Proceedings of the Human Factors and Ergonomics Society Annual Meeting
2023, Vol. 67(1) 1127–1133

DOI: 10.1177/21695067231192281
journals.sagepub.com/home/pro
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Team Workload in Action Teams: Exploring the Impact of Interdependence

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Abstract

Team workload is a team-level construct considered similar to, but not reducible to, individual workload and mediated by team coordination. Despite this, the conceptualization and measurement of team workload in action teams lags behind that of individual workload. In most empirical studies, team workload is often simply considered as the sum or average of individual team members' workload. However, unique characteristics of action teams, such as interdependence and heterogeneity, suggest that traditional approaches to conceptualizing and measuring team workload may be inadequate or even misleading. As such, innovative approaches are required to accurately capture this complex construct. This paper presents the development of a simulation designed to investigate the influence of interdependence and demand levels on team workload measures within a 3-person action-team command and control scenario. Preliminary results, which suggest that our manipulations are effective, are provided and discussed.

Keywords

team, team cognition, team workload, team performance

Introduction

Matching human capacities and limitations to the demands of work is necessary for safety and performance. Cognitive workload research addresses this challenge by characterizing the complex relationship between task demands, performance, and cognitive resources, often revealing opportunities to help workers manage workload more effectively (Norman & Bobrow, 1975; Young et al., 2015). Recently, research has shifted from focusing on workload almost exclusively at the individual level to considering workload at the team-level, referred to as *Team Workload* (Bowers et al., 1997; Funke et al., 2012; Zhang et al., 2023). This perspective may provide new avenues for understanding and improving the safety and performance of workers operating in teams. However, it also presents several challenges related to measurement and experimentation, especially in *action teams*.

Action teams are common in high pressure environments because they can be "more than the sum of the parts" and often need a variety of skill types and expertise. Examples include military command and control teams, search and rescue teams, surgical teams, armored vehicle crews, naval crews, and aviation crews (Sundstrom, 1999). Members of action teams are interdependent, which means that merely optimizing the workload of individual operators does not guarantee that it is optimized for the team as a whole.

Previous work on interdependent teams posits that team workload is different from the sum of the parts (Funke et al., 2012), similar to other team-level constructs like team situation awareness (Stanton et al., 2006), team cognition (Cooke et al., 2013), and team resilience (Bowers et al., 2017). However, it remains common in practice to quantify "team workload" by averaging or summing individual workload measures (Bowers & Jentsch, 2005; Cui et al., 2021; She et al., 2019), referred to as an *average* approach (Waller et al., 2016). These measures are typically subjective (e.g., questionnaires; Sellers et al., 2014), performance-based (e.g., secondary task paradigms; Lenné et al., 2014), or occasionally physiological (Verdière et al., 2019). Averaging individual measures to create collective measures is computationally straightforward and may be adequate for measuring some group-level emergent phenomena (Mathieu & Luciano, 2019). In particular, average approaches may be appropriate in relatively homogenous groups where the phenomena of interest (i.e., the group's workload) is accessible by everyone. For example, averaged/summed team workload has been found to be statistically associated with other team variables (e.g., Cui et al., 2021; She et al., 2019). However,

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average-style team workload measurement approaches carry implicit assumptions that are violated in action teams.

Action teams are highly interdependent and heterogeneous, which makes them prone to variations in individual workload that can reverberate throughout the team. For example, a unit commander being overloaded may have a non-linear, bottlenecking, impact on collective performance and team resource allocation, despite "average" levels of workload appearing low for the team. *Variance* approaches have also been utilized to understand the distribution of team workload (Entin et al., 1998), but fail to capture the nature of the team's overall workload levels or specific workload configuration as noted in the example above. Physiological workload measures have reached a somewhat higher level of sophistication in action team settings (Dias et al., 2019), yet the reliability of physiological measures in predicting overload states remains limited, and team physiological dynamics remain relatively dispersed (Kazi et al., 2021), with a lack of full-fledged experiments in action team settings.

Interaction-based measures (Cooke & Gorman, 2009), which would include the team workload-related "Strategy Shifts" suggested by Funke et al. (2012), remain relatively underexplored in controlled experimental settings. Several studies have indirectly demonstrated changes in team communication characteristics under increases in demand (Entin & Serfaty, 1999; Gervits et al., 2016; Grote et al., 2010; Stanton & Roberts, 2020). Additionally, one experiment where demand *was* intentionally manipulated to elicit changes in team interactions found that the patterning of speaker order and content tended to become less complex when demand was higher (Parker et al., 2016; Strang et al., 2012). However, the content-free analysis of speaker patterns was inconclusive. A primary benefit of interaction-based measures is that many have potential to be unobtrusive, suitable for automation, and may be able to be used in real time. Overall, there is still a significant gap in applying interaction-based measures to team workload measurement.

Several studies have empirically examined team workload directly or (more commonly) indirectly. However, few studies consider the role that team interdependence may have in modifying the relationship between a team's resources, the demands of their tasks, and team performance. Additionally, there is a lack of studies directly examining interaction-based measures of team workload for action teams. The present work describes the development of a 3-person action team command and control testbed designed as a part of a larger study to investigate both of these threads of inquiry.

Testbed Design And Development

There were four objectives for the development of this testbed: (1) Develop a teaming scenario cognitively relevant to action teams; (2) systematically manipulate team interdependence; (3) systematically manipulate team-level demand, and (4) enable relevant data capture. The approaches used to address each requirement are discussed in the following sections. It was an overarching requirement that the testbed have minimal overhead so one person could run the session and be suitable for rapid prototyping and development.

Objective 1. Develop An Action Team Scenario

Several commercial video games and existing research tools were tested for suitability. The task environment selected was Networked Fire Chief (NFC; Omodei et al., 2005), a video game-like software based on wildland firefighting command and control designed specifically for team research. NFC has been utilized for recent action team studies, evaluating team stress (Berger & Henning, 2019) and adaptation (SanchezManzanares et al., 2020).

Task Design. The NFC software was customized in tandem with the other testbed components to maintain suitable task fidelity, while emphasizing key teaming components that generalize across action teams (Sundstrom, 1999). Furthermore, design decisions were made to minimize the need for extensive training or expertise akin to a synthetic task environment (Cooke et al., 2004).

Several elements of the domain were distilled through investigation of training materials and reflection on the second author's experiences as a wildland firefighter. These elements were loosely emulated in the simulation, with priority going toward eliciting key action teaming characteristics (Table 1) and enabling the manipulation of interdependence and demand levels. In the simulation environment, the team's overall task was to fight fires by directing assets to protect houses (noted as the "priority" in training) and to reduce destruction of the forest.

Wildland firefighting follows an Incident Command structure that requires multiple "resources" (e.g., people and tools/vehicles), making coordination and communication absolutely necessary. For the simulation environment, three types of assets were customized from the NFC defaults: (1) helicopters, (2) fire trucks, and (3) bulldozers. The assets were given heterogeneous attributes (See Table 2) and were controlled directly by participants according to their roles and the experimental condition.

Reconnaissance and surveillance are foundational for identifying the status of the fire and deploying assets at the right place and time. In the simulation, visibility of the map was limited by asset line of sight to enhance the need to coordinate reconnaissance with *helicopters*. A *direct attack* strategy involves directly fighting a fire by applying water or other fire retardants with land vehicles, air vehicles, or fire crews. This was emulated with *fire truck* assets, which could extinguish fires directly. An *indirect attack* involves clearing flammable objects in the path of the fire to control the spread—achieved in the real-world by coordinating bulldozers, fire crews, or air vehicles dropping fire retardant. This

Table 1. Action Team characteristics captured in task environment.

Characteristic	Implementation in Simulation
The team is highly interdependent	*Multiple teammates and types of assets must be coordinated to complete team tasks
The team is highly heterogeneous	*Role designations for each participant result in heterogeneous capabilities regarding what each teammate can see, do, and is responsible for
The team must respond to rapidly unfolding events in real-time	The firefighting scenario driven by the forest fires evolves quickly and requires real-time adaptation and adjustment
Success is tied to effective team coordination	*Communication and coordination between roles are required to effectively complete team level tasks due to interdependence and scope of tasks

Note. * Indicates that characteristic was manipulated between-subjects.

Table 2. Asset attribute comparison.

Asset Type	**Capability**				
	Extinguish	*Treat*	*Mvmt. Speed*	*Line of Sight*	*Use Supplies*
Truck	Yes	No	Medium	Medium	Yes
Helicopter	No	No	Fast	Large	No
Bulldozer	No	Yes	Slow	Small	Yes

Note. Color coding indicates relative advantage: green = big advantage, yellow = moderate advantage, red = disadvantage.

was implemented with *bulldozer* assets, which could stop the spread of fires by creating firebreaks.

Teams could follow different strategies, but the general task flow included the following: (1) a potential fire warning is indicated by an auditory alarm and a flashing red "X" where it is suspected in the simulation; (2) an asset (typically helicopter) is sent by a participant to investigate the warning; (3) the map is marked to indicate if it was a real warning or a false alarm (⅔ of warnings were false alarms); (4) other assets are deployed to fight the fire by directly extinguishing the flames or creating firebreaks to stop the spread; and (5) assets resupply at supply points in the environment throughout the task. Only fire trucks and bulldozers required resupply.

Training. Training lasted approximately 45-60 minutes and consisted of an individual portion and a team training mission. During the individual portion, participants read slides and followed instructions to complete tasks in the simulation to learn all three roles. The team training mission was a small-scale mission where tasks were practiced as a team with the same team structure as the team interdependence condition.

Hardware and Layout. Participants were seated at one of three internet connected PC workstations with two computer monitors, a keyboard, and a mouse. On the left computer monitor was the browser-based map implemented in Qualtrics and the secondary task. On the right monitor was the NFC simulation environment. Participants were physically separated by partitions and communicated using a headset.

Objective 2. Systematically Manipulate Interdependence

Two conditions of team interdependence were implemented: *High Interdependence* and *Low Interdependence.* We explored interdependence by adapting the co-active design process proposed by Johnson et al., primarily used in human-machine teaming (Johnson et al., 2014). This consists of a joint task analysis followed by a systematic, iterative examination of the dependencies between different roles based on the task parameters. The initial design included 10 tasks and 41 subtasks. The task design was simplified and streamlined through piloting and iteration, resulting in a final design which included 5 tasks and 13 subtasks. Both conditions had the same number for tasks and subtasks (Figure 1).

The Low Interdependence condition had role assignments and asset allocations that minimized "hard" (non-discretionary) dependencies between roles, and instead mostly "soft" (discretionary) dependencies. Conversely, the High Interdependence condition had primarily hard dependencies (Figure 1). Role assignments included *Red Leader*, *Blue Leader*, and *Gold Leader.* In the Low Interdependence condition, all three roles had the same assets (1 helicopter, 1 bulldozer, 1 fire truck) and received the same information from the simulation (fire warnings, wind status and forecast), and could all complete the map marking task. In the High Interdependence condition, all three roles had a different asset type (either 3 helicopters, 3 bulldozers, or 3 fire trucks), and heterogeneous access to environmental information.

Joint Activity Task Analysis *High Interdependence*			Alternative 1				
			P*	Supporting		Task DEP	Sub DEP
Goal	**Task**	**Subtask**	RED	BLUE	GOLD		
Prevent descruction of property	Confirm new fire	Identify fire warning (potential fire) location				Hard	Hard
		Confirm new fire location as real or false alarm					Soft
		Mark map according to fire confirmation					Ind
	Identify fire characteristics	Identify fire by geographic location				Hard	Hard
		Identify fire size and intensity level					Soft
		Identify wind speed and direction (fire path)					Hard
	Identify exposures (at risk houses) by location					Soft	Soft
	Conduct direct attack	Maintain truck supply levels				Ind	Ind
		Extinguish fire with truck					Ind
	Conduct indirect attack	Maintain dozer supply levels				Hard	Hard
		Identify anchor / treatment location					Soft
		Treat terrain in path of fire with dozer					Hard

Joint Activity Task Analysis *Low Interdependence*			Alternative 1				
			P*	Supporting		Task DEP	Sub DEP
Goal	**Task**	**Subtask**	RED	BLUE	GOLD		
Prevent descruction of property	Confirm new fire	Identify fire warning (potential fire) location				Soft	Soft
		Confirm new fire location as real or false alarm					Soft
		Mark map according to fire confirmation					Soft
	Identify fire characteristics	Identify fire by geographic location				Soft	Soft
		Identify fire size and intensity level					Soft
		Identify wind speed and direction (fire path)					Soft
	Identify exposures (at risk houses) by location					Soft	Soft
	Conduct direct attack	Maintain truck supply levels				Soft	Soft
		Extinguish fire with truck					Soft
	Conduct indirect attack	Maintain dozer supply levels				Soft	Soft
		Identify anchor / treatment location					Soft
		Treat terrain in path of fire with dozer					Soft

Figure 1. Interdependence analysis compared between conditions for one role ("Red Leader "; adapted from Johnson et al., 2014).

Objective 3. Systematically Manipulate Team Demands

Demand manipulations in previous action team experiments have spanned across dimensions including task quantity (Strang et al., 2012), task difficulty (Verdière et al., 2019), time pressure (Cui et al., 2021), demand imbalances (Porter et al., 2010), workload transitions and non-routine events (Jobidon et al., 2006), and asset availability (Knott et al., 2006). For this study, we wanted to manipulate demand (1) at the team-level and (2) in a resource-limited manner (also at the team level). Here we used a *task quantity* manipulation because they are common in previous studies (allowing easier comparison) and relatively straightforward.

It is assumed that team-level demands must tax interdependent team-level tasks, rather than just increasing individual workload. Hard dependencies tend to increase the need for coordination, whereas soft dependencies allow for improvements in efficiency or performance via backup behaviors. Resource-limited tasks at the team-level are considered tasks which rely on the allocation of team resources, which may require more than one person to perform. For this study, team-level demand was manipulated by altering the nature of the simulated fires, the main driver of the team-level task. In the High Demand mission, two fires were generated instead of one at each spawn point with a moderate amount of distance between each. Fires in the high and low demand missions appeared at the same location and time between missions to provide equivalency between mission designs for comparison, but the fire spawn points were geographically mirrored between missions so that the participant would not be able to anticipate them. The demand manipulations were piloted

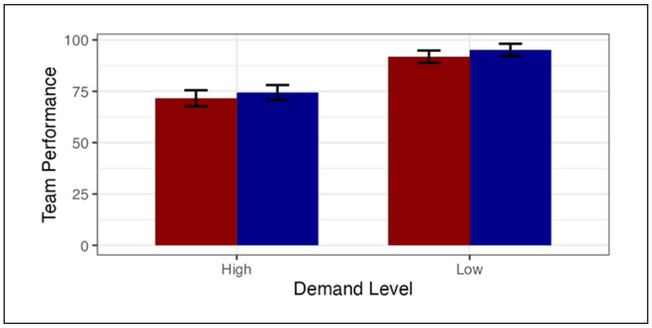

Figure 2. Average team performance scores between conditions. Error bars indicate 95% CI.

extensively to ensure that only high performing teams could "keep up" in the High Demand condition.

Objective 4. Enable Relevant Data Capture

The larger study centers on traditional subjective and performance-based team workload measures in addition to advancing interaction-based measures. Therefore, the following measures were collected.

Team Performance. Embedded within NFC and based on the number of trees (1 point) and houses (50 points) destroyed by the fire. Points begin at 100% and are deducted based on a percentage of the possible points in the whole scenario.

Defending houses requires a combination of surveillance, and both direct, and indirect attack strategies. Therefore, biasing toward houses ensures that scores are linked to cohesive team performance, rather than independent performance.

Workload Questionnaires. Common questionnaires found in action-team studies addressing individual (NASA-TLX; (Hart & Staveland, 1988), team-related (Sellers et al., 2014), and team-level (referent-shift; Helton et al., 2015) workload were administered immediately following each mission using browser-based Qualtrics software.

Secondary Task Performance. Individual secondary tasks were administered every 60s during the scenario by promoting the participant with "READY" on their left screen and an audible warning using custom software, providing high sample rate reaction-time data. They were instructed to click this as fast as possible without compromising their primary task. A followup single-item Likert-scale workload questionnaire appears after clicking where they rated their workload from 1 (very low) to 7 (very high).

Team Interactions. Audio communications were recorded during each mission via Zoom and using an AI-based transcription tool (Otter.ai, 2023) with manual verification.

Preliminary Results and Discussion

The experiment uses a 2x2 mixed design, with task demand (High Demand/Low Demand) as a counterbalanced within-subjects factor and team interdependence (High Interdependence/Low Interdependence) as a between-subjects factor. Participants were each randomly assigned to one of three roles (Red Leader, Blue Leader, or Gold Leader), and each team was assigned to either the High Interdependence or Low Interdependence condition, completing one High Demand and one Low Demand mission each (counter-balanced). Following completion of each trial, participants completed questionnaires. Preliminary results collected from 40 teams which focus on the effectiveness of the interdependence and demand manipulations are presented here.

Team Performance. A 2x2 split-plot ANOVA was conducted to assess differences between interdependence conditions (between) and demand conditions (within) for team performance scores. The results indicated that team performance was lower in the High Demand missions as intended by the resource-limited task design, $F(1, 38) = 270.75$, $p < 0.001$ (Figure 2). There was not a significant difference between High and Low Interdependence conditions, which will make future comparisons between conditions more favorable.

Workload Distributions. The distributions of NASATLX scores within teams were quantified as the coefficient of variation (*cv*) of individual scores Entin et al., 1998); higher *cv* indicates more variance between teammates. After removing two outlier points (>1.5 x IQR), a Welch's t-test was conducted, indicating that the High Interdependence condition had significantly more variance in workload ratings between teammates, $t(32.51) = -2.86$, $p < 0.007$ (Figure 2). This provides preliminary support to the hypothesis that increased team interdependence is associated with more workload variance, and therefore average-style approaches may not capture the full picture in action teams.

Teamwork-related Demands. A subset of questions from the TWLQ were analyzed using four paired t-tests to assess differences between the High Demand and Low Demand missions for a subset of questions in the TWLQ: (1) *communication demand*, (2) *coordination demand*, (3) *teamwork-taskwork balancing demand*, and (4) *support demands*. Ratings were significantly higher in the High Demand mission for all four questions (all $p < .05$), indicating that the demand manipulation successfully increased teamwork-related demands (Figure 3).

Team Interactions. A 2x2 split-plot ANOVA was conducted to assess the % of mission time speaking aggregated for each team between demand and interdependence conditions. Results indicated that teams communicated more in the High Demand mission, regardless of interdependence

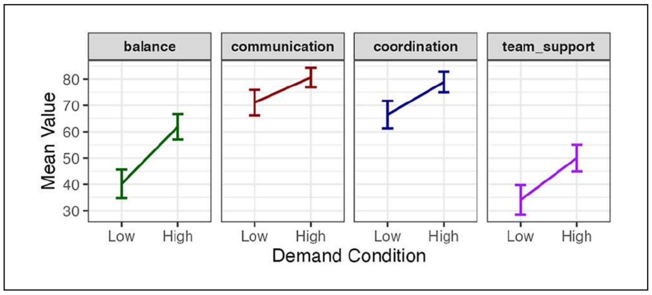

Figure 3. Teamwork-related demand items. Error bars indicate 95% CI.

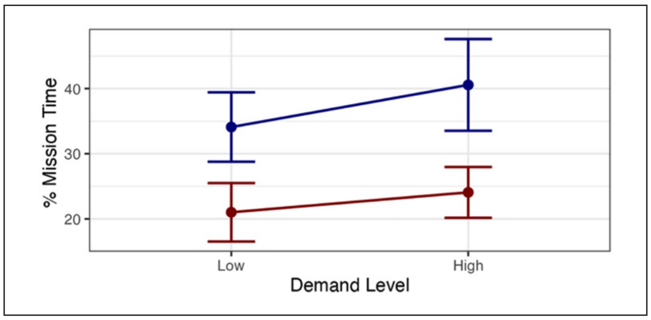

Figure 4. Changes in communication rates between demand levels. Error bars indicate 95% CI.

level, $F(1, 35) = 14.77, p < .001$ (Figure 4). However, High Interdependence teams did spend more time communicating, as would be expected due to the increase in hard dependencies requiring coordination, $F(1, 35) = 17.95, p < .001$. Further planned analysis will focus on communication distributions as well as more complex interaction patterns via dynamical systems analysis aiming to uncover trends in communications associated with demands.

In conclusion, the development of this testbed via a deliberate process manipulating interdependence and teamlevel demands has enabled closer study of team workload in action teams. The larger project is expected to provide insight on advancing the conceptualization and measurement of team workload in action teams.

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