by fire (71-2-0311) (Department of the Army, 1988).

Each event has task steps (processes) or subtasks, some which have critical subtasks associated with them. Success or failure of each task step was recorded.

A set of teamwork observation forms (measurement instruments) adapted from methodology used by both Johnston et al. (1997) and Smith-Jentsch et al. (1996a) were applied for each of four teamwork dimensions: communication, information exchange, team initiative and leadership, and supporting behaviors (team initiative/ leadership, Figure 2).

Team behaviors were categorized into effective and ineffective team behavior. Team behavior quality ratings were assessed three ways: the ratio of effective to ineffective team behaviors, the impact or severity of specific team behaviors, and an overall subject-matter expert rating of team behaviors. Quality ratings assessed the four teamwork dimensions and specific team behaviors (Table 1) using a 1 to 5 Likert scale.

Team Initiative/Leadership

Event One. Tactical movement en route to enemy contact: Event One begins at start of scenario and lasts until contact is made with an enemy force.

Task: PERFORM Tactical Movement (17-2-0301) Ref: FM 71-1

Unit: ______________________ Simulation Run: ______________________

Clear and appropriate guidance provided to team when needed.

1 2 3 4 5

Guidance is unclear or never stated. — Clear and appropriate guidance always stated.

Clear and appropriate guidance provided to team when needed.

1 2 3 4 5

Priorites unclear or never stated. — Clear and appropriate priorities always stated.

Clear and appropriate guidance provided to team when needed.

1 2 3 4 5

Reform inappropriate or never stated. — Reform appropriate and always stated.

Remarks:

Team Initiative/Leadership Frequency

- Provide guidance or suggestions (Effective) 0 1–5 6–10 >10___
- Provide guidance or suggestion (Ineffective) 0 1–5 6–10 >10___
- States clear team/ individual priorities (Effective) 0 1–5 6–10 >10___
- States priorities (Ineffective) 0 1–5 6–10 >10___
- Refocus team IAW situation (Appropriate) 0 1–5 6–10 >10___
- Refocus team IAW situation (Inappropriate) 0 1–5 6–10 >10___

Figure 2. Sample Team Observation Worksheet

Table 1. Teamwork Dimensions and Team Behaviors

Teamwork Dimensions	**Definitions of Team Behaviors**
Information exchange (Effective behaviors, 1–4; ineffective behaviors, 5–7)	1. Seeks information from available sources 2. Passes information to the appropriate persons 3. Provides accurate "big picture" situation update 4. Accurately informs higher commander 5. Has to be asked for information 6. Provides inaccurate situation update 7. Inaccurately informs higher commander
Communication (Effective behaviors, 1–3; ineffective behaviors, 4–7)	1. Uses proper phraseology 2. Provides complete reports 3. Adequate brevity; avoids excess chatter 4. Uses improper phraseology 5. Provides incomplete reports 6. Uses excessive chatter 7. Communications are inaudible or garbled
Team initiative/leadership (Effective behaviors, 1–3; ineffective behaviors, 4–6)	1. Provides effective guidance or suggestions to team members 2. States clear team and individual priorities 3. Appropriately refocuses team in accordance with situation 4. Provides ineffective or unclear guidance or suggestions to team members 5. States ineffective or unclear team and individual priorities 6. Inappropriately refocuses team in accordance with situation
Supporting behavior (Effective behaviors, 1–4; ineffective behaviors, 5–6)	1. Corrects team errors 2. Requests backup or assistance when needed 3. Provides backup or assistance when needed 4. Provides constructive feedback 5. Fails to correct team errors 6. Provides or uses nonconstructive feedback

In order to avoid inconsistency of assessment between multiple observers, one evaluator was trained and validated at 100% proficiency in identification and classification of teamwork dimensions and respective behaviors by using the "team dimensional training" computer-based-instructional software program (Smith-Jentsch, Zeisig, Acton, and McPherson, in press-b). The same observer assessed team behavior quality ratings and team task performance for all teams.

Results and Analysis

After training was completed, the CCTT after-action-review tapes were analyzed to observe, categorize, and record observations of teamwork and task performance. Eight company-level movement-to-contact mission scenarios were evaluated. All radio communications and team or unit actions were observed and monitored separately for each tactical command and control team.

Task performance was assessed for each task event based on the *U.S. Army Mission Training Plan for Tank and Mechanized Infantry Company and Company Team* mentioned earlier. Teamwork dimensions and team behaviors were analyzed for indication of improvement. In addition, the traditional loss exchange ratio measure was evaluated.

As a means of analyzing C3 task performance, a series of matched pairs, one-tailed *t*-tests compared the difference in critical task and subtask success between simulation run No. 1 and run No. 2. Matched pairs, one-tailed *t*-tests compared loss exchange ratios differences between runs but due to the nature of the selected tasks, not all tasks involved a LER. For all statistical tests a significant difference was declared if the probability of random occurrence was less than or equal to 0.05.

C3 Task Performance and LER Results and Analysis

C3 task performance indicated statistically significant improvement in mission training plan critical subtask ($\rho = .044$) and total subtask success ($\rho = .007$) as shown in Figure 3. For the LER, from a sample of eight tasks that did involve the LER, five teams had an increase in the LER, two teams had a decrease in the LER, and one team had no change in the LER. Statistically the LER did not indicate any change due to the variability in the sample, although the change was relatively large as Figure 3 shows ($\rho = .57$).

Variations in task difficulty during the second run, due to the free play in the

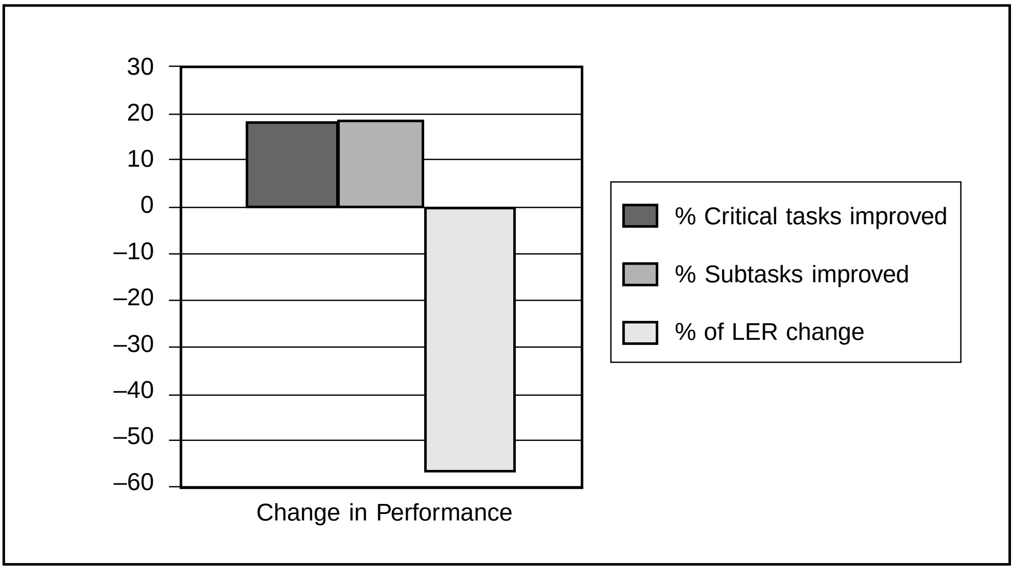

Figure 3. Performance Change between Run No. 1 and Run No. 2 based on Cited Technical Performance Measure

simulation, altered some tactical issues (holding of key [advantageous] terrain, enemy initiating contact from a hasty defense/attack-by-fire positions, force ratio of attacking to defending units, etc.). As suspected, these variations in task difficulty between the two runs may have influenced or confounded the outcomes of the LER data.

TEAMWORK QUALITY RATINGS

In order to determine if training in virtual simulation resulted in an improvement in teamwork, teamwork quality ratings were assessed for each run. Quality ratings between the first and second runs were found to have improved to a statistically significant degree for all teamwork dimensions. Additionally, improvements in quality ratings for 13 team behaviors that make up the teamwork dimensions were found to be significant.

CONCLUSIONS

Whether in athletic competition or in combat, quality teamwork demonstrates its tremendous value. An example process or task worked on by a highly skilled team might be the "no-look pass" between basketball players Michael Jordan and Scottie Pippen. Their teamwork created many national championships.

In the past the U.S. Armed Forces have had significant opportunity to develop expertise in unit teamwork and mission task performance during training involving field operations using actual equipment and formations. That environment has changed significantly due to a number of factors. But despite the change, we don't want to become the Chicago Bulls of 1999. To compensate, our armed forces appear ready to acquire less costly distributed-simulation training systems in order to help fill the gap created by reduced field training.

These findings indicate that training in distributed-simulation systems can result in statistically significant improvements in teamwork, C3 task performance, and, potentially, the loss exchange ratio. Specifically, our research indicates that distributed-simulation training systems can help fill at least two gaps—teamwork and C3 task performance. Statistically significant improvements in the quality of teamwork were shown while conducting training in a distributed-simulation training system. Also, C3 task performance was found to significantly improve between training sessions as shown by increased mission training plan critical subtask and total subtask successes.

Our study also indicates traditional measures such as loss exchange ratios do not appear to be appropriate as sole technical measure when evaluating the suitability of simulation systems used for training. We observed no overall statistically significant change in task performance between simulation runs as measured by the LER. As often the case in training, the LER may not be a credible indicator of improved proficiency of the unit as the difficulty of the opposing force fight might increase for training purposes from run No. 1 to run No. 2. While duplication of the same scenario and difficulty level

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is possible in training, this typically only occurs for units that fail that level and need to be retrained.

The findings provide initial indication that process-oriented measures such as teamwork and subtask and step performance are viable and should supplement the acquisition managers' set of technical performance measures for distributed-simulation training systems. These measures provide the acquisition system manager a more complete assessment of the ability of a prospective distributed-simulation training system than loss exchange ratio would by itself. Further, these measures are intuitive and simple, helping to satisfy the challenge of communications as well as evaluation.

We identify our measures, approach, and measurement instruments, which may prove useful for more general application to other distributed-simulation acquisition involving collective training. Further, they appear appropriate not only for U.S. Army acquisitions but also for the Air Force, Navy, and Joint organizations in light of DMT and HLA efforts. These findings imply that these process-oriented technical performance measures and methodologies may be additional tools with which astute acquisition manager should be familiar.

Further research is required to determine if these findings can be confirmed with larger sample sizes, perhaps over time and across other distributed-simulation systems used for collective training. Further research may address the application of these findings to other training audiences within distributed-simulation such as air wings, ship command and control, higher staffs, and other types of organizations.

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