

Data Visualization to Improve Evaluation for Live Training

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ABSTRACT

In a military context, after action reviews (AARs) can be an effective tool for providing feedback following a training drill or operation with participants openly discussing and discovering what happened, why it happened, and ways to improve. To maximize effectiveness, AARs must encourage active learning which involves active engagement, reflection, and self-discovery. Technological advancements in recording and measurement can provide instructors with more information for AAR discussions. If properly designed, data visualizations can depict critical information about team shooting, movement, and communication performance during a training exercise. This work is part of a larger, Army funded, research initiative to understand the relationships among different aspects of squad performance during Army Battle Drill 2A (React to Contact). Audio data was collected from individual members of Army squads executing the battle on a live-fire range. These audio files were processed to extract voice communications and rates of fire for fire team members laying down suppressive fire. Additionally, we collected hit data from targets. Using these data sources, we describe and illustrate how real data can be represented visually, in accordance with design principles, to augment battle drill instructor led AARs. This identification and discussion of ways to visualize performance measures so that they enable critical self-reflection can inform future team performance research and training technology development.

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The Army Operating Concept emphasizes the importance of maintaining advantage over the enemy under any circumstance (U.S. Army TRADOC, 2014). To do so, the United States (U.S.) Armed Forces infantry must achieve overmatch through “applying firepower with discipline and discrimination” (Department of the Army, 2014). This necessary discipline and discrimination is accomplished through team training in a dynamic, real-world environment. This project is part of an ongoing effort to develop a squad performance model that focuses on navigation, movement, communication, sustainment, protection, and shooting. While every Soldier must be a proficient shooter to engage a target with precision and accuracy, squad communication is also a significant component of lethality with requisite knowledge, skills, and attitudes that must be trained and assessed. This paper focuses on squad communication, specifically how communication data can be represented visually for use during after action reviews to augment instructor feedback with the aim of improving squad performance (i.e., communication data examined in the context of rate of fire data collected). The communication data was gathered as part of a larger study, funded by the U.S. Army Combat Capabilities Development Command, examining squad performance during an Army battle drill.

AFTER ACTION REVIEWS

After Action Reviews (AARs) have been part of military training for decades. In a military context, an AAR is a professional discussion conducted after a training drill or military operation where those involved in the event openly discuss and discover for themselves what happened during the event and evaluate why it occurred in order to learn how to maintain strengths and improve weaknesses (Morrison & Meliza, 1999). Studies in various sectors and contexts have shown that individuals, teams, and organizations can benefit from the incident review process common in AARs (Stoto et al., 2019). For instance, an AAR conducted in response to a pulmonary plague outbreak health crisis in Madagascar identified multiple issues related to communication, vector control, and case management and infection prevention. This helped to prioritize improvement recommendations and activities which resulted in a 90% decrease in the number of cases a year later (Stoto et al., 2019). In their meta-analysis, Tannenbaum and Cerasoli found that AARs improved quantifiable aspects of performance (e.g., self-ratings, performance appraisal ratings, performance on simulators) by 25% on average (Tannenbaum & Cerasoli, 2013).

Key elements in AARs

To maximize effectiveness, AARs must encourage active learning which involves active engagement, reflection, and self-discovery (Scott et al., 2015; Eddy et al., 2006; Ellis, 2005; Tannenbaum & Cerasoli, 2013). Techniques that spur learners to experiment with ideas and actions also reinforce learning (Kolb, 1984). AARs should be conducted with a development, rather than an evaluative, intent as this reduces defensiveness and increases the acceptance of feedback and the motivation to learn (Jawahar & Williams, 1997; Kluger & DeNisi, 1996; Mesmer-Magnus, 2009). To encourage setting of actionable goals and plans, AARs should focus on specific incidences or episodes instead of the drill or operation in general. Having learners generate these goals themselves fosters a sense of direction, motivation, and persistence (Locke & Latham, 2002). AARs that involve multiple sources of information increase the credibility of feedback and enable teams to formulate measurable goals based on empirical data (i.e., evidence-based) (Kluger & DeNisi, 1996; Locke & Latham, 1990).

Visualizations as AAR aids

Army instructors and trainers seek to incorporate the above key elements in both informal and formal AARs. Informal AARs, have a short preparation and turnaround time, involve simple of training aids, and rely mostly on Soldiers’

recollection of the training event. Formal AARs involve more complex training aids, take longer to prepare, and can include data from multiple sources (Combined Arms Center - Training (CAC-T), 2013). What these formal AARs lose in feedback immediacy they make up for with the inclusion of more credible, evidence-based feedback.

Technological advances in recording and measurement have contributed to a surge in the data and information available for AAR discussions. However, this does not necessarily translate to better AARs. With more data and information, the likelihood of information overload increases, where potentially useful information impedes comprehension rather than facilitates it (Bawden et al., 1999; Jackson & Farzaneh, 2012). A common strategy to minimize information overload is to curate appropriate information and use appropriate visualization to depict that information. Studies supporting the use of visualization report that it reduces cognitive load by offloading short-term memory, allows for comparisons to be made more easily, and facilitates inferential and strategic thinking (Shneiderman, 1996; Tufte, 1990; Ware, 2004). The type of visualization also impacts whether the information presented is beneficial to or impedes thinking. Guidelines recommend that visualization type should depend on the data depicted (Carr, 1999; Shneiderman, 1996), and meta-analysis of the effects of information visualization revealed that “given the same level of cognitive abilities, users tend to perform better with simpler visual-spatial interfaces” (Chen & Yu, 2000, p. 864).

RESEARCH CONTEXT

This work is part of a larger, Army funded, research initiative to understand the relationships among different aspects of squad performance during Army Battle Drill 2A (React to Contact). In support of this initiative, the study team participated in a pilot project sponsored by the Program Executive Office (PEO) Soldier that focused on evaluating squad performance. This pilot project involved 18 infantry squads from a unit executing a series of live training events featuring Battle Drill 2A. During the battle drill, Soldiers must proficiently engage a target with precision and accuracy while also communicating key information to their team about the enemy (e.g., description, distance, direction) and their actions (e.g., magazine change, weapon malfunction). This communication is critical to a squad’s success. Given the importance of AARs for performance feedback, and the opportunity for visualization, we propose that squad communication data specifically can provide critical visualizations of squad performance to facilitate squad AARs for Battle Drill 2A.

Battle Drill 2A

The Battle Drill 2A (BD2A) scenario for the study consisted of two teams coordinating and moving as part of the squad to conduct a squad assault. In this drill, the squad moved to a designated location then the cadre activated autonomous targets to appear and move forward approximately 5 to 10 meters. The autonomous targets simulated enemies initiating direct fire contact through sound and light. The squad then reacted to contact by locating the enemy, moving to the fire line, and shooting at the targets. The squad’s Support-by-fire (i.e., alpha) team, which typically comprises the Team Leader, SAW (Squad Automatic Weapon) gunner, Rifleman, and Grenadier, suppressed the enemy fire as the squad’s Assault (i.e., bravo) team prepared to maneuver or “flank” to assume the assault position. After 20 seconds, or after each target was hit, the targets began a pseudo-random sequence in which three targets were presented at a time for 3-5 seconds. Targets dropped after one critical hit or three non-critical hits. While the alpha team was engaging the targets, the bravo team would flank around the fire lane to engage the targets from a new position. The bravo team signaled the alpha team to *shift fire* away from the bravo team as it prepared to move in to assault the

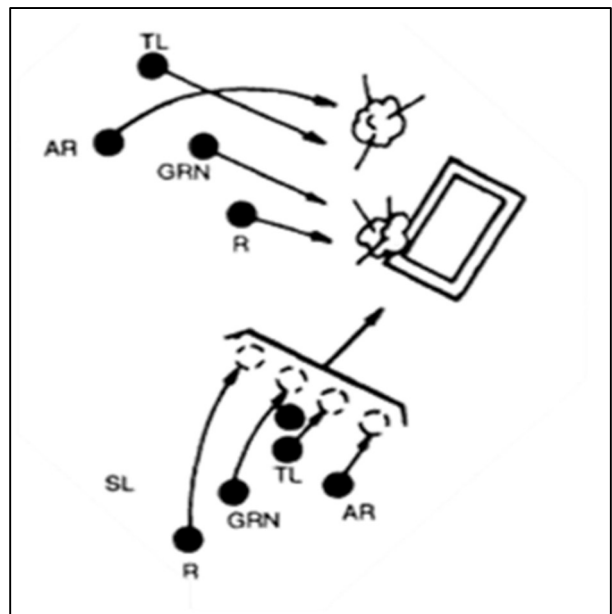


Figure 1: Schema of Battle Drill 2A
(SL: Squad Leader, TL: Team Leader, AR: SAW gunner, R: Rifleman, GRN: Grenadier)

enemy, and then to *lift fire* right before beginning its assault (see Figure 1):

Team verbal communication and shot data was captured using a TASCAM audio recorder placed on each member of the Support by Fire (i.e. alpha) team. The audio was then transcribed, coded, and analyzed. As the focus of the project was on the alpha team, data on the remaining battle drill performance involving the Assault (i.e. bravo) team were not collected. There were three main components of performance that were assessed for the alpha team on BD2A: (i) marksmanship, (ii) implicit coordination, and (iii) team communication.

BD2A Performance

Marksmanship and implicit coordination

Since the main function of the alpha team is to suppress enemy fire, the team's shooting performance was evaluated on accuracy of shots as well as the volume and sustainment of firing throughout the drill. According to military infantry doctrine, the alpha team is to output their greatest volume of fire (i.e., rapid rate of fire) at the beginning of the drill to achieve fire superiority at the outset, then drop to a more sustainable rate of fire (i.e., sustain rate of fire) throughout the drill to avoid early depletion of ammunition and weapon overheating. To achieve this sustained suppression, the SAW and the other weapons must coordinate their firing. This coordinated fire is known as "talking the guns". When one weapon is being reloaded or having a malfunction fixed, the firing rate of the other team members should be increased to compensate in order to maintain the overall effect of suppressing enemy fire. Such synchronization of individuals' tasks (Wilson et al., 2007) was taken to be a measure of implicit coordination, which occurs when the team synchronizes actions by predicting the task and team needs and then adjusting their behavior accordingly without overt communication (Espinosa et al., 2004; Fiore, Salas, & Cannon-Bowers, 2001; MacMillan, Entin, & Serfaty, 2004; Sánchez-Manzanares, Gil, & Gibson, 2008).

Team verbal communication

Data of the alpha teams' verbal communication (i.e., speech acts) were collected to examine the relationship between communication and performance during BD2A. Constructs and measures of team communication (i.e. information exchange, leadership, and communication quality) were derived from literature.. Information exchange refers to passing appropriate information without being asked and providing situation updates (Smith-Jentsch, Johnston, & Payne, 1998; Wilson et al., 2007). Leadership refers to a Team Leader (TL) providing guidance and stating priorities to team members (Smith-Jentsch, Johnston, & Payne, 1998). Communication quality, or "phraseology," refers to how information is delivered and includes using proper terminology, audibility, and avoiding excess chatter (e.g., Wilson et al., 2007).

BD2A Measures

Behaviors and measures in BD2A indicative of these communication constructs include team members exchanging information about the enemy description, direction and distance (DDD), providing updates about their weapon status (e.g., being reloaded, having a malfunction), closing the loop by acknowledging the team leader's commands. Leadership behaviors encompass Team Leaders' instructions on firing rate, and notifications of key drill events to the team. These measures were derived from our understanding of performance on BD2A and review of marksmanship and communication literature:

Table 1: Examples of performance measures in BD2A

Aspect of BD2A performance	Construct	Examples of Measure
Marksmanship	Accuracy	<ul style="list-style-type: none"> Proportion of hits and kills
Implicit coordination	Coordination (of fire activity)	<ul style="list-style-type: none"> Overlap of firing activity of team members Dead space between shots Overall suppression time
Team verbal communication	Leadership	<ul style="list-style-type: none"> Number of Team Leader commands pertaining to firing rate Number of times Team Leader notifies members of key drill events

	Information exchange	<ul style="list-style-type: none"> • Number of times Team Members exchanged information about enemy description, direction, and distance • Number of times Team Members exchanged information about their individual statuses. • Number of times Team Members exchange information about critical drill events (i.e., Shift Fire, Lift Fire) • Number of communications between pairs of members
	Communication quality	<ul style="list-style-type: none"> • Number of times Team Members used closed-loop responses • Number of times Team Members included non-essential words in their communication • Total word count • Count of non-essential words

VISUALIZATIONS OF TRAINING EVENT DATA FOR BD2A AAR

Unless stated otherwise, the data collected during the pilot project were used to generate the following visualizations. In designing visualizations and visual interfaces, Shneiderman proposes that visualizations should support the seven tasks that users perform (Carr, 1999; Shneiderman, 1996): 1.) overview, 2.) zoom, 3.) filter, 4.) details-on-demand, 5.) relate, 6.) history, and 7.) extract. Users typically first require an understanding of the “big picture” which is provided by the *overview* of the main data items available. With the ability to *zoom*, users will be able to focus on a subset of the data to see more detail within the subset. Enabling users to quickly zoom in and out of the display as well as other distortion techniques can help users keep the context in mind while viewing the detailed data. To manage the amount of detail in the visualization, users can apply various *filters* to reduce data set size by selected attributes. This way, users can control when and what type of data details are displayed (i.e., *details-on-demand*), which would depend on their purpose for seeking out those details at that moment.

Visualizations should also support the need for users to make sense of the data and draw inferences by relating similar or contrasting pieces of information. For instance, visualizations that depict actions and events that occur along the same time frame or time interval may encourage exploration of relationships among these actions and events. Similarly, side-by-side visual displays of similar training drills executed by the same squad on different occasions encourage comparisons of the squad’s performance over time. Interactive visual displays should also allow re-do, undo, and replay of certain user actions (i.e., *history*) to support user manipulation and management of the visual display for different data items. Lastly, visualizations should enable users to *extract* subsets of data or results of certain data queries to further analysis with other data sets (Carr, 1999; Shneiderman, 1996). The following are examples of visualizations of the BD2A training event that are proposed to support some of Shneiderman’s (1996) user tasks as well as address the four key elements of AARs (i.e., encourage active engagement, be conducted with a developmental intent, focus on specific episodes, and include multiple sources of information).

Visualizations on voice communications

Verbal communication was recorded and the audio files were transcribed. Squad communication was evaluated on constructs such as information exchange and communication quality. Figure 2 is an overview of the alpha team’s verbal communications depicting the number of communications conveyed to and from each team member to other team members. Such a summary supports the “overview” task (Shneiderman, 1996) as it quickly conveys where most of the team’s communication is focused, and if communications are two-way. These overview visualizations based on audio data provide a summary of the team member communication direction and frequency. Instructors responsible for training teams and assessing their performance can quickly see if team members are actively communicating.

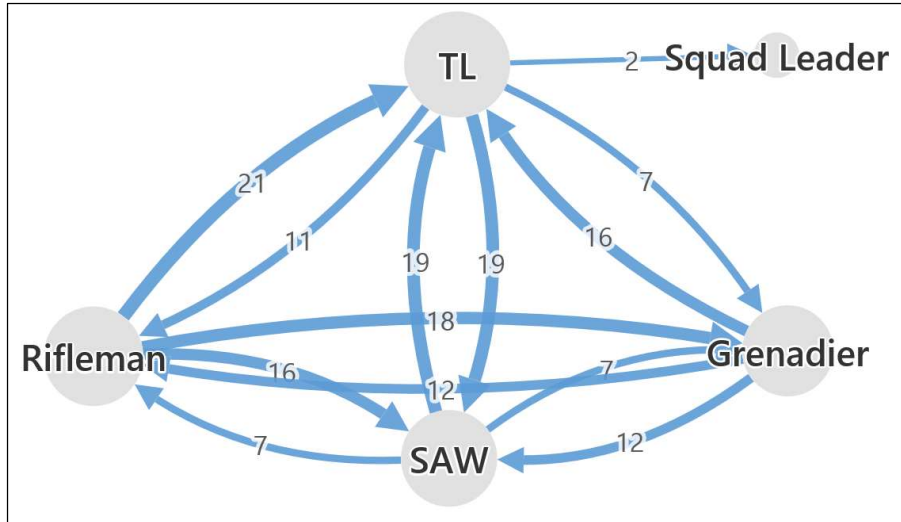


Figure 2: Overview of Team Verbal Communications: Number of communications between pairs of members (arrows show communication direction, arrow thickness and numbers correspond to counts of speech acts)

Quality of the verbal communication can be further analyzed by examining communication over time and coding the communication by type (e.g., situational information, individual status, closed-loop responses). Such details-on-demand (Shneiderman, 1996) should be available for further discussions about what was being communicated (i.e., Figure 3).

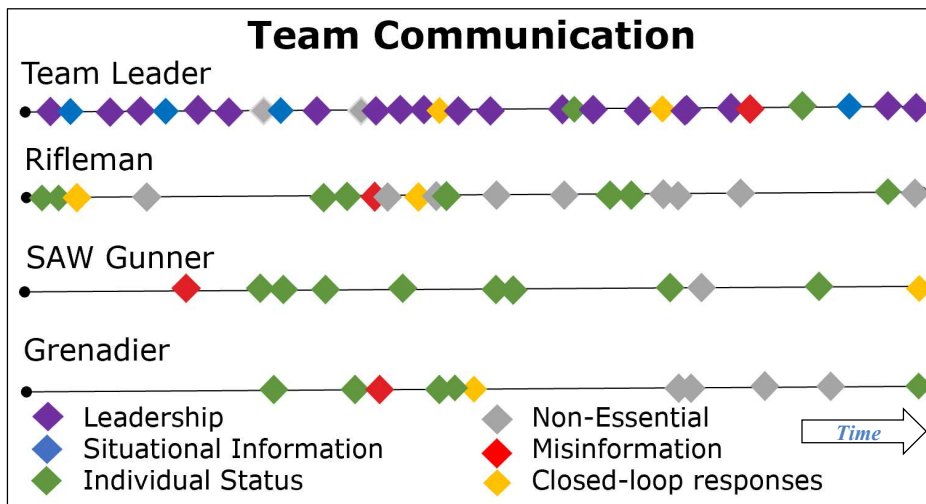


Figure 3: Team verbal communications over course of BD2A (Data points are notional)

If there are too many types or attributes, the visual display should allow the instructor the option to filter by selected categories/attributes thereby bringing attention to certain types of communication during the AAR discussions. Figure 4 is a result of filtering (Shneiderman, 1996) the team communication data. Both of these visualizations convey the amount and type of communication from each team member over the course of the drill.

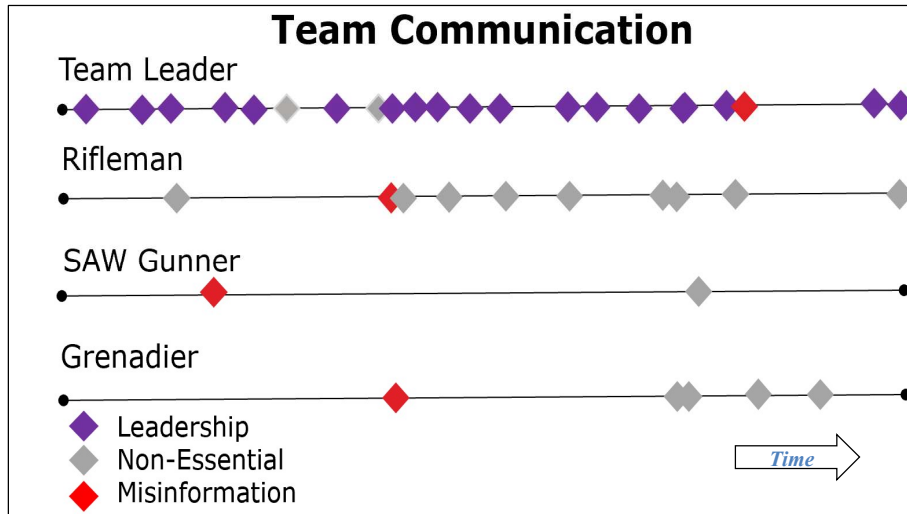


Figure 4: Team verbal communications over course of BD2A filtered by selected categories (Data points are notional)

Under certain circumstances, the instructor may require even greater detail about a specific category of verbal communication.

Figure 5 depicts the details of the verbal communications that pertain to team members reporting the status of their weapons (i.e., “Individual Status”). To help maintain focus on AAR discussions these details can be made to be available “on demand” (Shneiderman, 1996) and only be displayed when the drill instructor needs details of the status updates.

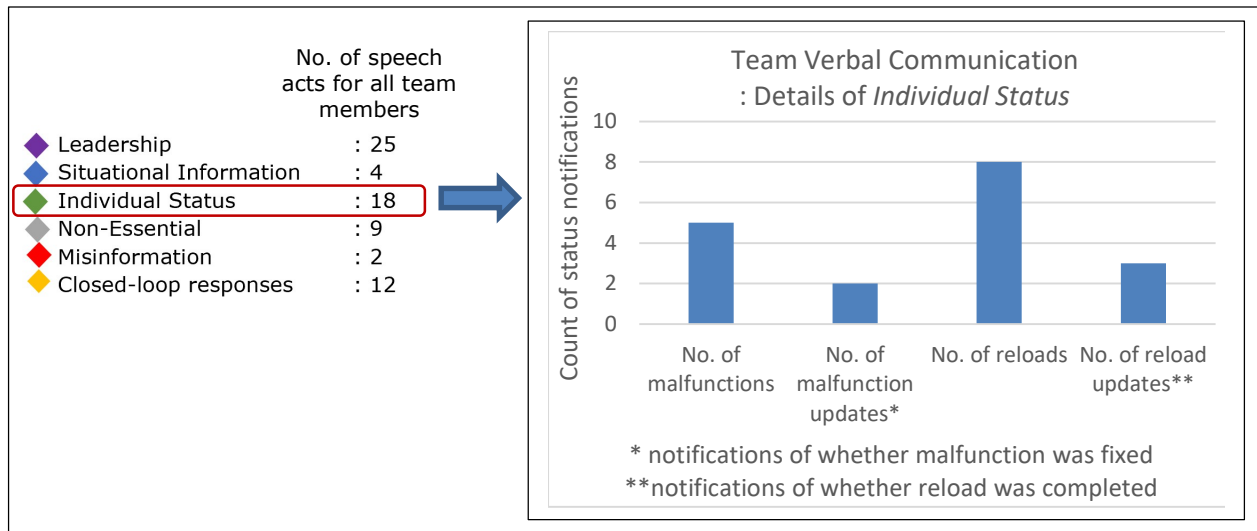


Figure 5: Details of the “Individual Status” category of verbal communications (Data points are notional)

Visualizations of shooting metrics by team members

Since the main function of the alpha team in BD2A is to provide suppressive fire, metrics of the shooting performance from each team member are important for the AAR. In particular, since the SAW is the main weapon for providing suppressive fire due to its ability to output large volumes of shots rapidly, a visualization that conveys an overview (Shneiderman, 1996) of the rounds fired by each alpha team member immediately conveys the stark difference in rounds expended by the SAW compared to the other weapons (see **Error! Reference source not found.****Error! Reference source not found.**).

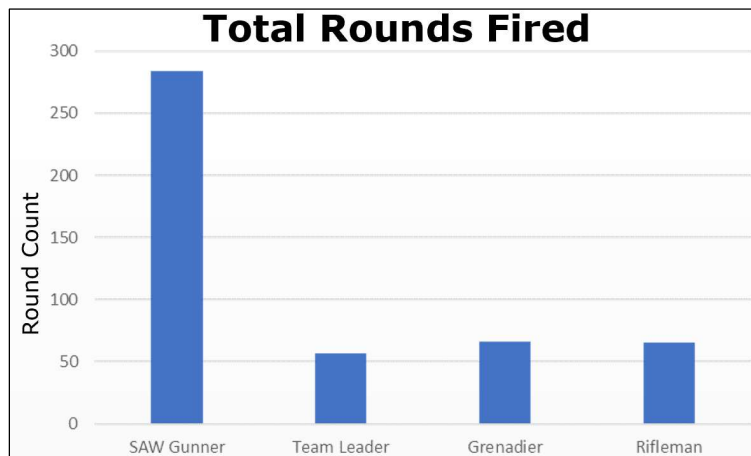


Figure 6: Overview readily conveys the striking difference between rounds fired by the SAW gunner fired relative to that by the other team members

Visualizations of shooting metrics by targets

Other visualizations from the team data can provide an overview of marksmanship quality. Such information about the team’s overall effective fire is necessary for the instructor to convey the general performance of the team, summarizing shooting performance in terms of various shooting metrics such as probabilities of hits and kills, total counts of vital and non-vital hits, overall suppression time, etc. Visualizations such as Figure 7, in encouraging discussions about quality of shots by target location, supports the “details-on-demand” task (Shneiderman, 1996), and possibly elaborates on differences in marksmanship accuracy of the team members according to their relative locations to the different targets.

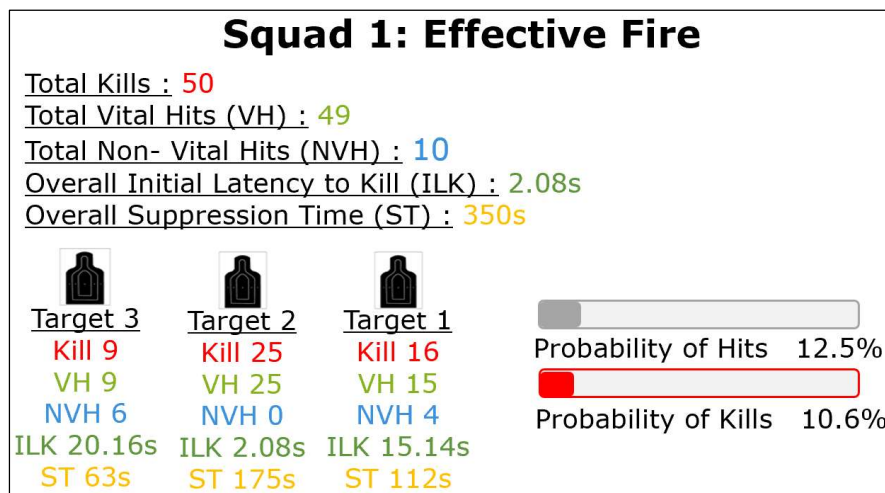


Figure 7: Overview of team marksmanship (Data points are notional)

Visualizations of volume of fire over time with overlays

Perhaps the most important task that the instructor would perform with the visualizations is to relate different data items to enable inferences about cause-effect and other relationships to be discovered. This is key to understanding the consequences of squad members' actions and directly contributes to the effectiveness of the AAR in helping the Soldiers identify behaviors and actions that should be maintained and those that should be improved upon.

In BD2A, successful suppressive fire depends largely on the synchronization of fire between the SAW and the other weapons. Since reloads, and an occasional weapon malfunction, can break a weapon's continuous fire, it is imperative that the other weapons compensate for the drop in fire power during these episodes. Figure 8 depicts the relationship between firing activity of the M249 (i.e. SAW) and M4 that is indicative of implicit coordination or "talking the guns". By depicting the rate of fire from the different weapons over time in conjunction with the information on malfunction and reloading incidences (i.e., the "call-outs"), Figure 8 supports the instructor's task of relating (Shneiderman, 1996) communication behaviors with firing activity, facilitating discussions on how these impact changes in the team's overall ability to maintain suppressive fire. The overlays of doctrinal rates of fire also allow the Soldiers to directly compare their firing performance to the doctrinal rates. Addition of key events such as the time of "shift fire" provides important context in which to interpret the graph.

Some interactive visual displays offer users the option to zoom (Shneiderman, 1996) to obtain greater granularity into a subset of a data items. For instance, a user could zoom into Figure 8 to obtain the exact time lag between the M249 and M4 in picking up their rate of fire right around the 100-sec mark when there was some squad movement (i.e., green box). However, this would not be particularly accurate or useful, hence the zoom function should only be available for data for which such level of scrutiny is appropriate.

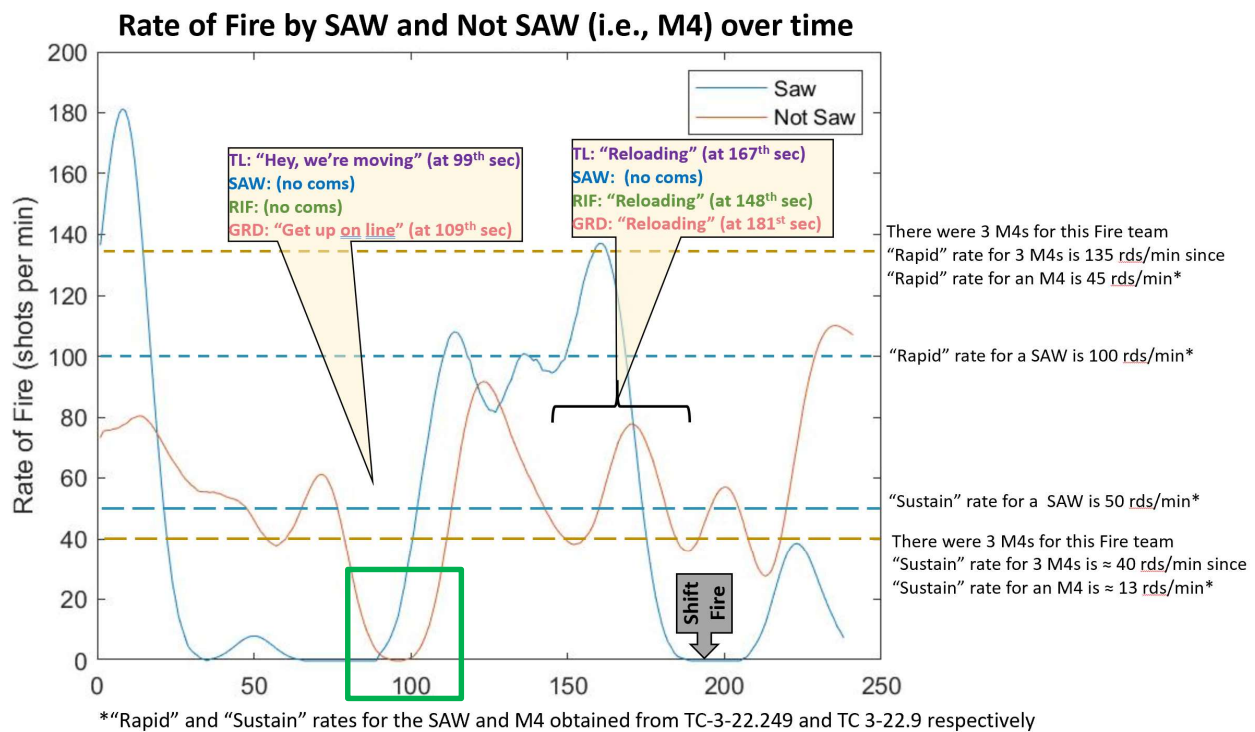


Figure 8: Visualization supporting discovery of relationships between different data items (see the text for discussion relating to the green box)

CONCLUSION

AARs are a critical component of training in the Army. Well conducted AARs encourage the team members to think critically about their performance and that of their teammates, identify errors they made, describe how they should have performed and think of ways that they can improve their performance through additional training. There is good

evidence that this kind of self-reflection is a very effective training tool (Donovan, Güss, & Naslund, 2015). A good AAR tool should facilitate this critical thinking process and not replace it with automated diagnostics. We have attempted to identify ways to visualize performance measures so that they enable this critical self-reflection.

The visualizations developed for the BD2A AAR, from overviews that summarize performance to visualizations that depict different aspects of performance across the drill duration or by team member, can help facilitate active engagement and discussions of shooting performance in relation to communication and coordination. Inclusion of multiple sources of data items in visualizations can enable relationships between aspects of drill performance to be identified and allow Soldiers to discover and identify specific actions to be sustained or improved. Such visualizations can confer advantages over video-based AARs for live training especially since the overlaying of related data can encourage exploration of possible causes and associations that can augment an instructor's ability to diagnose certain issues with the squad.

As we develop these visualization tools we want to encourage the team to compare their performance both to their own historical performance, to Army standards, as well as to other peer and expert teams. For example, in addition to having the "Rapid" and "Sustain" rates of fire for the SAW and Non-SAW, the graph in Figure 8 can include an "ideal" rate of fire profile for when the SAW and Non-SAW weapons demonstrated a high level of implicit coordination (i.e., the guns "talked" fluently). When overlaid on a squad's own rate of fire profile, this can help a squad visualize the outcome that they are training towards. By showing their historical performance, they can see progress towards those goals, and by showing the performance of peer and/or expert teams, they can set goals above and beyond the basic Army standard.

In some cases, an "ideal" Army standard profile may not be available. In such cases comparisons can still be made with normative data, which is derived retrospectively after much data from multiple drills and squads have been collected in a repository over time. Such normative data can include any number of the measures described in Table 1. Norms can be developed for similar drills executed by various types of Army units (e.g., no. of closed loop responses on the BD2A for Rangers vs. Airborne). While normative data may not yield definitive recommendations (e.g., "how much should the M4 rate of fire increase when the SAW is down?", "what is a good PH/PK?", or "what is the right amount of leadership communication?"), they provide guidance as to how a squad is performing relative to others. If further accompanied by other contextual or situational information and demographical data of the trainees, these norms can help instructors set appropriate performance expectations for their squad as well. For instance, after reviewing normative data of other squads with similar level of experience (demographical data) executing the BD2A at night time when visibility is low (situational information), an instructor can expect the current squad's level of performance to be within a certain range.

While good visualizations themselves do not necessarily translate to improved training and performance, they can help instructors identify problem areas (e.g., instances when the firing activity was not well-coordinated) and facilitate the correct diagnosis of potential underlying issues (e.g., inadequate communications when weapons were being reloaded). Further use of appropriate visualizations that help the squad track and compare their performance before and after certain training interventions can help instructors decide on the efficacy of the training in producing the desired performance benefits. Inputs from subject matter experts (SMEs) as well as human factors principles of information display especially in a training context, are needed to refine the visualizations. In addition to these visualizations for the instructor, there can also be visualizations for the trainees/students. This may consist of a visual display, such as on a tablet, that present the information to segment student feedback during the AAR such that the student only views information relevant to his training.

Further work from this effort includes the processing of team verbal communications. Continued advancements in natural language processing are necessary to overcome the challenge of representing verbal communication for immediate presentation in an AAR. A limited set of team direction and responses during BD2A and other battle drills is advantageous for training an algorithm to recognize team member verbal communication.

ACKNOWLEDGEMENTS

This research was sponsored by the U.S. Army Combat Capabilities Development Command - Soldier Center (CCDC SC). The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the official policies, either expressed or implied, of CCDC-SC or the U.S. Government. The U.S.

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