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Supporting the Design of Autonomous Platform Behaviors with an Adapted Cognitive Task Analysis

by Craig J Johnson, Joe T Rexwinkle, and Julia L Wright

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14. ABSTRACT
Future robotic platforms are anticipated to include autonomous technology that will work interdependently with operators to execute complex tasks. Therefore, it is important to understand the nature of these behaviors more precisely in order to design effective systems. This report provides generalized guidelines for developing a contextual understanding of military tasks in support of robotic platform development. It describes how that process was applied to elicit and characterize the berm drill—a common, crew-level, tactical task in armor formations—to support the design of a vehicle platform outfitted with autonomous technology. The process includes an extended cognitive task analysis, which was tailored to capture elements needed for effective algorithm and system design in anticipated iterations of robotic platforms capable of performing mobility and target identification functions interdependently with an operator.

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1. Introduction

Human–autonomy research at the US Army Combat Capabilities Development Command Army Research Laboratory focuses on the development of autonomous systems that learn from human expertise and demonstration. This research has led to the development of autonomy that can be trained by operators via behavior cloning to complete basic tasks such as landing a drone on a moving platform (Waytowich et al. 2018; Goecks et al. 2019) and computer vision capable of continuously adapting based on minimal human feedback (Rexwinkle et al. 2024).

This research continues to advance toward the automation of more complex behaviors in more realistic and operationally relevant environments, which are characterized by more diverse demands and will require greater collaboration between the technologies and human operators to adapt to the ever-changing circumstances ubiquitous to battlefield environments. However, as tasks become more realistic and complex, it is likely that behavior cloning alone will no longer suffice to complete more complex sets of tasks such as reconnaissance of an objective with a ground vehicle. Cloning approaches may be too brittle and result in autonomy that is unable to adapt to the variability and change associated with realistic settings. Instead, it is likely that operators and autonomy will remain tightly coupled for at least portions of a tasks, and the autonomy will still need to learn as it goes.

It is therefore important to understand the coordination and sequencing of behaviors and tasks. This can support the learning process of the intelligent systems by appropriately structuring the data used to train autonomous agents and will ultimately enable more effective design of joint human–autonomy integrated tasks. Human factors tools and methods can help bridge the gap by providing a formal process for breaking down the elements of more complex tasks, providing context to system designers.

Current Analysis

The analysis presented here is intended to provide a basis for understanding the functional steps of an armored vehicle crew-level task, and the information required by and communicated between teammates. The joint cognitive activities of legacy armored vehicle crews (e.g., M1A2 Abrams tank, M2/M3 Bradley IFV) provide an established foundation upon which to build a deeper understanding for future systems that may utilize these technologies. At a functional level, legacy platforms and their crews are accomplishing many of the same tasks that will be conducted using future systems (e.g., target acquisition, maneuver); although, the mechanisms of execution will change as technology evolves.

Because the nuances of armored vehicle crew behaviors are not captured in their entirety in field manuals and other formal documentation, further knowledge elicitation and elaboration is needed to support the design, training, and early-stage testing of autonomous technology. We achieved this by conducting a Cognitive Task Analysis (CTA) and then extending the traditional CTA methodology. Conducting a CTA consists of breaking a task or behavior into discrete subcomponents so that it can be understood more fully (Crandall and Hoffman 2013). The CTA described here takes on a hierarchical structure in which higher-level tasks are broken down into subtasks and the key information requirements for executing those subtasks. The CTA is extended by including further detail about how an algorithm could support these tasks and which streams of data could be used to provide required information for task execution. The intent of this analysis is to support training autonomous behaviors on robotic platforms under the joint control of an autonomous system and a human operator. The subsequent sections describe each of the following steps of the process in detail:

1) Define a collective task
2) Knowledge elicitation
3) Define tasks and subtasks
4) Define information requirements
5) Determine suitability
6) Define information sources
7) Identify potential autonomy actions and feasibility

This was not a linear process but was developed in an iterative fashion. In addition, some of the information on the process provided here did not end up being used for the design process, but was retained in this report as a means of helping to inform further, related research.

2. Analysis Methods

2.1 Cognitive Task Analysis

2.1.1 Define a Collective Task

We based the initial cognitive task analysis on the activity *conducting a berm drill*, specifically to engage a single target in an M1A2 Abrams tank from the turret defilade. The berm drill was selected as the battle drill of focus for this study because it is a well-characterized and critically important behavior that involves several aspects of the envisioned task environment—in particular, movement/mobility and target acquisition—while still maintaining a reasonable scope for tractability and management of pragmatic constraints. Furthermore, it also serves to push the existing limits of the state of the art in human–autonomy interdependent learning.

2.1.2 Knowledge Elicitation

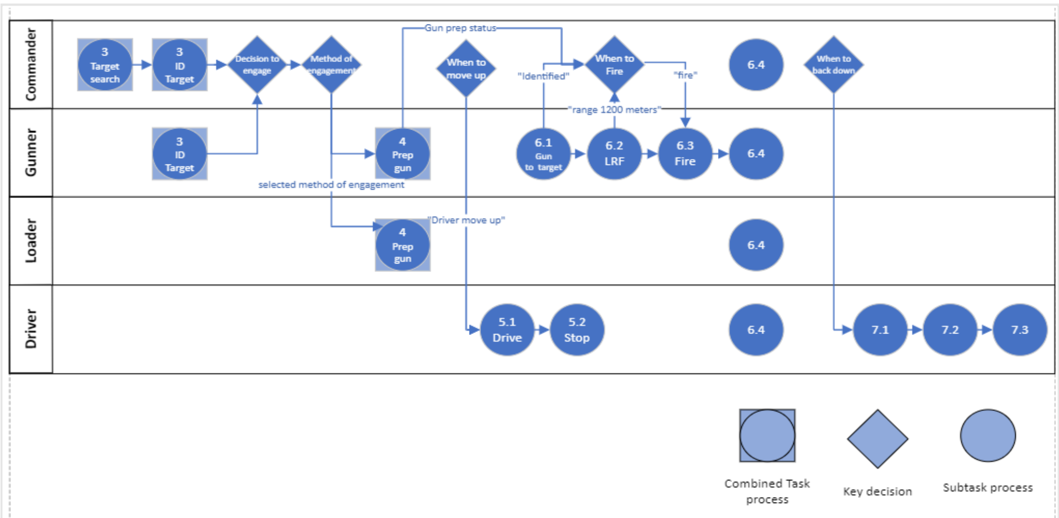
The cognitive task analysis was developed iteratively using several information sources:

- US Army documentation review, focusing on armor field manuals and doctrinal publications
- Knowledge elicitation conducted based on the first author's experience as a US Army Armor Officer and M1A2 Abrams tank platoon leader
- Adaptation of related task analyses where appropriate (Huang et al. 2020; Mitchell 2009)

2.1.3 Define Tasks, Subtasks, and Information Requirements

The task analysis was organized into top-level tasks and subtasks, which could be executed by one or more individuals. These tasks were separated by crew roles that would be responsible for the task or subtask in an M1A2 Abrams crew. Four roles exist on the Abrams tank crew: Tank Commander (TC), Gunner, Driver, and Loader. The TC is responsible for the overall command and control of the tank and crew, the Gunner operates the primary weapons system and engages with targets, the Driver drives the vehicle, and the Loader loads ammunition into the primary weapon and picks up and performs several other duties (i.e., assisting the TC with navigation and maintaining the communications equipment).*

The goal of this step was to identify and characterize key task/subtask elements rather than be completely exhaustive and focus on behaviors and functions that might generalize outside of the legacy system (M1A2 Abrams tank) and into future armored vehicle platforms. Figure 1 provides a diagram of the sequence of key actions that take place between crew members in the legacy platform across execution of a berm drill. Note that this analysis is not exhaustive of all possible instantiations of a berm drill or target engagement and does not include all the potential fire commands, but rather serves as an archetypical example.



Note: Numbers identify task and subtasks from the CTA in Table 1.

Fig. 1 Example of a berm drill task sequence in an M1A2 Abrams tank

Next, key information requirements (KIRs) to execute each task/subtask were identified (Elm et al. 2003). The task analysis (Table 1) consisted of 7 tasks, 21 subtasks, and 55 KIRs.

* For a more detailed description of the Abrams tank crew duties see ATP 3-20.15, *Tank Platoon* (2019).

Table 1 Task analysis and KIRs for conducting a berm drill

Task	Subtask	KIRs
1. Navigate vehicle to hull down position	**1.1** Identify appropriate position for vehicle	Enemy direction relative to vehicle location
		Sector of responsibility relative to vehicle location
		Location of potentially suitable terrain relative to vehicle location
	1.2 Start moving vehicle to firing position	[a] When to move relative to tactical situation
		Cover and concealment of vehicle en route to firing position relative to enemy direction
		Direction of potentially suitable terrain relative to vehicle location
	1.3 Situate vehicle in hull down position so that the Commander's Independent Thermal Viewer (CITV) or Common Remotely Operated Weapon Station (CROWS) (optics) can see within sectors of responsibility and conduct berm drill on command	Cover and concealment of vehicle relative to enemy direction
		Sight line of optics relative to enemy direction
		Position of vehicle relative to terrain and enemy direction (exposure)
		Trafficability of terrain to conduct berm drill
	1.4 Stop when position deemed adequate	
2. Search for targets	**2.1** Scan for targets with optics (not gunner optics)	Current orientation of optics relative to vehicle
		Enemy direction relative to vehicle location and optics
		Sector of responsibility relative to vehicle position and optics

Table 1 Task analysis and KIRs for conducting a berm drill (continued)

Task	Subtask	KIRs
3. Identify target	**3.1** Identity target type	Target description (tank, troops, etc.)
		Target alignment (friendly, enemy, neutral)
	3.2 Identity target location	Target distance relative to vehicle
		Target direction relative to vehicle
	3.3 Identify target activity	Target direction of movement relative to vehicle
		Target hull or turret orientation relative to vehicle
		Target behavior (shooting, berm drill, etc.)
4. Prepare weapon	**4.1** Load appropriate ammunition for target	Ammunition requirement relative to target type
		Ammunition availability in vehicle
		Type of currently loaded ammunition (if applicable)
		Operability status of weapon system
	4.2 Index appropriate ammunition for target	Currently loaded ammunition (if any)
		Status of ammunition (loaded, not loaded)
	4.3 Remove safety and prepare to fire	Correct ammunition loaded
		Status of loader safety
		Status of gunner safety
5. Move vehicle up from of *turret down* to *hull down* position	**5.1** Drive forward to hull down position	[a] When to move based on tactical situation
		Distance of vehicle relative to desired position
		Direction of vehicle hull relative to desired position
		Trafficability of terrain relative to desired vehicle position
	5.2 Stop in appropriate location	Visibility status of commander's optics
		Visibility status of gunner's optics
		Weapon system barrel clearance of terrain relative to desired field of fire
6. Engage target	**6.1** Place gun on target	Location of weapon system relative to target
	6.2 Adjust for ballistics (use laser rangefinder [LRF] to set range to target)	Status of LRF (safe, armed/first return, last return)
		LRF reading relative to vehicle size (ballpark distance)
		Distance of target from vehicle
		Adjustments required to account for ballistics
	6.3 Fire	Correct ammunition loaded
		Status of loader safety
		Status of gunner safety
		[a] When to fire relative to tactical situation
	6.4 Sense impact	Status of target after firing
		Location of impact relative to desired location
	6.5 Adjust fire	Adjustments needed to match impact location to desired location

Table 1 Task analysis and KIRs for conducting a berm drill (continued)

Task	Subtask	KIRs
7. Move vehicle back to turret down position	**7.1** Drive backwards into turret down position	[a] Status of engagement (not currently shooting or about to shoot)
		Distance of vehicle relative to desired position
		Direction of vehicle hull relative to desired position
		Trafficability of terrain relative to desired vehicle position
	7.2 Situate vehicle in hull down position so that CITV or CROWS (optics) can see within sectors of responsibility and conduct berm drill on command	Cover and concealment of vehicle relative to enemy direction
		Sight line of optics relative to enemy direction
		Position of vehicle relative to terrain and enemy direction (exposure)
		Trafficability of terrain to conduct berm drill
	7.3 Stop in turret down position when position deemed adequate	

Note: [a] Flagged as unsuitable for automation.

2.2 CTA Extension to Support Human–Autonomy Task Design

2.2.1 Determine Suitability for Automation

Next, the CTA was extended to help guide the development of autonomous tasking and design, covering tasks that may span levels of automation from partially to fully autonomous. A review for suitability was conducted of each task, subtask, and KIR outlined in the CTA shown in in Table 1. The aim was to identify any KIRs that would be inappropriate to assign to an autonomous system. Tasks and subtasks that were deemed desirable or suitable for automation were identified by considering if the task/subtask met the following conditions:

1) Appropriate to delegate to autonomy (e.g., legally, ethically)
2) Depends on information that can be reliably collected (e.g., objective measures of the surrounding environment)
3) Can be defined as a series of related steps toward a specific goal

For example, initiating the subtask 1.2, *Start moving vehicle to firing position* relies on the KIR, *when to move relative to tactical situation* (see Table 2, column B). It was determined that this subtask was not suitable for automation due to the decision-point relying too heavily on subjective context, not meeting KIR 2, *depending on information which can be reliably collected*. Many KIRs have complex parameters that require combining information from multiple sensors/data sources. Inappropriate KIRs, tasks, and subtasks were marked as unsuitable and were therefore removed from further consideration for automation. The specific technological feasibility of automating a task/subtask was not considered during the suitability identification phase. See annotations in Table 1 for all the exclusions identified.

Table 2 Example subtask 1.2 with KIRs, suitability, data sources, parameters, and potential autonomy actions

Subtask (A)	KIRs (B)	Data source (C)	Local information (D)	External information (E)	Potential autonomy actions (F)
1.2 Start moving vehicle to firing position	When to move relative to tactical situation	** KIR not suitable for automation **			
	Cover and concealment of vehicle en route to firing position relative to enemy direction	Electro-optical (EO)/IR, Light Detection and Ranging (LiDAR), GPS	• Terrain features (rise, fall, coverage) • Vehicle location (coords) • Vehicle specifications (physical dimensions; weight) • Enemy location (coords)	• Identify foliage type/density and structures beyond immediate area • Number and location of friendlies/ hostiles/neutrals in area beyond sensor range • Movement of other vehicles in area	• Plan routes to suitable potential firing positions • Rate/rank position suitability based on location, access to enemy, IV, vehicle coverage
	Direction of potentially suitable terrain relative to vehicle location	EO/IR, LiDAR, GPS	• Terrain features (rise, fall, coverage) • Vehicle location (coords)	• Once a berm location has been selected to conduct the drill, use Phoenix Autonomy Stack for navigation to the berm	• Identify potential berm locations on COP/map • Distance and directional indicators added to camera views

Note: This table was applied to the entire task analysis in Table 1.

2.2.2 Identification of Data Sources

After the subtasks and KIRs deemed potentially suitable for assigning to autonomy were identified, the potentially available vehicle sensors and data sources were identified and assessed for what data each could provide (see examples in Table 2, Column C). The data sources presented here are based on a hypothetical vehicle platform and not necessarily generalizable. Researchers applying a similar approach to ours should tailor this step and the following to suit the constraints of the platforms they are developing.

We divided sources of information as “local” or “external.” Local information is information that may be directly available from the environment and may or may not require processing by other algorithms or models. Local information sources were defined as being hypothetically available to the vehicle assuming no network is available to transfer information onto the vehicle, such as information collected from the vehicle's EO cameras or LiDAR (Table 2, Column D). The data gathered from local sources is assumed to be processed solely onboard the vehicle, including any classification or AI reasoning tasks required to derive actionable information. External information sources were defined as information sources that require external transfer of information from another entity—for instance, distributed intelligence assets or other robotic platforms providing additional visual or geospatial information (Table 2, Column E).

2.2.3 Identification of Potential Autonomy Actions

After determining which sensor information was potentially available and how each KIR could be addressed, we identified actions for each subtask that could potentially be performed autonomously on the platform (see Table 2, Column F). These possible actions included identifying important terrain features, navigating autonomously, and identifying targets. Connecting the KIRs and information sources that would enable autonomous systems to carry out subtasks provided a starting point for developing what would ultimately become more collaborative and complex sequencing of tasks between the operator and the platform autonomous systems.

The research team reviewed which actions in Table 2, Column F could be executed by existing autonomous behaviors available on a hypothetical ground vehicle platform under development for a research project and through associated technologies, as well as which specific data streams addressing KIRs were available on the platform. The intent was to establish which actions could be executed without additional development and if the KIRs to train necessary autonomous behaviors were available. This process identified which actions needed to be trained for that project and which information sources must be added to the platform to facilitate model training and execution of tasks/subtasks. The goal of this step was to assist developers in creating models that would support the desired autonomous actions.

3. Conclusion

The current work defines the full set of actions that define an archetypical berm drill behavior and outlines the process used to identify key data sources necessary to support autonomous execution of parts of this behavior (mobility and identification) on a robotic platform outfitted with autonomous technology. In this instantiation, the human–machine integrated robotic platform would work in tandem with a human operator who also executes parts of the tasks. The human operator would also be solely responsible for firing any weapon systems. The iterative nature of this work means that the final instantiation is likely to be much different than what might have been envisioned at earlier stages. Nevertheless, it provides developers with a general overview of which tasks and subtasks need to be executed, what information is required to execute those tasks, which potential data streams can support execution of those tasks, and where autonomous functions may be integrated to improve performance on tasks.

Future Work

In the short-term, this expanded CTA is intended to inform future work such as training autonomous behaviors on a robotic platform. This will enable iterative testing and development with much lower overhead and quicker early-stage turnaround time.

More generally, this approach may provide general guidelines for executing an adapted CTA in a way that allows technical experts and researchers to more effectively collaborate with operational SMEs to characterize behaviors in the early-stage design of autonomous platforms. This may allow Soldiers and other operational SMEs to assist in training autonomous behaviors by integrating their expertise early in the design process. This approach begins with a focus on the behaviors to be executed, rather than the technology itself, and may help to ensure that the necessary data is considered when training autonomous systems for complex tasks. The expectation is that such an approach will also provide greater operational clarity during earlier stages (when technical investment is still low), and improve efficiency of the design process.

Future work should continue to refine and improve this process. It should also be aimed at providing more detailed guidance specific to the interdependence between operators and the systems—for instance, by examining potential role allocations and sequences of joint behaviors (e.g., Johnson et al. [2020]). Currently, this work is limited to characterizing the tasks themselves, the information deemed key to executing those tasks, where that information might be gathered, and how the autonomy might feasibly be integrated into the set of tasks. However, it has not reached the level of maturation where actual task sequences and dependencies are delineated, or roles are allocated between the operator and autonomous systems. This is likely to require a more fine-grained understanding of the technological constraints and capabilities of the system under development and in some cases may be best if executed iteratively during relatively later stages of development.

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List of Symbols, Abbreviations, and Acronyms

AI	artificial intelligence
CITV	Commander’s Independent Thermal Viewer
CROWS	Common Remotely Operated Weapon Station
CTA	Cognitive Task Analysis
EO	electro-optical
GPS	global positioning system
IR	infrared
KIR	key information requirement
LiDAR	Light Detection and Ranging
LRF	laser rangefinder
SME	subject matter expert
TC	Tank Commander

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