

Analyzing and Modeling Future Army Wet Gap Crossings to Determine Requirements for an Autonomous Rafting System

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Abstract: Wet-gap crossings are essential yet highly vulnerable combat operations, particularly under persistent drone surveillance and precision fires. This study evaluates the feasibility of an autonomous pontoon systems designed to operate as unmanned surface vehicles capable of rafting vehicles or forming modular bridges. A three-phase methodology integrates threat analysis, wargaming, and discrete-event simulation. Model-based threat analysis identifies system vulnerabilities, with loading, unloading, and bridge assembly assessed as highest risk. Brigade-level wargames in Indo-Pacific and European scenarios refine a 2040 concept of operations, emphasizing dispersion, counter-drone integration, and rafting in contested environments. These insights inform a discrete-event simulation of a Brigade Combat Team crossing two representative rivers. Trade-space analysis varying payload capacity and engine power found diminishing returns beyond 7 metric tons and 20 kW respectively. Overall, the findings suggest autonomous pontoon systems can sustain tempo and reduce vulnerability if optimized for speed, dispersion, and integrated counter-drone protection.

Keywords: Wet-gap crossings, Autonomous pontoon systems, Counter-drone assessment, Discrete-event simulation

1. Introduction

Wet-gap crossings remain among the most complex and hazardous operations in modern warfare, yet they are essential to success in large-scale combat. For the U.S. Army, the ability to project combat power across rivers, canals, and other water obstacles is critical to maintaining freedom of maneuver and sustaining operational momentum. These operations force units to concentrate movement at limited crossing sites, compressing maneuver into narrow corridors and creating predictable chokepoints vulnerable to enemy fire. The proliferation of unmanned aerial systems has intensified these vulnerabilities. Drones provide persistent surveillance, rapidly identify bridging assets and troop concentrations, and enable near real-time targeting, reducing a crossing force's ability to achieve surprise or maintain concealment. Even small, low-cost systems can monitor assembly areas, cue artillery, or directly attack critical equipment. Despite these growing risks, wet-gap crossings remain unavoidable in contested environments and often prove decisive to operational success.

One promising approach to future wet-gap crossings is the development of autonomous pontoon systems that operate as unmanned surface vehicles. In this concept, individual pontoons maneuver as self-propelled rafts or link together to form a bridge capable of supporting military vehicles. This paper examines the challenges such a system would face on the future battlefield through a systematic, threat-based assessment. The results inform a wargame exploring wet-gap crossings for a brigade combat team in 2040. These insights then shape a proposed concept of operations for a future wet-gap crossing, modeled through a discrete-event simulation. The simulation subsequently identifies the system's key technical requirements.

2. Background

Wet-gap crossings are among the most demanding operations in large-scale combat. U.S. Army doctrine defines them as complex combined arms operations requiring synchronized maneuver, fires, engineers, sustainment, and protection. Army Field Manual 3-90 describes wet-gap crossings as one of the most complex combined arms missions. (Department of the Army, 2001) Army Training Publication 3-90.4 outlines five overlapping phases: advance to the crossing site, assault across the obstacle, advance from the far side, establish security, and expand the bridgehead. Each phase requires precise coordination, disciplined traffic control, and rapid execution to limit exposure to enemy observation and fires. Command and control is organized through designated crossing areas led by commanders who regulate movement and timing. Success depends on reconnaissance, site selection, rehearsals, concealment, and synchronized fires, with sustainment and protection integrated to

preserve tempo and mitigate the vulnerability of constrained crossing points (Department of the Army, 2016). Ultimately, the purpose is to rapidly build combat power on the far bank and expand the bridgehead before the enemy can concentrate fires.

Historical experience reinforces these doctrinal principles. During the Allied crossings of the Rhine in 1945, assault elements secured initial footholds, engineers rapidly emplaced pontoon bridges and treadway systems, and follow-on forces expanded the bridgehead to sustain the advance into Germany (Liddell et al, 1984). The operation demonstrated that river crossings succeed when combat power is applied faster than the enemy can respond. More recently, Russian forces attempting to cross the Siverskiy Donets River suffered significant losses after Ukrainian forces detected the bridging effort and targeted it with artillery and drones in May 2022 (Stashevskiy, 2022). Similar engagements along the Dnipro and Oskil Rivers show how persistent drone surveillance and precision fires have increased the vulnerability of traditional pontoon bridging operations. Continuous observation compresses the timeline for surprise and magnifies the consequences of delay (Ells et al, 2026).

Both doctrine and historical experience point to the same operational realities. Wet-gap crossings are inherently time-sensitive, and prolonged concentration at crossing sites increases exposure and risk. Suppression of enemy observation and fires is essential during bridge emplacement. Rapid bridgehead expansion and disciplined traffic control are necessary to sustain tempo and prevent isolation of forces on the far bank. While emerging technologies may mitigate some risks, they do not eliminate the fundamental vulnerability created by predictable crossing points. Ultimately, success depends on synchronized combined arms execution, speed, concealment, and cohesive units capable of operating under pressure.

3. Methodology

As shown in Figure 1, this research employed a three-phase methodology integrating threat analysis, wargaming, and discrete-event simulation to evaluate the feasibility and operational implications of an autonomous pontoon bridging system for wet-gap crossings. The approach progressed from identifying vulnerabilities to developing an operational concept and quantitatively assessing performance and technical tradeoffs.

The first phase applied model-based threat analysis to assess risks posed by enemy threats, with a focus on drones. A model-based systems engineering approach identified vulnerabilities in a wet-gap crossing through analysis of a series of System Modeling Language diagrams. Operational roles were defined through use cases, which were decomposed into activity diagrams. Each action in the activity diagram was then assessed for enemy vulnerabilities. These vulnerabilities were scored for likelihood and severity and combined into a risk index to prioritize threats.

The second phase used tabletop wargaming to further examine a brigade-level wet-gap crossing using an autonomous bridging system. Participants operated within structured scenarios to explore sequencing, risk, and operational challenges. Two wargame series examined crossings in the Indo-Pacific and European theaters. The wargames incorporated surveillance, fires, electronic warfare, and drone capabilities identified in the threat analysis. The primary output was a refined concept of operations describing how autonomous pontoons would be deployed, protected, synchronized with maneuver and fires, and sustained. The wargames also identified decision points, failure modes, and constraints that informed subsequent analysis.

The third phase translated this concept into a discrete-event simulation developed in ProModel. The model represented the crossing as a sequence of time-based events, enabling analysis of process flow, resource allocation, congestion, and timing. By formalizing wargame assumptions, the simulation enabled quantitative assessment of throughput, system utilization, and exposure duration. It also supported trade-space analysis by varying design parameters of the autonomous pontoons. The results identified performance thresholds and critical technical requirements necessary to achieve acceptable tempo and survivability.

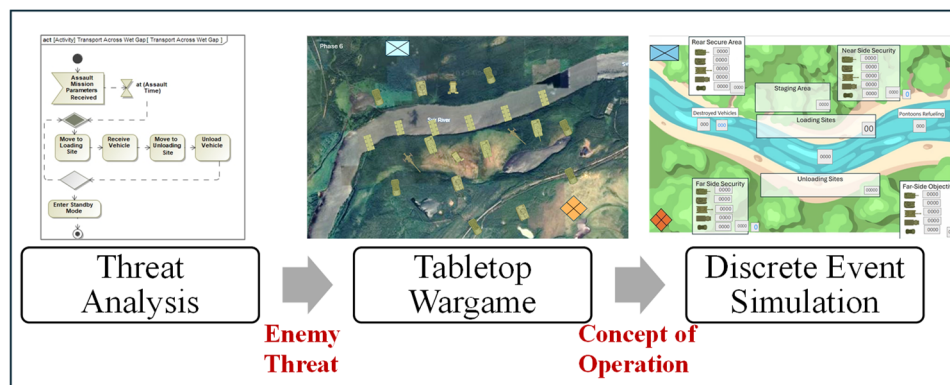


Figure 1: Methodology employed for this study.

4. Threat Analysis

Figure 2 presents the use case diagram for the autonomous pontoon system, which consists of three primary functions. The first use case is a site survey of the wet-gap, during which the system operates as an unmanned reconnaissance platform. In this role, it enters the water, autonomously navigates the river, collects data on water conditions and terrain, identifies suitable crossing locations, and monitors for enemy activity before transitioning to a standby posture until the assault phase begins. The second use case involves rafting operations, where the system ferries soldiers and equipment across the gap in a controlled sequence of loading, movement, unloading, and return trips to build combat power on the far bank. The third use case occurs after the bridgehead is secured, when individual pontoons maneuver into position and interlock to form a continuous bridge structure, enabling the main maneuver force and follow-on elements to cross.

An activity diagram was developed for each use case to decompose system behavior into discrete operational steps. Each activity was then evaluated for vulnerability to future enemy attacks, with particular emphasis on drone threats. For every potential exploit, likelihood and severity were assessed on a 1–5 scale and combined to generate a risk priority number, enabling prioritization of the most critical vulnerabilities. A detailed description of this process and the associated activity diagrams is provided in (Ells et al., 2026).

Figure 2 consolidates the risks identified through analysis of the use cases and associated activity diagrams for the autonomous pontoon system, incorporating insights from the wargaming phase. The highest-risk activities are loading, unloading, and bridge assembly, designated as 4, 6, and 8. During these phases, the system is stationary, exposed, and reliant on multiple critical interfaces, increasing both the likelihood and potential consequences of attack. A successful strike at these points could destroy the platform and its payload, effectively halting the mission. Reconnaissance and signal-detection vulnerabilities, identified as 2, 3, also represent significant threats. Drone-enabled surveillance or signal interception could compromise operational security and enable subsequent targeting. In contrast, activities conducted while the system is moving or in standby mode, labeled 1 and 7, were assessed as moderate risk due to shorter exposure durations or a lower probability of successful engagement.

The analysis identified bridging as the highest-risk phase of the wet-gap crossing, as the bridge presents an easily detectable target and creates a bottleneck that could result in significant vehicle losses. Therefore, it is recommended that the system prioritize rafting operations, as rafting presents a less risky method for river crossing. Bridging should serve as a secondary function used only when the system is operating in a secure environment. The analysis also found that given the threat from drones, the pontoons will require both passive and active counter-drone protection measures.

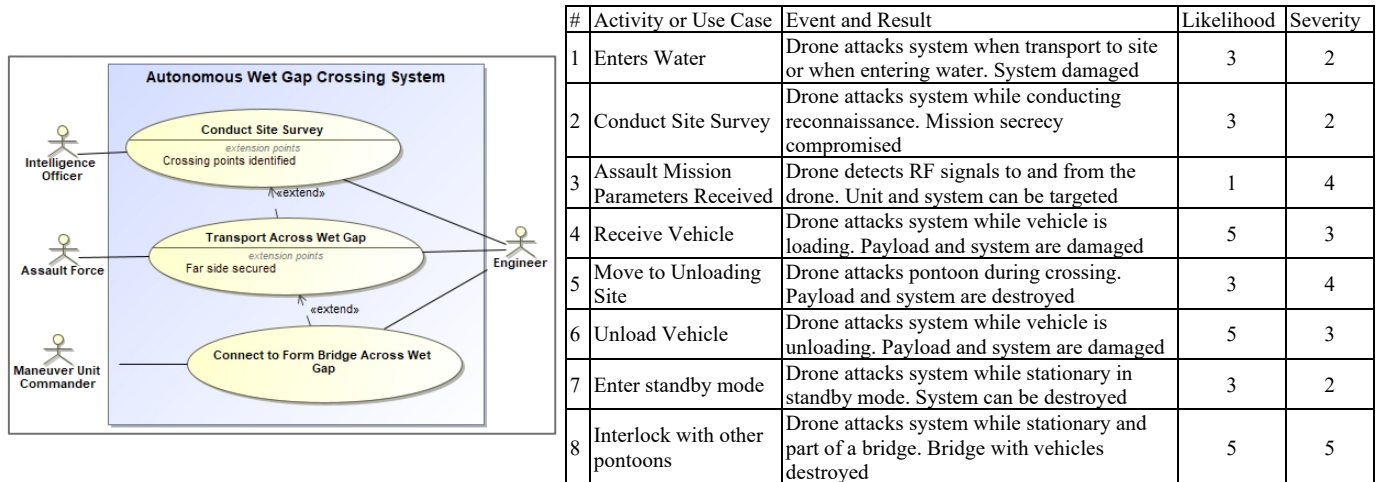


Figure 2: Use case diagram for an autonomous wet gap crossing system and the associated risk analysis matrix.

5. Wargaming

Following the completion of the threat analysis, the next step was to emulate a 2040 Brigade Combat Team (BCT) conducting a wet gap crossing. The wargame was conducted for two different environments. The first emulated a river in the Pacific region, which was characterized by mountainous terrain and severely restricted mobility corridors. The second emulated a river in Europe, featuring flat, open terrain near the crossing sites. These terrain differences significantly shaped operational

considerations. In the Indo-Pacific (INDOPACOM) scenario, restrictive terrain required friendly forces to operate in closer proximity and limited the number of feasible crossing sites. In contrast, the European terrain enabled dispersion and the establishment of multiple crossing sites. The maps for the two wargames are shown in Figure 3.

The wargame was structured into four sequential phases: reconnaissance and preparation, assaulting, main element crossing, and consolidation. Phase I occurred on the near side of the river, extending from the assembly area to the crossing site. Key tasks during this phase included identifying primary and alternate crossing sites, establishing near-side security, identifying enemy avenues of approach, and selecting suitable assembly area locations. Phase II took place at the alternate crossing site and focused on conducting the initial assault crossing and reporting significant intelligence updates. The assault wave was divided into two elements. The initial element crossed the river to clear and secure the far side and establish far-side security and emplaced counter-drone systems to mitigate enemy drone threats. The second assault wave would then cross the gap to push past the first assault wave to push back enemy artillery. Upon completion of Phase II, Phase III began at the near-side assembly area of the primary crossing site. The primary task during this phase was to move the main body across the river and initiate operations on the objective. Phase IV began at the crossing sites with the near-side security element crossing and maneuvering toward the objective, followed by the far-side security element. The key tasks during consolidation were to secure equipment, reorganize forces, and prepare for follow-on missions.

Three iterations of the wargame were conducted at each river location, with enemy capabilities increasing during each successive iteration. In the first iteration, the enemy possessed drone capabilities comparable to those observed in the Russia-Ukraine conflict. This iteration demonstrated that counter-drone systems were required on both the near and far sides of the river, as well as on bridging assets such as pontoons. It also highlighted the necessity of securing multiple crossing sites and maintaining responsive artillery and counter-artillery capabilities, as landing sites were likely to be contested and required rapid loading and unloading to minimize exposure. In the second iteration, the enemy was equipped with enhanced drone capabilities and employed water obstacles. This development required the adaptation of pontoons as armed unmanned surface vehicles to counter waterborne threats. Additionally, the threat environment made traditional bridging operations for the main element infeasible, necessitating the use of rafting techniques to cross the river while reducing exposure. In the third iteration, the enemy demonstrated increased artillery proficiency, including improved targeting speed and accuracy. As a result, friendly forces were required to integrate artillery into the assault force to provide immediate suppression, designate multiple landing sites to complicate enemy targeting, and significantly reduce loading and unloading times to mitigate vulnerability to indirect fires. Collectively, the wargame results underscore the increasing importance of dispersion, speed, integrated counter-drone capabilities, and adaptive crossing techniques for a 2040 BCT conducting wet gap crossings against a near-peer adversary.



Figure 3: Tabletop wargame maps showing U.S. Army elements crossing a river in EUCOM (left) and INDOPACOM (right)

6. Discrete-Event Simulation

6.1. Model Development and Setup

A discrete-event simulation was developed in ProModel to model a contested wet-gap crossing with autonomous pontoon systems ferrying military vehicles across a river. The simulation replicated key stages of the operation, including vehicle staging on the near side, securing the near bank, establishing loading sites, assaulting and securing the far bank, and the crossing of the main body of the brigade. The model was linked to an Excel document as shown in Figure 4 to enable rapid adjustment of operational variables. River variables included width and current speed. Pontoon system variables included the

number of pontoons, load capacity, and engine power. Friendly force variables captured the number and type of vehicles crossing, with vehicle weight affecting movement speed and total crossing time. Threat variables represented overall enemy pressure and drone activity, allowing the model to simulate varying levels of surveillance and targeting risk. By adjusting these parameters, the simulation generated outputs including total crossing time, vehicle throughput, and exposure duration, providing a repeatable framework to assess tempo and vulnerability.

Friendly forces consisted of a BCT organized into multiple assault waves. The first assault wave includes counter-drone assets to reduce the effectiveness of drone strikes on the pontoons as they cross the river. The second assault wave includes artillery to push enemy artillery out of range. Following the second assault wave, the main body of the brigade then crosses over. The total brigade included 1028 vehicles, including 87 main battle tanks, 178 infantry fighting vehicles, and 18 self-propelled howitzers. The operation employed 100 autonomous pontoons.

Similar to the wargame, the model was run for a European and a Pacific environment. The European scenario is based on crossing the Svir River, which is 0.4 km wide with open terrain on either side. The Pacific scenario is based on crossing the Lanjaing River in China, which is 1.3 km wide with mountainous, forested terrain on either side of the river. Enemy forces relied primarily on drone-based attacks. Drones patrolled the river at an altitude of 100 meters and a speed of 8 meters per second, with a density of two drones per kilometer. Upon detecting a pontoon, a drone struck with a probability of 0.30 and, given a hit, had a 0.30 probability of incapacitating the platform.

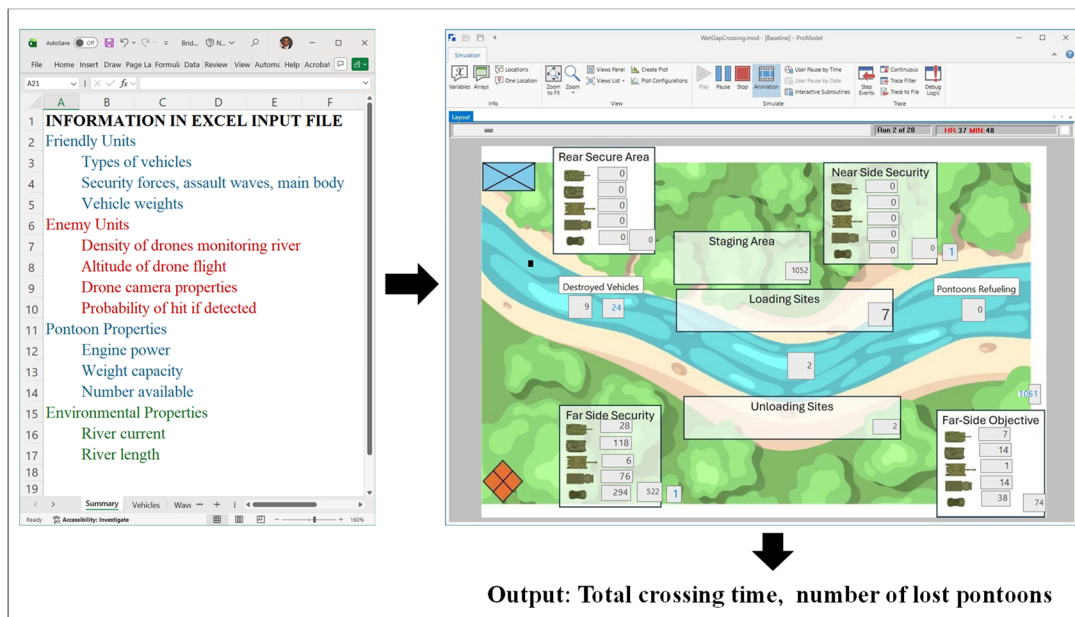


Figure 4: Schematic for the discrete event simulation, where an Excel-based input file feeds the parameters for the discrete-event simulation executed in ProModel.

6.2. Results

Two key design requirements under consideration for the autonomous pontoon system are payload capacity and engine power. Current designs provide a payload capacity of approximately 7.5 metric tons per pontoon; in this configuration, eight pontoons must connect to ferry a single main battle tank. The models were run in this configuration to create a base case. The results of the base case were then validated against values published in doctrine (Department of the Army, 2016).

From the base case, payload capacity was varied from 4.8 metric tons to 10.2 metric tons in 0.45 metric ton increments while holding all other parameters constant across both river-crossing scenarios. Engine power was similarly varied from 5 kW to 65 kW, with other parameters held constant. Each design point was run for 50 iterations, with the primary performance measure being total brigade crossing time. The results are shown in Figure 5, which plots the total crossing time for both scenarios as a function of rated load and engine power. As expected, increasing engine power reduced total crossing time; however, improvements plateau past 20 kW, indicating diminishing returns beyond that threshold. Similarly, increasing payload capacity from 4.8 metric tons to 10.2 metric tons also reduced crossing time, with performance gains stabilizing at 7.3 metric tons.

Payload capacity and engine power also affected pontoon losses from enemy drone strikes. The model showed an approximately linear relationship between pontoon losses and both rated load and engine power. Lower payload capacity requires larger pontoon groupings, creating more detectable and vulnerable targets. Lower engine power increased crossing duration, extending exposure to drone attack. As pontoon losses increased, total crossing time rose further due to reduced system capacity.

These trends were consistent across both river distances, though effects were more pronounced in the 1.3 km crossing because of longer transit times and greater exposure. Overall, the model indicates that system performance is optimized at approximately 20 kW of engine power and a 7.3 metric tons payload capacity, beyond which improvements in efficiency and survivability diminish relative to added cost and complexity.

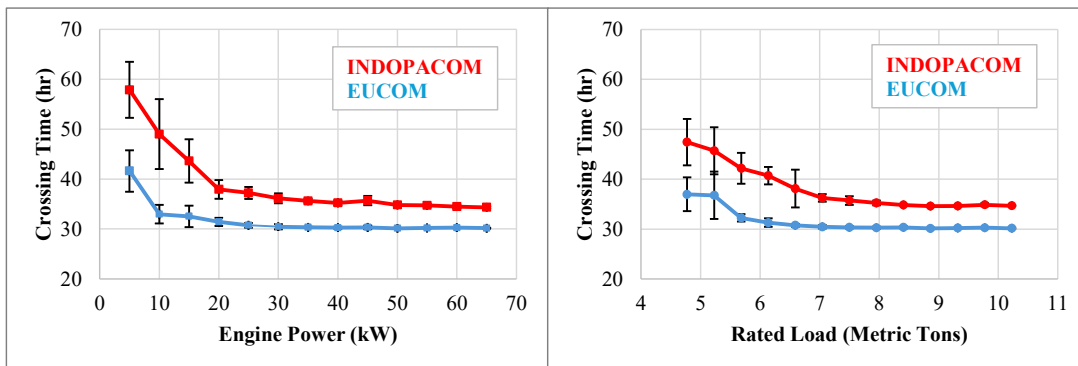


Figure 5: Crossing time for a BCT as a function of pontoon engine power (left) and pontoon rated load (right)

7. Conclusions

This study demonstrates that autonomous pontoon systems can enhance survivability and sustain tempo during brigade-level wet-gap crossings when designed against clearly defined, threat-driven requirements. By integrating model-based threat analysis, iterative wargaming, and discrete-event simulation, the study translated doctrinal demands and battlefield vulnerabilities into measurable system performance thresholds. The threat assessment identified loading, unloading, and bridge assembly as the most critical risk nodes due to stationary exposure, reinforcing the need for dispersion, reduced dwell time, and integrated counter-drone protection. Wargaming refined a 2040 brigade concept of operations that prioritizes autonomous rafting over static bridging in high-threat environments and synchronizes crossings with fires, security elements, and counter-drone assets. The ProModel simulation quantitatively validated these insights. Results showed diminishing returns in engine power beyond approximately 20 kW and in payload capacity beyond 7.3 metric tons. Lower power and payload increased exposure time and pontoon losses, particularly in longer river crossings, compounding delays and degrading throughput.

Overall, the findings indicate that autonomous pontoon systems are feasible for contested wet-gap crossings if optimized for speed, dispersion, and integrated protection. Effective technical development must remain grounded in operational analysis and simulation-based validation to ensure relevance for a 2040 BCT against a near-peer adversary.

8. References

- Ells, Alec et al., "Designing Military Vehicles For A Battlefield Characterized by Drones," SAE Technical Paper 2026-01-0262, 2026.
- Liddell, Robert et al., (1984). *Rhine River crossing conducted by the Third U.S. Army and the Fifth Infantry Division: Offensive, deliberate assault, river crossing, 22–24 March 1945* (Report No. ADA165907). U.S. Army Combat Studies Institute. <https://apps.dtic.mil/sti/citations/ADA165907>
- Stashevskiy, O., (2022). Russia takes losses in failed river crossing, officials say. Military Times., 13 May 2022, <https://www.militarytimes.com/news/2022/05/13/russia-takes-losses-in-failed-river-crossing-officials-say/>.
- United States, Department of the Army. *ATP 3-90.4: Combined Arms Mobility*. Headquarters Department of the Army, 8 Mar. 2016.
- United States, Department of the Army. *FM 3-90: Tactics*. Headquarters Department of the Army, 4 July 2001