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MOBILIZING INNOVATION: VENTURE CAPITAL ALIGNMENT FOR DEFENSE WITH AN AUTONOMOUS CONSTRUCTION CASE STUDY

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ABSTRACT

Defense acquisition often struggles to match the pace of private investment, slowing the transition of mature commercial technologies into military use. This paper examines how aligning government acquisition with venture-oriented business models can increase industry participation, accelerate fielding, and reduce government program office risk. Using autonomous construction as a case study, it highlights how commercial investment has advanced autonomy while traditional procurement limits adoption. The paper outlines approaches such as non-traditional partnerships, phased acquisition, and performance-linked revenue structures to improve flexibility, leverage private capital, and expand the Defense Industrial Base while speeding operational capability delivery.

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1. INTRODUCTION

The landscape of American finance is undergoing a fundamental realignment toward what billionaire investor Bill Ackman describes as "Patriotic Capitalism", [1] a model that prioritizes national industrial strength and long-term innovation over short-term arbitrage. This shift is most visible in Ackman's recent advocacy for the venture capital ecosystem as the 'long-term driver of the economy' [2]. Just as finance titans have moved to support and scale emerging technologies to ensure national resilience, the Department of War (DoW) is recognizing that the next generation of mission-critical capabilities, from autonomous construction to Artificial Intelligence (AI)-driven Intelligence, Surveillance, and Reconnaissance (ISR), will be fueled not just by traditional government appropriations, but by the strategic mobilization of venture capital.

Army procurement and fielding contracts for ground systems have historically been underpinned by regulatory statutes including the Federal Acquisition Regulation (FAR) and Defense Federal Acquisition Regulation Supplement (DFARS). Historically these contracts have used full and open competition, or in some cases sole source acquisition, requiring companies to comply with a scope of work and a performance requirements document such as performance specification or purchase description. In parallel with the pilot of the Defense Innovation Unit (DIU) since 2015, a growing number of transactions have moved from FAR/DFARS based acquisition to Other Transaction Authority (OTA) contracts for prototyping & subsequent production via consortia and mechanisms like Commercial Solutions Offerings (CSOs). While these trends have improved acquisition agility and expanded the industrial base, there may be pockets of industry innovation and investment that the Army is not fully considering or accessing in its acquisitions.

The DoW published the Acquisition Transformation Strategy (ATS) in 2025, as directed by Executive Order 14265, Modernizing Defense Acquisitions and Spurring Innovation in the industrial base. The ATS calls for expanding the Defense Industrial Base (DIB) and making it easier for new companies to do business with the defense sector. Sections of the strategy call to "Stabilize Demand Signals: Award companies bigger, longer deals, so they'll be willing to invest more to grow the industrial base that supplies our weapons" [3], and "Accelerate Private Capital Investment: Attract increased private capital investment to accelerate the creation of new companies, expand current factory production rates, and improve innovation" [3].

For decades, the DIB has operated on acquisition models that are increasingly misaligned with the fast-paced venture-backed technology sector. While the government provides substantial financing to established prime contractors, this insular system can deter new entrants. The Government Accountability Office (GAO) captured this friction in its 2019 report, where "Industry officials also noted that the emergence of high-technology companies may pose a challenge to traditional defense contractors in terms of attracting financing and investment from commercial and private investors at competitive rates" [4]. This challenge is now a strategic imperative, as Army senior leaders wish to see venture capital partnering with traditional defense contractors to provide more mature capabilities that innovatively address operational problems.

This paper aims to familiarize the ground systems acquisition and systems engineering community with how venture capital works (Section 2), the differences it has with defense interests (Section 3), ways to leverage and learn from its incentives (Section 4), alternative partnering models, and flexible acquisition approaches to accelerate capability development while taking advantage of external innovation resources. It introduces the concept of venture investment in defense-related technologies, explains why traditional acquisition practices fail to attract such investment, and offers guidance on how to align acquisition strategies with the metrics and incentives that matter to investors and startups.

Section 5 examines the rapidly advancing autonomous construction and heavy equipment industry whilst highlighting how its emerging technologies could be integrated into ground vehicle programs. Section 6 discusses methods for shifting from legacy procurement mindsets toward strategies that consider factors such as recurring revenue models, market timing, and team quality to sustain private-sector interest and long-term capability development. The paper concludes with a few recommendations and a path forward for accelerating the adoption and fielding of new technologies.

2. WHAT IS VENTURE CAPITAL

As Bill Gurley, general partner at Benchmark known well to the Venture Capital (VC) community, once said, "Venture capital is not even a home-run business… it's a grand-slam business." [5]. America's dynamic startup ecosystem is made possible by our homegrown venture capital industry which seeks high-risk, high-reward investment opportunities.

VC, as an industry, has the singular purpose of investing in new technology companies that have the potential for asymmetrical upside. In VC, any singled out initial investment has a capped loss (i.e., the loss of that initial investment if the company goes out of business), but potentially unlimited upside if the company succeeds. Over the past several decades, the business of VC has grown in scale and impact far beyond its start as a cottage industry with just a few firms.

While VC is most associated with software startups, venture capitalists can invest in almost any company across any industry with the potential for asymmetric upside. VC funds have invested in unexpected products like coffee shops (e.g., Blue Bottle Coffee), eyeglasses (e.g., Warby Parker), vitamins (e.g., Grüns), and even munitions (e.g., Aeon Industrial). In all these examples, early investors felt there was asymmetric upside to these initial investments. Understanding this mindset is essential for defense stakeholders who seek to leverage commercial innovation, since it reveals why venture-backed companies gravitate toward strategies like scalable software models, rapid iteration cycles, and market environments where speed is prioritized.

The VC lifecycle (**Figure 1**) runs from raising money to distributing gains. VCs raise money for their funds from Limited Partners (LPs), who might be corporations, endowments, family offices, or pension funds. These LPs typically allocate a small portion of their portfolio for VC. VCs seek commitments from a variety of LPs to pool into a fund from which they invest into startups. Once they've received enough commitments to execute their investing

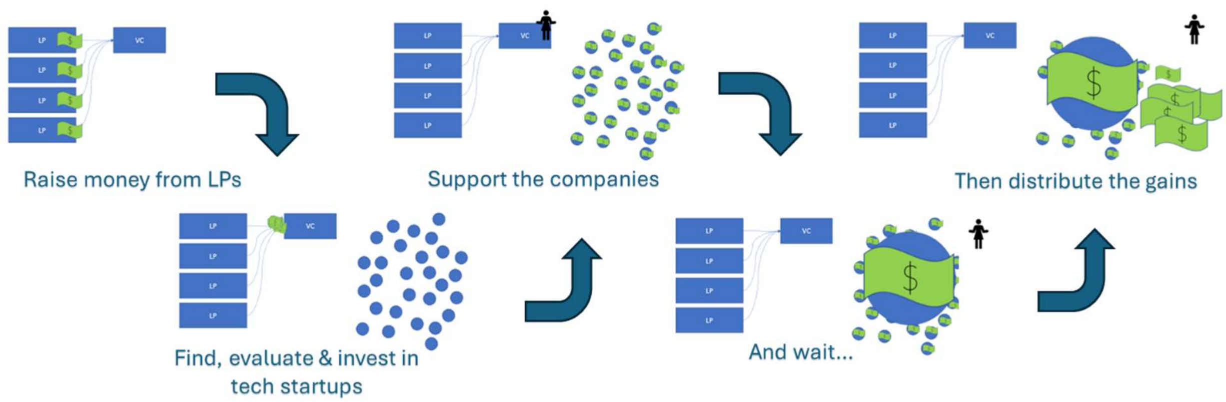

Figure 1: Venture Capital Lifecycle showcasing initial fundraising via LPs through the distribution of gains.

strategy, VCs will find, evaluate, select (i.e., invest), and support startups. Concurrently these startups grow – the compounding growth of their winners will lead to certain investments bringing in most of the portfolio's gains while others fail. This dynamic in VC is referred to as the Power Law, which states a small subset of investments account for most of a portfolio's returns, as referenced in the Bill Gurley quote above [5].

The Power Law dynamic incentivizes investors to support bold, high-risk initiatives that would be untenable in traditional contracting environments. For defense applications, this risk posture explains why venture-backed startups may pursue emerging technologies even when technical hurdles are steep. However, it also clarifies why these companies struggle in acquisition systems that reward guaranteed performance, fixed schedules, and incremental risk reduction rather than breakthrough innovation.

A company is considered "venture backable" when it demonstrates the potential for exponential growth, defensible market advantage, and a scalable business model that can unlock significant future value. VCs assess factors such as team quality, market timing, technological differentiation, and the ability to expand rapidly across customers and industries. Importantly, venture back-ability is not merely about having an innovative product; it depends on whether the company can grow large enough and fast enough to justify risk at the portfolio level.

Companies "exit" when they are either acquired or go public. When an exit occurs, VCs distribute the gains back to their LPs. The traditional VC model often involves a fee structure called 2 and 20. This means that for every year of deploying their fund, LPs support the operation of the fund with a 2% fee on the total fund size. In addition, the investors of the venture fund take 20% of the carried interest (also known as "carry" or the share of the profits of the fund) as performance-based compensation.

As an example, a $100M fund deploying its monies across 3 years will charge $2M/year in fees to its LPs. If the fund ultimately returns $300M back, the fund's investing team will receive $40M (or 20% of $200M in profits) in carry to split amongst themselves.

Overall, VC investing is distinct from other investing strategies. Since a small set of winners in a venture portfolio will dictate success or the failure of the fund, most VCs are willing to invest in companies that have a significant chance of going to zero. This differs greatly from the traditional value-based investing approach that a public equities investor might employ.

VC invests with limited information at the earliest stages of company formation. Early-stage venture capital involves seed stage investments where companies may not have built a full product. VCs evaluate the team, product, and the market to make their decisions. As venture-backed companies mature, they have more data and VC metrics to share with investors.

VC typically acquires minority stakes in companies and supports the founders of the companies as they lead their businesses. Private equity and buy-out firms often buy companies completely and/or buy control of the company to then install their own management based on the thesis that professional executives can take the company to the next level of performance. As it operates today, VC is diametrically opposed to this method of company building save a few exceptions. To a venture capitalist, there is no better leader for a company than its founder.

VC invests in companies where employees have "skin in the game." Those with skin in the game are often the scientists and engineers that initially invented or championed the technology. This is core to venture capital, and some may overlook the foundational role of equity grants and options in the success of the industry. VC invests in companies that almost always reward employees with equity. This means whether you are hired as the first operations lead, a sales executive, or a staff engineer, you will receive some level of compensation outside your salary as equity in the company you are working for. Startups intrinsically align incentives better than many large corporations by giving their employees ownership. Employees do their best work, because if everything goes right, they share in the spoils.

VC invests in software-defined products too, since software has unique traits that make it highly lucrative compared to most other businesses. Software is often sold in an "as-a-service" model that allows software developers to continually improve the underlying product in return for a recurring fee for maintaining access to the product. As a result, software has better margins than most other businesses while providing recurring revenue instead of one-time revenue. Thus, software businesses are usually treated with better valuation multiples than other businesses.

Venture fundraising is not one-and-done. Founders raise capital in stages (seed, series A, series B, series C, and so on) based on their progress with the business. Real estate investors buy a property outright, public equities investors might dollar-cost average into a position, but venture capital differs in that there are predefined financing gates that a company must go through to continue its journey to exit or obtain self-sufficiency. Investors and founders both optimize growth over profitability. Any startup must fight to hit the metrics that will help it raise its next round of fundraising (unless it is already profitable).

The process outlined in this section can accelerate the timeline for achieving technological milestones. The defense industry is one of the newest sectors to be

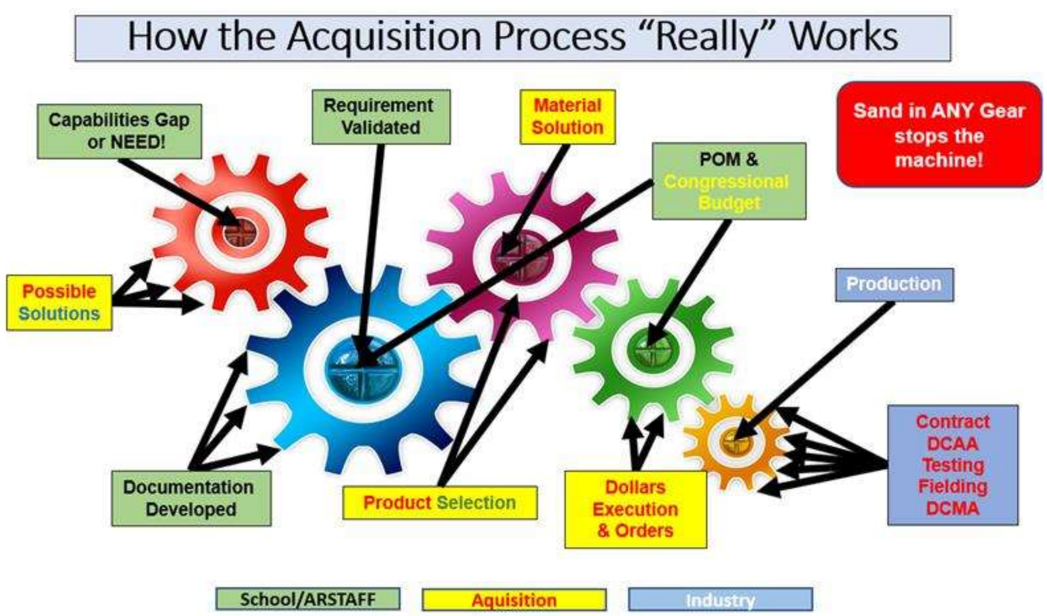

Figure 2: General execution of the Acquisition Process [6]. Colored gears showcase the many moving parts that can fail leading to loss of time and insurmountable complexity.

disrupted by VC. The ground systems acquisition & systems engineering community can benefit from both understanding how VC works and how VCs measure company success. Understanding how VCs think about investment opportunities will hopefully help the community to channel investor interest and dollars toward relevant Army programs.

3. WHY DOW CONTRACTS ARE VALUED DIFFERENTLY BY VENTURE COMMUNITY

Defense contracts are often designed for compliance and stability; however, VC interests favor speed and massive scale. While latest policies like the ATS are helping to shift the landscape towards more Agile practices that are friendlier to the venture industry, it is difficult to reconcile with the behemoth that is the traditional acquisition process (**Figure 2** [6]). Many promising technologies struggle to attract venture investment because the market is too small, procurement cycles are too long, and revenue cannot scale predictably.

Historically the defense acquisition system has involved an extremely complex and multi-year orchestration of requirements, funding, fiscal years (FYs), color of money, contracts, testing, and production. To add to the chaos, interactions between the executive & legislative branches and industry occur amid changing administrations, congressional configurations, new policies, and constantly evolving technology. There are so many failure modes in this process that it typically takes years or decades for a high-demand capability to get to the point of fielding, while the demand signal to industry often undergoes numerous drastic changes. Suffice it to say, this is not conducive to or aligned with VC interests.

In venture capital, investors are often looking for Product Market Fit (PMF), a clear sign that the market wants the product that the company has built. Companies selling to government end-users often struggle if a single issue can pop up and block the Rube Goldberg-esque acquisitions machine. For example, if a company experiences a government shutdown and must operate in a Continuing Resolution (CR) environment, it may become difficult for that company to raise their next round of venture capital as a CR can be disruptive to revenue metrics. This is an exogenous factor totally disconnected from any of the merits or underlying qualities of the business. CRs can cause defense tech companies great harm as they may degrade the ability to show the revenue, they need to prove PMF to their investors.

Another challenge is that CRs hinder the ability of government Program Managers (PMs) to incorporate subscription-based products (e.g., business applications, modeling & simulation software, autonomy as a service software, or leases) into their plans. Without an effective and reliable plan in place to use these services, PMs' viability in the defense market is significantly reduced; thus, it degrades the attractiveness of companies producing these products to investors.

It should be noted that the Army recently established the Pathway for Innovation & Technology (PIT) to accelerate requirements and procurement processes – which it does by prototyping at the edge and serving as an immediate bridge to scale emerging tech at the speed of relevance. Within the PIT, is Army FUZE, which combines efforts & legacy funding from separate sources: Tech Maturation, xTech, Small Business

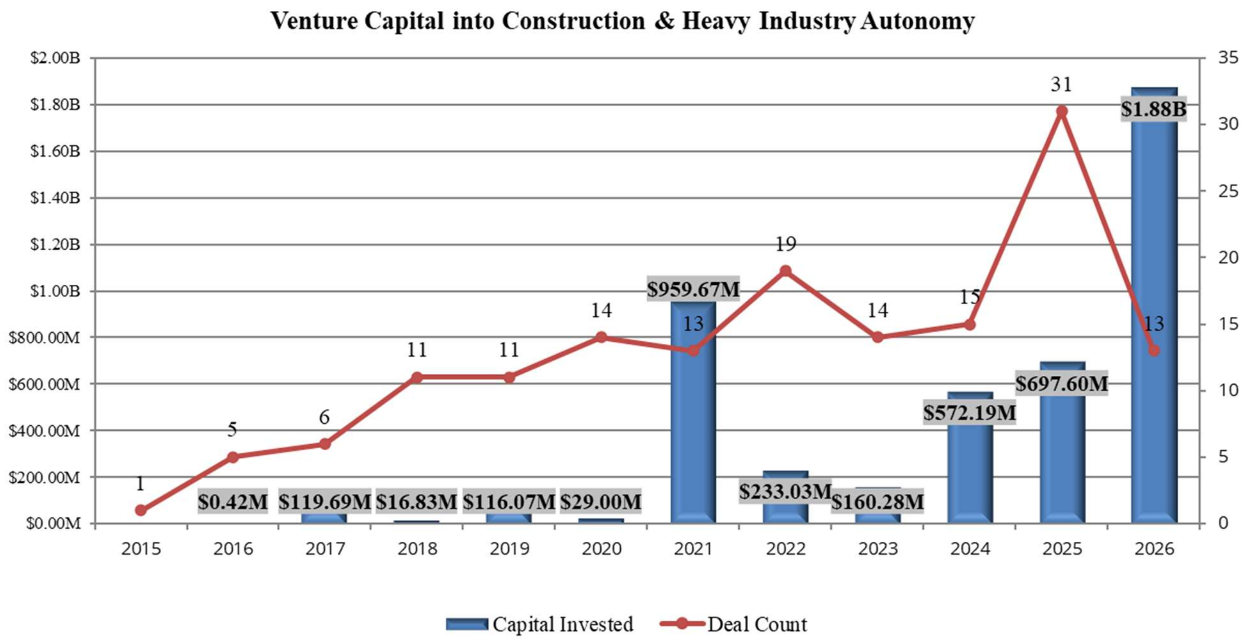

Figure 3: Venture Capital into Construction & Heavy Industry Autonomy [7]. The large spikes within the 2021-2026 period indicate immense VC interest with $1.88B already invested in 2026 alone. (Data pulled on May 26, 2026.). **NOTE:** All venture investment data is backwards looking and may not be reflective of future trends. The 39 companies included in this search were compiled from research conducted using Harmonic and PitchBook.

Innovative Research and Small Business Technology Transfer (SBIR/STTR), and the Manufacturing Technology program (MANTECH). The FUZE is envisioned as a consolidated "technology intake pipeline" to Find, Evaluate, Prototype, and Transition Technology At-Speed. PIT defines potential metrics such as Speed of Delivery (i.e., Days), and the number of Gaps Addressed, Capabilities Delivered, Transition Sponsors, Duplication Efforts, and New Entrants. The FUZE mission is to adopt a VC mindset to accelerate the transition of innovative capabilities to the field by connecting programs, scaling impact, and reshaping acquisition through a unified Soldier-centric approach.

Evidentiary data strongly demonstrates how VCs over the last five years have significantly ramped up funding of defense technology and dual-use companies focused on ground autonomy. VCs have scaled up their investments based off the continued energy and action behind acquisition reforms. According to Michael Brown, Partner at Shield Capital [8], defense tech can be appealing to investors due to the record market size (roughly $1T in the US military budget and three times that globally), potential for revenue quality, and it is becoming increasingly dual-use between military and commercial market opportunity.

The construction and heavy equipment industry is also growing. (**Figure 3** [7]) shows non-exhaustive investment data sourced from PitchBook and includes 39 companies, demonstrating the large surge in venture investment over the last few years. Aligning defense pathways to be better conduits for venture-backable businesses can improve industry participation and accelerate technology transitions.

4. APPLYING COMMERCIAL BEST PRACTICES TO DEFENSE

There are many ways for the government to gain greater leverage from external venture investments. One way, early in the technology development process, is by partnering early with small innovative companies by leveraging the DoW Domestic Technology Transfer Program. This program is a federally mandated initiative that is designed to bridge the gap between military R&D and the private technology development sector. This program allows DoW's science labs to partner with small technology companies, providing the technology companies with access to world-class labs, specialized testing equipment, and military research, allowing small business to reduce their internal R&D costs and to accelerate their time to market.

Another is to understand how venture investors assess prospective investments in companies and consider nudging government contracts in ways that could move the needle on the awardees' attractiveness to private investors. VCs use North Star [9] metrics when judging the financial attractiveness of a business. At the earliest stages of venture capital, these metrics can be sparse especially if a company is pre-revenue or pre-PMF. Understanding how startups are defining their most important growth metrics or PMF metrics, can help defense acquisition planners to consider those perspectives as they are formulating the right acquisition strategy for their program.

Another practical example of adapting commercial best practices to defense is the application of what we would call a "streamlined Fast V" development and production model to quickly bring in commercially developed / relatively mature technology. The framework leverages how commercial Original Equipment Manufacturers (OEM)s integrate new technologies into existing hardware platforms. Like Agile processes, the Fast V emphasizes rapid iteration and the disciplined use of digital engineering tools. This model leverages Commercial Off the Shelf (COTS) solutions and utilizes engineering tools like Voice of the Customer (VOC) feedback to tech suppliers, to ensure they understand any necessary modifications needed to achieve military suitability. This process can use experimentation campaigns like the Army's Transformation in Contact (TiC), to rapidly drive the closure of any gaps between current commercial functionality and suitability in the intended Army operating environment. Implementing Fast V models should consider a larger pool of mature COTS technology providers, and focus on validating mission specific performance.

The Fast V begins with defining an Operational Design Domain (ODD) to anchor mission context, operating conditions, and performance expectations. These customer driven requirements could flow directly into a digital engineering design model that focuses on "strip, rebuild, test," enabling the Army to provide feedback changes early and avoid unnecessary reinvention. Formal tech gate transitions can be used to move the effort from design into production, mirroring commercial practices where engineering hands off validated requirements and test results before a platform is rebuilt to the new specification.

Prior to production, the Fast V can promote commercial discipline by emphasizing Verification and Validation (V&V) of any rebuilt platform against the updated requirements before Launch & Sustainment. If any element fails V&V, the model could loop back through a focused Engineering Change Proposal (ECP), essentially a mini gate to quickly resolve the issue without derailing the overall schedule. This ensures the system progresses toward scalable production in a controlled, predictable manner.

The Fast V model (**Figure 4**), is an approach to making the traditional systems engineering V-model development process Agile. What distinguishes the Fast V from traditional defense approaches (e.g., Waterfall methodology) is its deliberate incorporation of Agile and digital engineering methodology. These practices mirror venture style expectations for speed, efficiency, and continuous learning, making the Fast V one candidate tool for helping the Army to thoughtfully adapt proven commercial methodologies to accelerate capability fielding while maintaining engineering rigor.

Another way to potentially drive better leveraging of external investment, is to focus on significant metrics that are important to the companies receiving that external investment. For example, recurring revenue, often measured by Annual Recurring Revenue (ARR), introduces one of the financial lenses through which venture-backed companies evaluate long-term defense engagement.

For many venture-backed companies, ARR serves as a central metric through which value, scalability, and long-term viability are assessed. Unlike one-time sales that provide a temporary revenue spike, ARR reflects a predictable revenue stream that ideally compounds over time and signals strong customer retention—critical indicators of product-market fit. Some investors have viewed ARR as the backbone of modern software enterprises because it provides a quantifiable, repeatable measure of financial health and growth trajectory. However, some of this is changing as new developments in AI have challenged software companies to rethink service delivery. Some AI companies have explored outcome-based pricing (i.e. every successful customer complaint sorted by an AI agent might cost roughly a fixed amount). And different investors value different metrics, so ARR is just one example. Regardless, a reliance on ARR helps to explain why traditional defense contracting models, which emphasize upfront hardware purchases and irregular procurement cycles, are often misaligned with venture expectations.

As companies mature, VCs rely on metrics such as ARR, daily/weekly/monthly active users, new customer acquisition cost, average contract value or duration, and lifetime value to forecast a company's trajectory and determine its investment worthiness. These metrics are difficult to apply within traditional defense procurement structures,

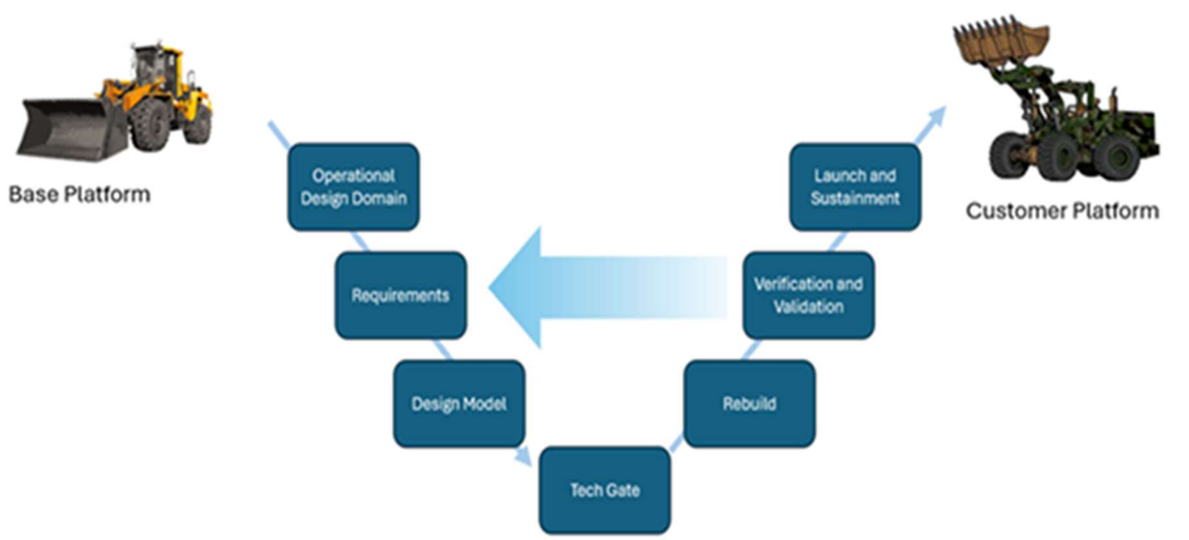

Figure 4: A Fast V Model that leverages traditional phases and focuses on rapid iteration, digital engineering tooling and processes, and Agile practices.

where purchases often occur as single, unpredictable transactions tied to multi-year cycles. For venture-backed companies to meaningfully participate in defense markets, acquisition pathways may benefit from considering the above metrics and how they can affect desired commercial interests (especially if the government is interested in commercial technologies like construction autonomy with dual-use applications).

One set of metrics that can be of mutual interest to both defense acquisition leaders and the venture community are Technology Readiness Levels (TRLs) and Manufacturing Readiness Levels (MRLs). Because defense hardware requires physical materials, supply chains, and testing, VCs must determine if the technology is scientifically sound and scalable. TRL, a scale ranging from 1 to 9 originally developed by NASA, has been used for years to assess the maturity of Army technology. VCs also track TRL progression. A TRL of 3-4 indicates lab validation, while TRL 6-7 means a prototype has been demonstrated in a relevant operational environment.

MRL assesses how easily the hardware can be mass-produced. A high TRL with a low MRL is a red flag, meaning the tech works but cannot be built at scale or cost-effectively. A related, perhaps harder metric to measure is Tech Milestone per Dollar: a ratio used to evaluate capital efficiency in R&D. VCs ask: "For each $1M invested, how much does the technology de-risk or advance in its TRL/MRL?

Suffice it to say, when market research indicates small innovative companies in a commercial market with applications to defense use-cases, programs may want to consider in their acquisition strategy how the contracts/agreements could affect the ARR or average contract value/duration or other metrics. If the program is going to use phases of competition and down-select, then it can consider how the metrics change for the companies remaining past down-select based on the planned period of performance and budget outlook.

Clearly articulating priorities, anticipated budget levels, quantity expectations, and then keeping those priorities consistent over multiple FYs and administrations, can positively influence the level of external investment into novel technological approaches. Looking at the history of priorities and procurements of both ground combat and ground support vehicles during this century, there are very few that have stood the test of time and not been cancelled, reprioritized, or had requirements changed.

5. CASE STUDY: VC INVESTMENT IN AUTONOMOUS CONSTRUCTION

One area that aligns with VC interest is the autonomous construction & heavy equipment industry. In recent years autonomous construction has been shaped by significant investment by both commercial and the Army. Within the last decade alone, major advancements in AI, Light Detection and Ranging (LiDAR), and Position, Navigation, and Timing (PNT) solutions have greatly improved efficiency and productivity [10][11].

Commercial autonomous construction systems have already demonstrated strong real-world performance. Dozers in particular show mature and reliable autonomous capabilities for tasks such as automated grading. Excavators and loaders have likewise proven dependable in performing autonomous trenching and loading operations. Autonomous trench-digging [12] has also been successfully demonstrated in controlled soil conditions, reflecting a high degree of technical maturity across these platforms. However, these autonomous functions can only be employed successfully in very controlled environments.

Capabilities developed for the mining industry rely very heavily on assured communications. Significant sums have been invested in high speed 5G networks, reducing the heartbeat frequency of each autonomous platform to milliseconds. Assured positioning using Real Time Kinematic (RTK) Global Positioning System (GPS) signals cover the entire worksite. Complete a priori mapping is used via survey teams performing new surveys to capture topography and soil conditions at the start of every shift.

Furthermore, operations are generally controlled from a central control station, essentially planning each minute detail of the mining platform's movement. The only autonomous decision left to the platforms in these environments is to perform a full and complete stop when issues arise. Once a platform stops, it can take up to four engineers to travel to the platform and clear it to continue its mission.

Additionally, these mining sites are supported by numerous support capabilities behind the scenes, such as human operated bulldozers and graders, to ensure that the mining environment stays within acceptable conditions to ensure that the autonomy continues to operate (e.g., humans fixing potholes).

Similarly, mature autonomous capabilities operating in the agricultural industry are used in uniquely controlled environments. Each robot may be focused on one type of crop, using previously mapped fields, with a reliance on 5G and both remote & local PNT reference signals.

While commercial autonomy investments have resulted in mature, profitable and scaling mining, agriculture, and construction operations, they still need to be adapted to Army use cases & operating environments. There are opportunities to adapt such technology for novel military purposes like optional fitting of capabilities onto other vehicles (e.g., bulldozer blades on battle tanks).

If we look at how venture capital has invested into construction & heavy industry autonomy over the last few years (**Error! Reference source not found.**), VCs have scaled up their investments into these spaces based off new developments in AI as well as renewed interest in investments that help reshape physical industries. **Figure 3** shows how VCs over the last few years have significantly ramped up funding of construction and heavy industry autonomy companies with dual-use potential. From 2021 (a previous record year for venture capital in this category) to 2026, the total venture funding for U.S. based autonomy companies in these industries ballooned from $959M to $1.88B in total funding. Several stand out companies in this category raised very large amounts of funding to compete in this category.

One growing venture backed company in this space is Bedrock Robotics, founded by former leaders from Google's autonomous driving project, Waymo. In July 2025, Bedrock announced it had raised $80 million in Seed and Series A funding to enhance existing heavy equipment with autonomous capabilities [13]. This was followed by a massive $270 million Series B round in February 2026, suggesting immense investor confidence [14].

Other such firms include Construction Robotics and Built Robotics. Construction Robotics uses an autonomous masonry machine called the SAM100 machine, and their MULE system that lifts materials up to 135kg can operate in hazardous environments [15]. Built Robotics develops their Exosystem, a retrofit system that automates excavators, dozers, and other equipment. Currently focused on solar energy construction, their software allows machines to perform tasks like digging, grading, and hauling autonomously, and they offer a subscription-based model for autonomy, allowing contractors to pay only for what is needed [15]. TerraFirma is another venture backed company focused on construction autonomy with the eventual focus on mining & construction on other planets [16].

On the defense investment side, the US Army's Engineer Research & Development Center (ERDC) has matured technology through the Robotics for Engineering Operations (REO) Science & Technology project, which has resulted in mature prototypical capabilities such as semantic work site models using advanced multi-modal sensing (i.e., combining data from different types of sensors), decision support tools, beyond visual line of sight unmanned operations, and demonstration of autonomy on a wide variety of construction vehicles for different tasks.

REO focused on military-relevant use cases such as lane proofing and construction of fighting positions in uncontrolled and adversarial environments, while minimizing reliance on assured positioning and communications capabilities. Such investment has led to the emergence of requirements for Robotics & Autonomy for Construction Equipment (RA-CE), a draft requirement document for prototyping experimentation under development. This experimentation would test the efficiencies, military suitability, and limitations of autonomous technology applied to dozers, excavators, compact track loaders, and site support equipment such as drones and ground robots. Such autonomous technology could be used operationally to provide Mobility (i.e., facilitating Army force movements), Counter-mobility (i.e., degrading enemy forces ability to move) and Survivability (i.e., improving Army soldier lethality & survivability).

While this prototype experimentation is planned & executed, the Army could send a demand signal to industry for a larger scale procurement & fielding phase by programming steady procurement dollars and articulating its confidence that priorities will not change, while beginning to buy & use prototypes to drive learning. Changing priorities across various programs over the years sends poor signals to the VC industry and to the dual-use companies in this category who may want to enter this space.

The Army can find ways to leverage VC-backed companies like Built Robotics or TerraFirma to de-risk further investment in this space. Encouraging companies to expand from the commercial market to the military market can encourage partnerships between larger OEMs and Primes and startup – ensuring the role of user feedback to drive agile software updates, modular hardware swaps, and algorithmic learning toward successful operation in the military operating environment.

As construction solutions learn from diverse commercial jobsites, their software, in aggregate depending on the software trunks and branches, is like an "always-on" system, meaning the software is already driving quite a bit of learning for a long-tailed product backlog. This could help enable rapid retrofitting of existing fleets, turning an excavator from existing inventory into a capable autonomous system quickly. The external investments have already paid for some "failed" prototypes, meaning the Army only needs to pay for the successfully operating layer (i.e., the production-worthy iteration) and any remaining customization, hardening, and testing for the military environment.

Today, major hardware OEMs like Caterpillar, Komatsu, and Volvo are integrating semi-autonomous features and remote-control capabilities directly into their new equipment lines. Jason Ramshaw, Global Commercial Manager of Caterpillar's Construction digital & technology Division, emphasizes "Having more than ten years of experience in the use of fully autonomous mining trucks, we are now targeting autonomous work in the construction industry. With Cat Command, we are now on the road to semi-autonomous construction equipment." [17]. Komatsu's solution automates grading and excavation with impressive accuracy, while Volvo's autonomous hauler demonstrates technical maturity in controlled environments like quarries [18].

Not only are these industry giants rapidly integrating autonomy into their systems, but they are also partnering with startups to accelerate the development of fully autonomous solutions. As a larger OEM buying a startup often represents a successful venture exit, the OEMs may be able to use Army prototyping activities to better survey the market or partner temporarily to inform a future acquisition.

Heavy equipment technology is mature for commercial operations under specific operating environments and conditions, but it still needs to be adapted to work operationally for military use cases involving unstructured or adversarial multi-domain environments.

6. APPROACH & RECOMMENDATIONS

This section explores a few approaches for expediting adoption of these critical and advanced technologies whilst taking better advantage of the full breadth of the industry ecosystem and expanding the market space for startups by reducing friction and creating better opportunities for both the Army and industry. This may suggest a shift from procuring highly specified platforms to acquiring performance, capability, and uptime of software-intensive systems. To provide the greatest leverage from recent VC investments for commercial market opportunities, it makes sense to break the problem down into two categories. The first is how to identify which pieces of commercial market systems can be used in Army use cases now with little or no adaptation. Call the first problem "the existing overlap". This means things like, which construction operations does the Army conduct now in an uncontested environment, with great 5G cellular, GPS & internet service, with a well-defined process, well defined soil conditions for example, where costs could be reduced, or operations made more efficient by fielding newly available technology to those locations. The "existing overlap" is how the Army can get better at adapting itself to better leverage what new technology is out there now.

The second category would be the hardened, military unique, contested environments, with unstructured or highly variable work plans and conditions. Call the second problem "the target". The recommendations that follow primarily fall into supporting "the target". For this latter category, it makes sense to prioritize the types of operations that seem most relevant in the near term, and find better ways of specifying or communicating what the unique conditions of the intended operations are, in terms of threat, communications, and what is different about the military operation compared to the commercial operation.

For "the target", this is where the Army can focus more on what the demand signal is and what the opportunity is for industry. This can help smaller companies to determine whether to put the military use cases onto their product roadmap and can help those companies show their investors how those updated roadmaps can move their growth metrics in terms of projected revenue. "The target" is how the Army can help companies to make decisions on whether to evolve their product toward the military market and upcoming opportunities and allow the companies to get better at understanding the voice of the users and decision makers in the military market.

The following recommendations offer some ideas and concepts for de-risking technology adoption for the government while creating the better opportunities for VC-backed startups to compete.

6.1 Non-Traditional Partnering and Contracting Pathways

The "Valley of Death", or the costly delay between a successful prototype demonstration and fielding a productionized unit of capability, is a primary reason VC firms hesitate to back defense-focused startups. To bridge this gap and entice private capital toward "the target", the Army could further explore non-traditional partnering and contracting pathways. One approach involves leveraging the expertise and authorities of the congressionally designated Science and Technology Reinvention Laboratories (STRLs) (i.e., the DoW's R&D organizations) to partner with highly technical startups before formal contracting begins.

For the VC and startup community, an STRL is highly valuable across two distinct phases of the Venture Capital Lifecycle (**Figure 1**). The first occurs during the early-stage funding phase, where startups seeking initial seed or Series A funding could form a partnership with an Army STRL. This activity validates the technology's relevance to Army use cases and potentially demonstrates that the startup has achieved an early "Mission-Market Fit"; thus, de-risking the investor's capital deployment.

Second, STRLs like the Ground Vehicle Systems Center (GVSC) utilize broad technology transfer authorities to establish formal partnerships with startups early in the product development cycle. In addition, partnering with a STRL like GVSC opens laboratory infrastructure and testing environments to the startup. This enables them to have access to a more realistic mission environment or "virtual proving ground" if they want to do the work to harden their system for fielding if needed.

GVSC has been utilizing this strategy to partner with many start-ups in the vehicle autonomy domain to provide invaluable VOC feedback on their technology. GVSC Ground Vehicle Robotics (GVR) and GVSC Experimentation teams work with the company and TiC units to get their technology in the hands of the soldiers in operationally relevant scenarios. The real-time VOC feedback provides a massive advantage to VCs: it reduces the startup's R&D burn rate, accelerates product iteration, and ensures the product is shaped by actual end-users rather than theoretical requirements.

VC groups, understanding the resources that the start-up can leverage, can utilize this information when they make their funding decisions. Crucially, these STRL activities and partnerships can happen before any contracting or prototype development occurs. In addition, a STRL-first approach increases the number of "possible solutions" entering the acquisition machine (**Figure 2**), bypassing the low funding ceilings historically associated with Small Business Innovation Research (SBIR) programs.

To attract VCs that meticulously evaluate the Total Addressable Market (TAM) before authorizing investments, the Army could communicate the demand signals to prove a lucrative TAM exists. Through the strategic use of Characteristic of Needs (CoNs) and acquisition Annexes, the Army can articulate a validated operational problem (e.g., navigating an unmanned ground vehicle through a contested, GPS-denied environment) based on desired outcomes without being too prescriptive on the specifications of the solution. This non-traditional approach allows venture-backed firms to remain commercially viable whilst building a better fit solution for Army use cases.

Through strategies like CoNs and Annexes, the Army signals that the requirement is not theoretical or doomed to innumerable R&D contracts (i.e., "Valley of Death"); rather, it is backed by programmed intent. When VCs see a clear CoN embedded in an actionable acquisition Annex, it de-risks the investment and provides the necessary confidence to inject more private capital into the a potential new member of the (DIB).

6.2. Modular Autonomy Architecture and Alternative Funding Models

Instead of funding the development of completely new and integrated autonomous systems, the Army can center its strategy around a Modular Open Systems Approach (MOSA)-compliant autonomy architecture. A variety of industry analysts have argued that it is difficult for construction companies to vertically integrate autonomy technology with the rest of their business and therefore it makes sense to form partnerships and/or outsource the autonomy piece by relying on well-defined interfaces [19] [20]. In addition, the automotive industry has migrated toward a common electronic and zonal architecture over the preceding decades. DoW and Army examples of pioneer efforts to develop and implement a common architecture can be found in Army Acquisitions - Robotics & Autonomous Systems, Ground (RAS-G) Interoperability and Profile (IOP), Ground System Survivability PM Vehicle Protection Systems (VPS) Modular Active Protection Framework (MAF) Architecture, and Program Acquisition Executive (PAE) Ground (formerly Ground Combat Systems (GCS)) Common Infrastructure Architecture (GCIA).

Having a small number of well-defined, key interfaces can serve to provide a known way to integrate new technologies – especially from smaller, innovative firms, into the existing or planned operational architecture. RAS-G IOP already attempts to serve this purpose between key interfaces in ground robotics such as the messages moving wirelessly between a robot and controllers, or how to plug a new payload or autonomy kit into an existing vehicle. The RAS-G IOP is not perfect, but the Army has a process to update it with industry feedback and evolve with industry as technology changes or commercial trends change. There are other key interfaces coming online, such as the Next Generation Command & Control (NGC2) Data Layer. Key interfaces can be adopted from either "the existing overlap" (i.e., existing industry interfaces, or previously defined standards) or "the target" (e.g., a new interface needed for future functionality), depending on what makes sense for a given program. Such architectures are aligned with standards like GCIA and can sometimes function as software-defined middleware between commercial hardware and tactical mission software.

Developing a MOSA-compliant autonomy architecture that complies with the aforementioned standards can: allow the Army to leverage the massive R&D investments already made by industry; allow purely commercial software to be used without modification; and allow other companies to integrate their commercial or military software. This strategy also confronts a critical market barrier: the dominance of large OEMs whose proprietary, closed ecosystems often prevent smaller companies from contributing their technology. A MOSA framework, could act as a common interchange, enabling the Army to procure and "plug in" best-in-class autonomy software, sensor packages, and other subsystems from multiple vendors. This allows for integration without forcing OEMs to expose sensitive proprietary data or requiring small innovators to have deep, pre-existing integration partnerships.

Another benefit of a MOSA-compliant autonomy architecture is that it helps the government avoid vendor lock; if one provider's performance wanes, the government can open a new competition for another vendor to plug their software into the common architecture, fostering continuous competition and innovation. The Army's new Right to Integrate (R2I) initiative, informally known as "Operation Jailbreak", underscores the importance of easing the integration burden for COTS or newly developed capabilities through open interfaces such as Application Programming Interfaces (APIs). Stabilizing a modular, industry-developed autonomy layer directly accelerates R2I, and it improves the conditions for future capability insertions. Getting access to such interfaces promotes small companies' ability to evolve their product and stress test it for a realistic product like using a "virtual proving ground".

Another related model that the Army could further explore includes purchasing autonomy as a recurring service rather than a static asset. While there are challenges to this alternative funding model, the recurring aspect can provide startups with more predictable ARR, which would help them scale their software sprints and product backlog prioritization to their budget and runway. It also helps with their ability to secure subsequent rounds of venture funding. In addition, it may shift the burden of obsolescence and costly sustainment from the Army to the larger pool of paying users accessing their license. The provider is economically incentivized to push software updates and modular hardware upgrades, delivering the iterative capability the Army requires to outpace near-peer adversaries.

For the government, it could dilute the software iteration expenditure into a predictable, manageable operating expense. Payments in "as a service" models are often tied to performance and "uptime," not just delivery. If the software fails, is vulnerable to electronic warfare, or does not adapt to new operational needs, the recurring payments can be stopped, though switching to a different provider can come with risks.

6.3. A Metric-Driven Evaluation Framework

The unpredictability of the defense budgeting and selection process is a major hurdle for venture-backed firms. A clear, metric-driven evaluation framework addresses "the target" problem by providing much-needed demand signal stability for companies and investors. The Navy's Budget Execution-Year Technology Selection (BETS) board, used by its Rapid Capabilities Office (RCO), serves as an excellent model for prioritizing its investments [21]. The BETS board plans to prioritize projects like a VC Investment Committee, using a straightforward formula to calculate expected value and then deciding whether to scale or end projects based on the expected value.

This model can translate complex operational needs, or gaps, into a quantifiable score. When this score is combined with the probability of a project resolving the gap and the probability of the project developing into an operational capability, an expected value is derived. This expected value can then be used to continue the project (i.e., a good bet) or terminate the project (i.e., a bad bet).

Adopting a similar, transparent evaluation process for ground systems could send a clear signal to industry and investors about which capability gaps the Army is serious about funding. It would replace ambiguity with a tangible process for matching mature technology with funded operational problems, like the Navy RCO's BETS Board [21]. This approach directly addresses the investor's need for market validation before committing significant capital. Furthermore, it encourages a competitive environment where both venture-backed innovators and traditional prime contractors can propose solutions, with the best-value proposition winning based on transparent metrics.

6.4. Explore Phased Acquisition Strategies

Another option the Army could further explore is structuring traditional acquisitions into complementary phases. Although there are practical challenges to this model including how the annual funding process works, the scenario described highlights how it could be advantageous.

The first phase in this model could involve platform procurement, using traditional contracting methods to obtain the foundational hardware. Essentially the base vehicle chassis (e.g., dozers, excavators, etc.) can be procured from major OEMs like Caterpillar, Volvo or John Deere. The hardware would then become government-owned and should feature a standard "drive-by-wire" capability with known interface or data dictionary that supports integration with industry-developed autonomy architectures. This would establish an autonomy-vendor-agnostic baseline that prepares the Army for future upgrades for these and other platforms supporting the autonomy architecture.

The second phase could focus on contracting with one or more autonomy providers, whether they be the OEMs themselves, other established companies, or venture-backed firms driving commercial construction autonomy like those listed in Section 5. These firms could be vetted to provide autonomous driving and mission software as a subscription service, or other business models, if they were able to show the ability to successfully & suitably operate with acceptable uptime in the intended operating environment (i.e., achieves PMF). Considering subscription models, which have been proposed in various forms by numerous companies, but have some practical challenges, would intentionally shift from a traditional procurement and sustainment strategy to a subscription/licensing framework that aligns with internally tracked metrics.

Next, a pilot phase could commence where commercial autonomy kits are installed for limited operational use or limited fielding, on a small number of platforms (e.g., twenty standard bulldozers from one OEM) prior to a later production phase. Throughout the pilot phase, the Army and the vendor could cooperatively keep track of the vendor's North Star VC metrics like ARR, Gross Margin, Average Contract Value (ACV), and Lifetime Value (LTV), while also keeping track of the Army's operational metrics of success.

This process can enable the adoption of the idea of paying for "uptime" rather than "repairs" of the platforms. If the software fails or continues to pose significant issues during fielding, then the subscription payment stops. This would negatively impact the vendor's Net Revenue Retention (NRR), a critical metric in VC valuation, and therefore would serve as an economic motivator to provide constant, ideally over-the-air updates that fix bugs and counter evolving threats. There are risks introduced by this scenario, such as terminating the subscription without having an already qualified backup source known to work in the operational environment. Such scenarios also include challenges with funding timing/availability and scaling available budgets to potentially fixed subscription fees.

If a venture-backed autonomy system successfully demonstrates capability and achieves PMF upon completion of the pilot phase, then the vendor would want a subsequent production contract to follow to provide the immediate revenue scaling that VC investors are seeking. Such a production contract would provide the type of booked immediate funding that VC investors would be seeking to justify subsequent, larger funding rounds (e.g., Series B or C). In addition, it would signal the Army's intent and reliability as a customer, proving to the VC ecosystem that defense applications for construction autonomy is a viable, profitable direction for their portfolio companies. Upon receiving this validation and unambiguous follow-on intent, VCs are encouraged to deploy more private capital into defense-focused R&D. This could theoretically result in a continuous pipeline of innovation that feeds into Army use cases.

In this type of hypothetical phased model, all parties win by designing acquisitions around these metrics. For startups serving the ground systems community this means more predictable revenue, higher valuations, and an easier ability to raise capital. For VCs, this means familiar metrics, higher survival rate for their portfolio companies, and more valuable exits for their portfolio companies. For government, this means better vendor competition, performance accountability where government stakeholders can swap software if performance is unsatisfactory, and better access to innovation. Government stakeholders can address lock-in concerns (i.e., reducing vendor lock), high pricing (e.g., spreading software costs over multiple years), and leveraging commercially produced hardware as the skeleton for autonomy.

7. CONCLUSION

Recent policies like the Acquisition Transformation Strategy highlighted the need to leverage private investment and venture capital in various areas for procurement of tactical capability. Our paper highlighted the potential for VC to be leveraged for defense, where capability may be harnessed from the autonomous construction industry; significant investment exists on both the commercial and defense front, and the industry has achieved progressive levels of technical maturity over the years with potential applications to defense use cases.

Several approaches and recommendations were explored that the Army may not be accustomed to but is beginning to adopt. By creating transparent, metric-driven evaluation processes modeled on concepts like the Navy's BETS board, the Army can provide the stable demand signals that attract private capital. In addition, shifting from monolithic hardware procurement to a "capability-as-a-service" model built on a MOSA-compliant autonomy architecture and funded via recurring revenue, means the Army can foster a competitive ecosystem where both startups and primes are incentivized to deliver continuous innovation.

Non-traditional partnering and pathways like STRLs, CoNs, and Annexes are invaluable and allow for early-stage funding avenues and vital real-time VOC feedback that VCs can directly use in their valuations. Lastly, traditional contracting strategies can be utilized under a multi-phased acquisition approach to procure major construction OEM hardware, acquire autonomous driving and mission software that adheres to a MOSA-compliant autonomy architecture, followed by a prove-out or "pilot phase" and eventual production contract. This alignment of incentives is the key to unlocking the speed and innovation of the venture-backed technology sector to deliver more mature and resilient capabilities to the warfighter.

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11. ACRONYMS

ACV	Average Contract Value
AI	Artificial Intelligence
API	Application Programming Interfaces
ARR	Annual Recurring Revenue
ARSTAFF	Army Staff
ATS	Acquisition Transformation Strategy
BETS	Budget Execution-Year Technology Selection
COTS	Commercial Off the Shelf
CoNs	Characteristic of Need
CAT	Caterpillar
CPE MA	Capability Program Executive Mission Autonomy

CPE CL	Capability Program Executive Contested Logistics
CR	Continuing Resolution
CSO	Commercial Solutions Offerings
CTO	Booz Allen Chief Technology Office
DCAA	Defense Contract Audit Agency
DCMA	Defense Contract Management Agency
DFARS	Defense Federal Acquisition Regulation Supplement
DIB	Defense Industrial Base
DIU	Defense Innovation Unit
DoD	Department of Defense
DoW	Department of War
DTG	Booz Allen Defense Technology Group
ECP	Engineering Change Proposal
ERDC	Engineer Research & Development Center
FAR	Federal Acquisition Regulation
FY	Fiscal Year
GAO	Government Accountability Office
GCIA	GCS Common Infrastructure Architecture
GCS	Ground Combat Systems
GPS	Global Positioning System
GVR	Ground Vehicle Robotics
GVSETS	Ground Vehicle Systems Engineering and Technology Symposium
ISR	Intelligence, Surveillance, and Reconnaissance
IOP	Interoperability Profile
IP	Intellectual Property
LiDAR	Light Detection And Ranging
LP	Limited Partners
LTV	Lifetime Value
MAF	Modular Active Protection Framework
MOSA	Modular Open Systems Approach
NGC2	Next Generation Command & Control
NRR	Net Revenue Retention
OEM	Original Equipment Manufacturer
ODD	Operational Design Domain
OTA	Other Transaction Authority
PAE	Portfolio Acquisition Executive
PM	Program Manager
PMF	Product Market Fit
PNT	Position, Navigation, and Timing
POM	Program Objective Memorandum
POR	Program of Record
R&D	Research and Development
R2I	Right to Integrate
RAS-G	Robotic & Autonomous Systems - Ground
RA-CE	Robotics & Autonomy for Construction Equipment
R&D	Research & Development
REO	Robotics for Engineering Operations
ROI	Return on Investment
RTK	Real Time Kinematic
SaaS	Software as a Service
SBIR	Small Business Innovation Research
SoS	System of Systems
STRL	Science and Technology Reinvention Laboratories
TAM	Total Addressable Market
TIC	Transformation in Contact

TRL	Technical Readiness Level
V&V	Verification and Validation
VC	Venture Capital
VoC	Voice of the Customer
VPS	Vehicle Protection Systems