The Impact of Supply Chain Issues on Military Training and Readiness

Lt. Col. Paul Santamaria, U.S. Army
Maj. Sam Yoo, U.S. Army
Dr. Vikram Mittal

The success of the U.S. military rests on two key requirements. First, the military must "train as it fights," completing extensive amounts of training to ensure that it can adequately perform its missions in combat. Second, the defense industrial base must be able to provide a robust supply chain of goods that allows the U.S. military to conduct both training and combat operations. This first requirement hinges on the second requirement since without proper access to equipment and supplies, the U.S. military is not able to conduct its training to standard.

The Russian failures in the Ukraine-Russia War highlight the results of the inability to meet these two requirements. In the years leading up to the war, the Russian defense industrial base faced numerous challenges stemming from the COVID-19 pandemic. These supply chain issues resulted in Russian soldiers unable to collectively train to standard; this in turn, resulted in an inability to conduct large-scale operations. If the United States is not able to maintain a steady supply chain of defense material, it could potentially face similar failures in future large-scale combat operations.

Over the last few years, the U.S. defense industrial base has been plagued with supply chain issues. This study discusses these supply chain issues with a focus on how they directly impact the ability of the U.S. Army to train. The analysis includes a case study that considers supply chain issues related to medium-caliber ammunition, which are the rounds that are used in many crew-served weapons.

State of the Defense Industrial Base

The defense industrial base consists of companies, laboratories, research organizations, and suppliers that comprise the supply chain that ensures that the U.S. military has the right resources. A 2022 report from the National Defense Industry Association (NDIA) found that this base has an overall grade of "unsatisfactory, failing."[1] This is the first year that the report has awarded it a failing score. The NDIA report looks at the following criteria to capture the health of the defense industrial base: demand, production inputs, innovation, supply chain, competition, industrial security, political and regulatory, and productive capacity and surge readiness.[2] In each of these categories, the report awarded a score between 0 and 100, with the overall score as the average of the individual scores. The overall score was 69, one point short of passing.[3]

Soldiers from the 13th Missile Defense Battery, 10th Army Air Missile Defense Command, and Israel Defense Forces soldiers load and stack up magazines with 5.56 mm ammunition to perform advanced rifle and reloading tactics on 27 January 2022 at an undisclosed location. (Photo by Spc. Xabiel Schindler, U.S. Army)

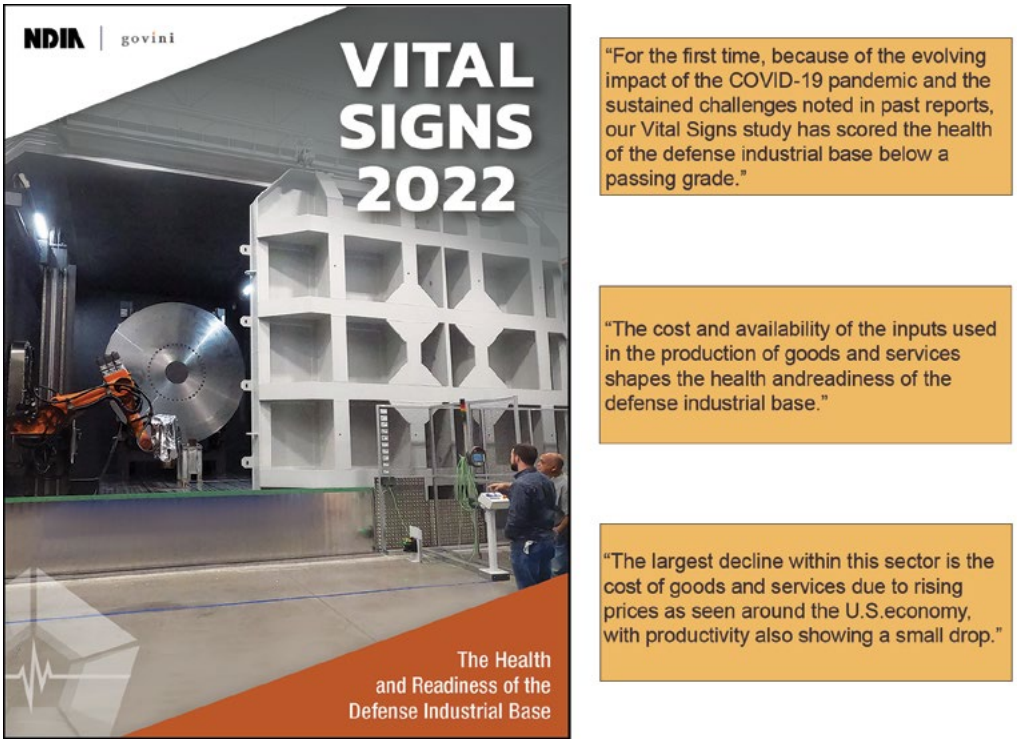
Figure 1 (on page 87) provides several quotes from the report that explain the reasons for the failing score.[4] One of the largest issues with the state of the defense industrial base is the impact that the COVID-19 pandemic had on the supply chain and production capacity. These two criteria saw a decrease in scores of 8 and 15 points, respectively. Naturally, these issues have hit every industry; however, in the past, the defense industry has been more resilient to larger economic issues. Moreover, shortfalls in these two areas have a direct impact on ensuring that the U.S. military has the necessary equipment, a critical issue given the current sociopolitical climate. The pandemic also decreased public approval for defense spending, which resulted in a decrease in the political and regulatory scores.

The industrial security indicator achieved an overall score of 50, the lowest score among the eight criteria. This score was based on information security and intellectual property rights; the low score is indicative of several data breaches and economic espionage. These security risks pose a significant issue given that the defense industry is heavily dependent on the sharing of sensitive and classified information among the government and defense industries. This issue becomes even larger given a recent RAND report that

Lt. Col. Paul Santamaria, U.S. Army, is the product manager for Medium Caliber Ammunition at Joint Program Executive Office Armaments and Ammunition, Picatinny Arsenal, New Jersey.

Maj. Sam Yoo, U.S. Army, is a faculty member in the Department of Systems Engineering at the United States Military Academy.

Dr. Vikram Mittal is a faculty member in the Department of Systems Engineering at the United States Military Academy.



(Figure by author)

Figure 1. Quotes from *Vital Signs 2022*

states that the Chinese military heavily relies on intellectual property theft.[5]

Further, the report gave a failing score to innovation for the defense industrial base, pointing to a decrease in basic research and development investments from the Department of Defense. Several studies have shown that innovation is key to success on the modern battlefield, given the dynamic nature of modern warfare.[6] However, innovation in the defense sector has been somewhat stagnant, especially when compared to the commercial sector.

One of the key underlying causes for these issues is that vendors in the defense sector project future cash flow on the defense budget publication every year through the president's budget submission. Any significant fluctuations in the budget for certain goods can result in a reduced cash flow leading to decreased investment in infrastructure and layoffs of skilled labor. Moreover, with many defense items procured on fixed-price contracts, defense vendors assume the risk of price fluctuations in the market. This decreases the incentive for the defense industry to invest their own funding in modernization and manufacturing innovation.

Current Challenges with Defense Supply Chain

One area of concern in the defense industrial base is the supply chain and the associated ability of the defense industrial base to get the necessary production inputs. There has been a global shortage of numerous different products ranging from baby formula to semiconductors. Many of these shortages were caused by the COVID-19 pandemic, which brought national attention to the holistic fragility of the supply chain. The pandemic caused many companies to implement COVID-19 safety measures such as limits to the number of employees in the workspace, social-distancing measures, and travel restrictions. These measures in turn resulted in decreased productivity and output from these companies, resulting in numerous shortages.[7]

These issues were most readily seen in the health-care system, where the U.S. industrial base was not able to respond to the increased demand associated with the pandemic, leaving hospitals without critical supplies. Despite numerous efforts to boost the U.S. industrial base's capacity to produce the ventilator systems, personal protective equipment, and life-saving medicines necessary

to combat the pandemic, the response remained sluggish. These issues highlight the need for a more resilient supply chain that can better respond to national issues.

Unfortunately, the defense industrial base is not immune to these supply shortages. Although some critical, military-specific materials have preexisting stockpiles designated for the military, many raw materials are procured on the open market. Moreover, while there are specialized pipelines in place to ensure the flow of critical components, this seldom extends to the raw materials.

The forces of supply and demand have tested the resilience of the defense industrial base commodity areas as they now must share the market with other constrained commodity areas. Many defense vendors find pricing for raw materials to not only be too high but also often unreliably held for a sufficient period for them to price out contracts for the Defense Department. Raw material vendors cannot guarantee pricing because of the volatility of the customer base demand, labor shortages, and exponentially high shipping costs. This leads to the defense industry pricing in the risk that its initial cost estimates will come in higher than when it originally bid.

For example, steel, aluminum, and other metals have seen a significant amount of volatility in their market trends. Steel and aluminum are used in multiple different military applications, including aircraft carriers, military aircraft, rifles, tanks, ammunition, shipping containers, and radios. Another item that has impacted a range of military applications is computer chips. As technology evolves, computer chips are now used in almost every military vehicle in addition to many pieces of weaponry. The shortage of computer chips has slowed the production rates associated with certain missiles, including the Javelin missile.

There are further issues related to the steady deindustrialization of the defense industrial base over the past fifty years, to include workforce and manufacturing innovation. This deindustrialization was brought on by changing mission requirements associated with the end of the Cold War, the advent of high-tech and advanced digital technologies, and the rise of the People's Republic of China as a dual military and economic threat. This deindustrialization has weakened the U.S. defense industrial base and exposed it to major vulnerabilities and risks.[8] In particular, the reliance on foreign suppliers for key materials coupled with limited surge capacity poses a threat to supply chain resilience when faced with future supply shocks and operational demands.

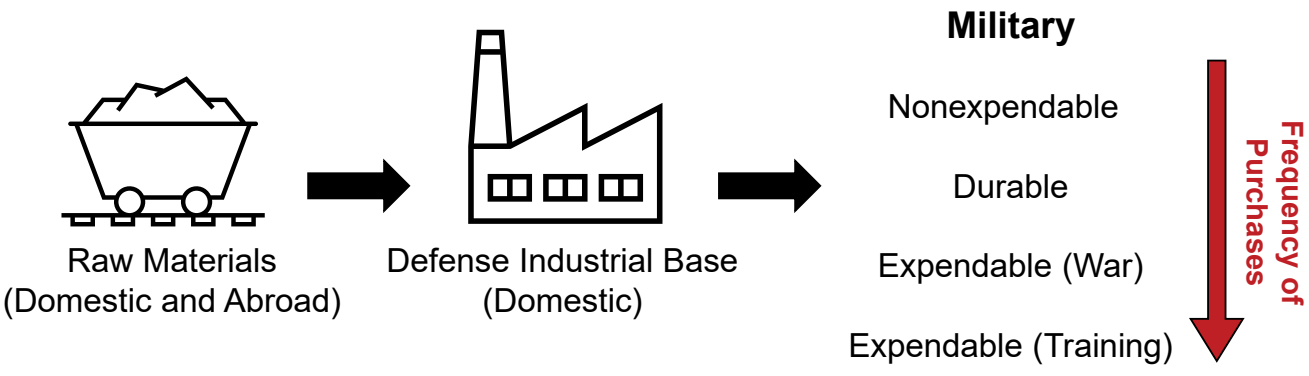
These issues are further amplified by the advances in the commercial sector. Nondefense industries have innovated new manufacturing technologies that have been integrated into their production operations. Generally, the commercial sector is moving toward "Industry 4.0," which is characterized by the integration of advanced technologies such as artificial intelligence, additive manufacturing, and advanced robotics into the manufacturing process.[9] These innovations are driven by the potential for huge sales from a global consumer market along with foreign and domestic competitors.

While some of these innovations have carried over to the defense sector, much of the defense sector still relies on traditional manufacturing processes. This is in part due to the cash flow uncertainty related to annual budgets. However, a larger issue is the general lack of competition in the defense industrial base. The defense industrial base is limited to only domestic companies with several prime defense companies dominating the field. Moreover, there is limited overlap between defense technology and commercial technology, so the companies are not able to leverage advances in the commercial sector without significant investment.

Impact of Supply Chain Issues on Military Training

The supply chain issues associated with the production of defense materiel result in soldiers unable to get the necessary materiel. Military material is typically classified as expendable, durable, and nonexpendable. Nonexpendable items are major end-items that a unit is expected to maintain proper accountability. Nonexpendable items range from vehicles to weapons to computers. Durable goods are those items that wear out in time and include uniforms and tools. Expendable items are those items that are used up consistently and include bullets and food.

As shown in figure 2 (on page 89), while supply chain challenges impact all three classes, expendable items tend to be the least resilient to perturbations in the supply chains, since they must be constantly replenished. Nonexpendable items, which can range from aircraft carriers to rifles, have significant development timelines that can absorb delays in raw materials. Most



(Figure by author)

Figure 2. Impact of Supply Chain Issues on Military Equipment

nonexpendable items are replenished infrequently, allowing corporations the time necessary to deal with supply chain shortages. To a lesser degree, most durable items tend to last on the order of years, allowing these items to have some resiliency to supply chain shortages.

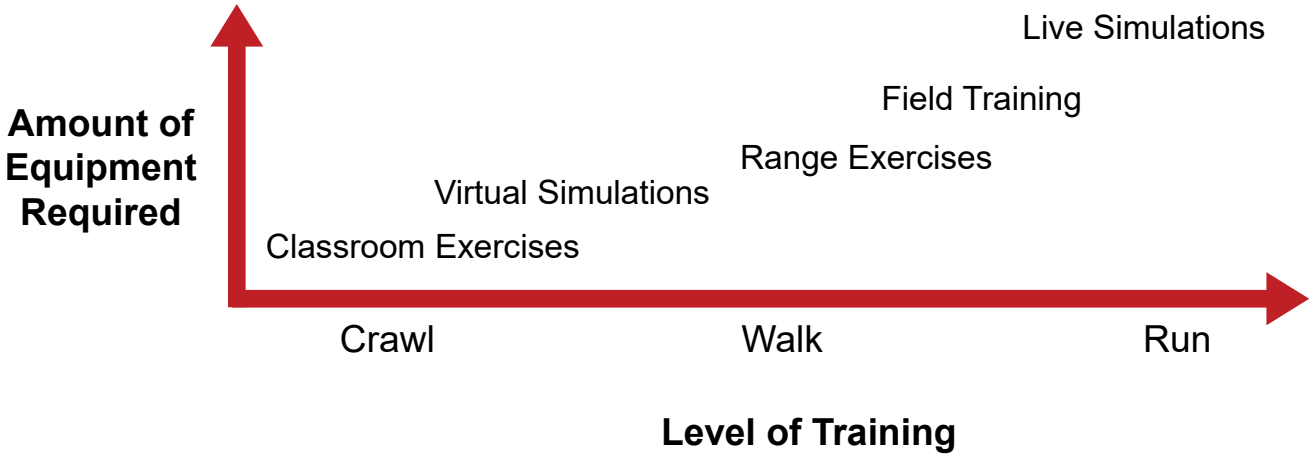
Expendable items intended specifically for combat are typically stockpiled and replaced sparingly. Meanwhile, those expendable items purposed for training are continually procured and depleted, typically on an annual basis. For example, each year, the Department of Defense establishes the total munition requirement for each service, a quantity of ammunition that constitutes the amount needed to support war reserve, operational, training, and test use cases. The demand for the purchase and usage of supplies and equipment for training is not resilient to supply chain perturbations.

As shown in figure 3 (on page 90), military units train using a crawl-walk-run structure. Initially, much of the training is classroom based and on simulators. However, as the units move into the "walk" and "run" phases, the training exercises become more real. As units move into the "run" phase, they are typically conducting live simulations, where soldiers are using real equipment in a simulated environment, such as a combat training center. For an Army unit to be considered adequately trained, it must have completed these tasks in a realistic environment as part of a live-fire exercise.[10] Such exercises require a tremendous number of resources, including a large number of training rounds, massive quantities of jet fuel, and a plentiful supply of spare parts. When units cannot get the necessary supplies and equipment, they cannot adequately conduct training to standard. While they can manage with what they have, to achieve an adequate level of readiness, a unit must train with the right equipment and supplies.

To better understand these numbers, consider the 5.56 NATO standard rounds used by soldiers across the Army. There are approximately one million soldiers on active duty, in the National Guard, and in the Army Reserve. It takes approximately one hundred rounds per soldier to qualify with their weapons, resulting in a need for one hundred million rounds per year.[11] Without this ammunition, soldiers would have to qualify on weapon simulators, which would not adequately prepare them to fire their weapons in combat. Additionally, blank rounds, which have many of the same components as standard rounds but without the projectiles, are commonly used for training exercises. During a combat training center rotation, a soldier may readily deplete hundreds of blank rounds. Without these blank rounds, soldiers would just have to yell "Bang" to simulate gunfire.

Case Study on Medium Caliber Ammunition

The ammunition community has become increasingly susceptible to significant supply chain issues. There was a reduction of over $600 million in funds allocated for the procurement ammunition, Army appropriation between fiscal years (FY) 2021 and 2022. Meanwhile, the COVID-19 pandemic resulted in increased prices of commodity metals and shipping costs. With most ammunition procured on fixed-price contracts, the risk was assumed by the defense vendor. The ammunition suppliers, at large, had to return to the government to request price adjustments to account



(Figure by author)

Figure 3. Impact of Shortage of Military Equipment on Training

for increased costs which in turn led to the Defense Department buying less ammunition than required.

Medium caliber rounds include the 20 mm rounds used by the F-15 Eagle or F-22 Raptor, 25 mm rounds used by the M2 Bradley, and the 30 mm rounds utilized by the A-10 Warthog and AH-64 Apache. Typically, most of the medium caliber ammunition produced for military applications are target practice rounds. Generally, program managers procure a stockpile of the necessary high explosive and armor piercing rounds for combat operations. The rounds have a shelf-life greater than twenty years, so the stockpiles are infrequently replenished. However, target practice rounds are used for weapon qualification and training exercises, so they must be replenished annually.

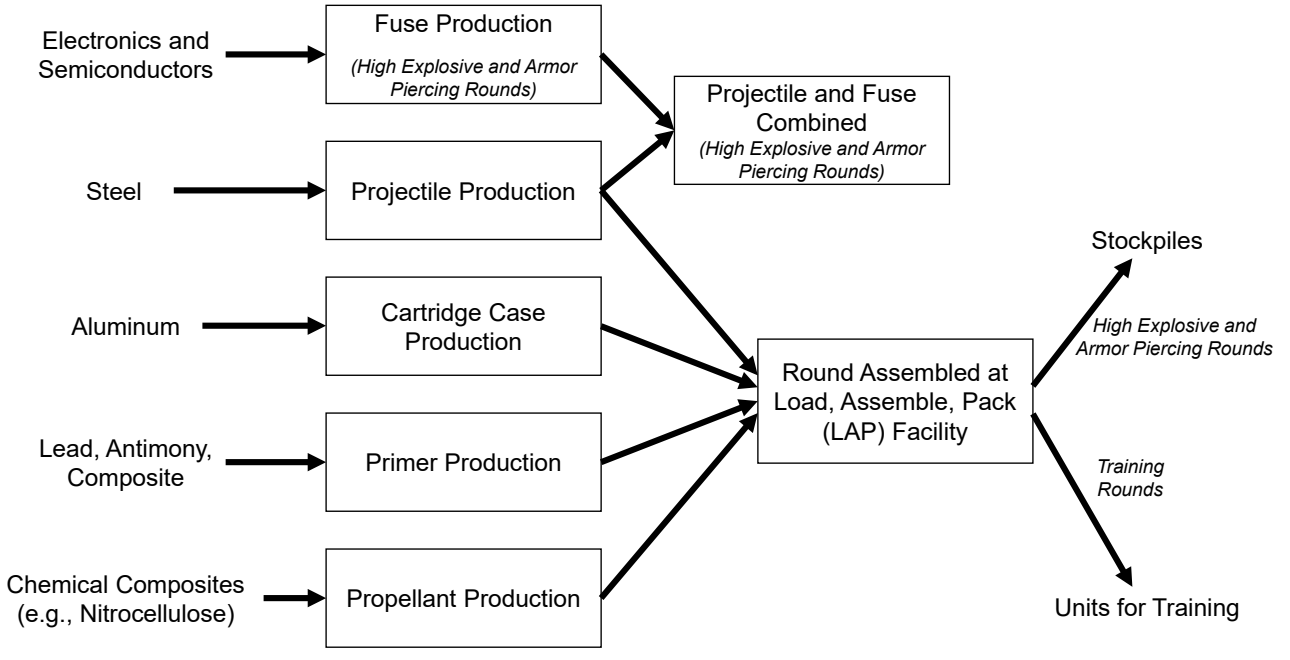


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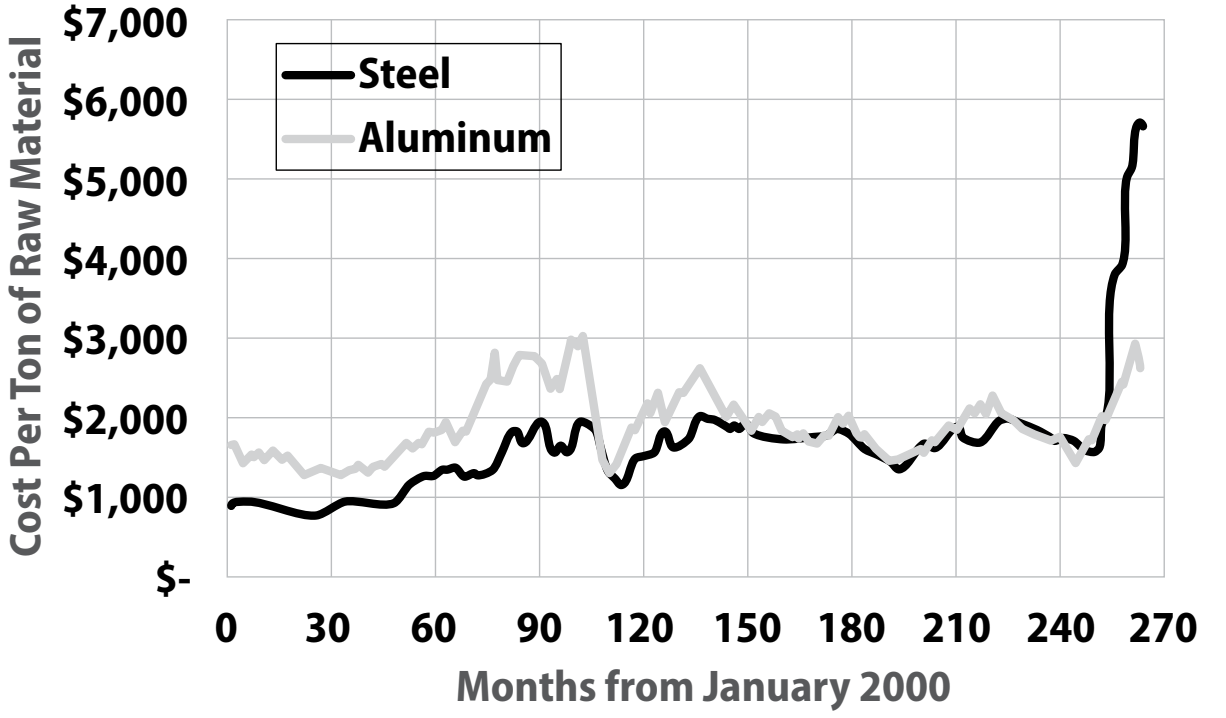
Figure 4. Assembly Process for Medium Caliber Ammunition



(Based on data from the U.S. Bureau of Labor Statistics and International Monetary Fund)

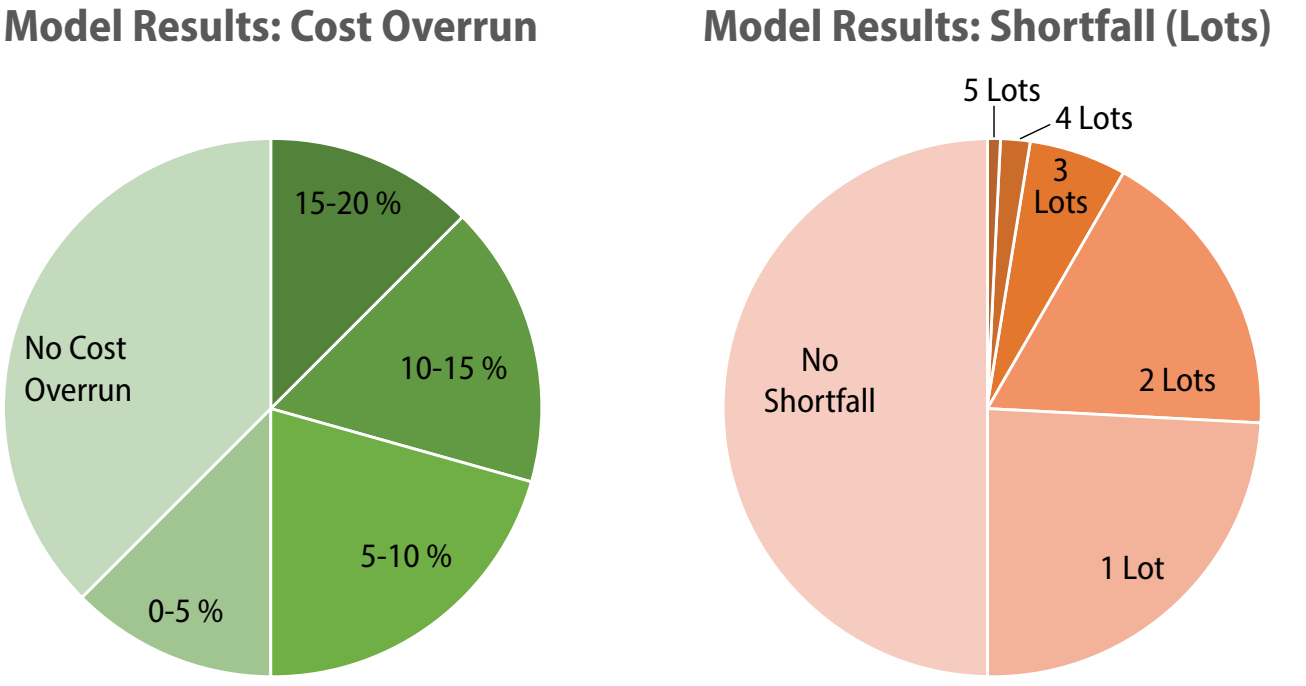
Figure 5. Steel and Aluminum Prices Over Time

Medium caliber rounds are typically comprised of five main components. First is the *primer*, which is struck by the weapon system and sparks the chemical reactions needed to begin the firing process. Second is the *propellant*, which ignites following the striking of the primer. The exothermic chemical reaction from the propellant pushes the *projectile* forward out of the weapon barrel and toward the target. All these components are held together by the *cartridge* case. The fifth component, the *fuse*, provides a primary trigger to initiate the detonation of the explosive material in the projectile. However, target practice rounds do not include a fuse. Moreover, the projectiles for target practice rounds are much simpler and are simply shaped blocks of steel.

Figure 4 (on page 90) displays the flow of materials that go into each component of the round. Some fuses require electronics and semiconductors; however, fuses are only required for high explosive and armor piercing rounds that have limited production. The raw ingredients for primers are lead, antimony, and composite material, while the propellant requires a chemical composite material such as nitrocellulose. Meanwhile, the projectiles and cartridge cases rely on steel and aluminum respectively. Note that the ammunition producers must compete with the commercial sector for procurement of steel and aluminum for their rounds.

Much of the ammunition defense industrial base is supported by government-owned, contractor-operated (GOCO) or government-owned, government-operated (GOGO) facilities. These facilities are owned by the government, but GOCOs are managed by contractors and GOGOs by government employees. Many of these GOCO or GOGO facilities have been in operation since World War II and still utilize the same tooling and production processes from that era. This has resulted in several challenges in ramping up production, as the old tooling and processes may not be as efficient or effective as modern methods. The lack of investment in updated technology and equipment has hindered the ability of these facilities to increase their output and meet the growing demands of the defense industry.

Furthermore, most ammunition is procured on a fixed-price contract. In a fixed-price contract, the supplier assumes the risks associated with producing a product or service at a predetermined price. This



(Figure by author)

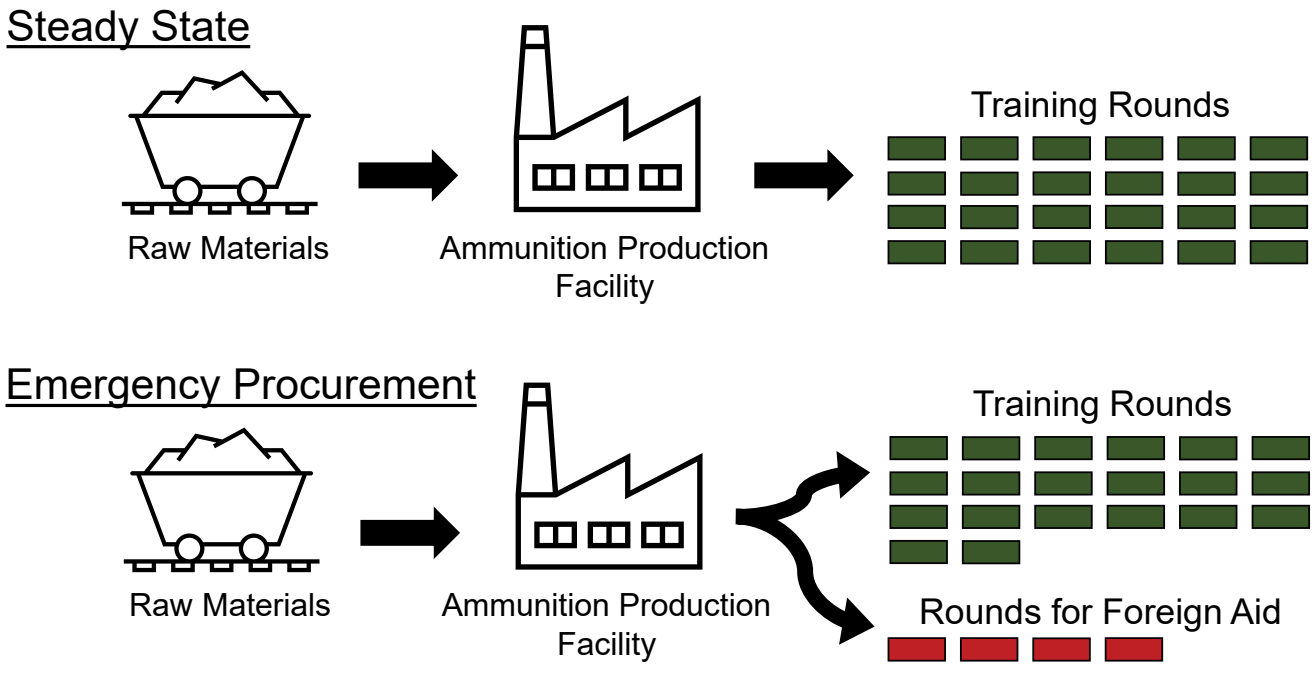
Figure 6. Simulation Results for Cost Overrun and Annual Shortfall from Simulation

means that the supplier could be responsible for any cost overruns or unexpected expenses that may occur during the production process. As a result, ammunition suppliers who operate under fixed-price contracts have a reduced incentive to invest their own funding in modernization and manufacturing innovation. This is because any investment made by the supplier to upgrade their equipment or processes will not necessarily result in a corresponding increase in the price they receive for the product. In fact, the fixed-price nature of the contract may discourage suppliers from investing in modernization and innovation as they would be assuming the risk of those investments without any guarantee of a return.

Raw material shortages impact on medium caliber rounds. Any shortages in the raw materials shown in figure 4 can result in a shortfall in the acquisition of medium caliber target practice rounds. Perhaps the most likely issue is the procurement of the steel and aluminum for the projectile and cartridge cases respectively. Figure 5 (on page 91) plots the cost of steel and aluminum since 2000. It becomes clear that there is a substantial amount of volatility in the market.[12] In particular, there was a rapid rise in the cost of steel relative to aluminum over the past year. However, even without the COVID-19 pandemic, there is still significant fluctuation in prices month to month.

The availability and cost of medium caliber rounds depend on the availability and cost of the steel and aluminum necessary for making the projectiles and casing. To analyze this relationship, a model was created in ProModel, a discrete event simulation that allows for modeling process flows and manufacturing processes. The model was set to run for one year to produce 30 mm rounds specifically for the U.S. Army for annual weapons qualification. The requirement was for one lot, containing one hundred thousand rounds, per active-duty brigade combat team and 0.25 lot per reserve brigade combat team. As such, the annual production requirement was thirty-eight lots per year.

The model was run for five hundred iterations, using random number seeds mapped to price fluctuations of steel and aluminum shown in figure 5. The results from the model are shown in figure 6 (on page 92). Of particular interest, the model indicated a 62 percent likelihood of a cost overrun on the rounds. These cost



(Figure by author)

Figure 7. Rounds That Are Sent as Part of Emergency Foreign Aid Compete with Resources Necessary for Producing Training Rounds

overruns varied from just a marginal increase all the way up to the cost 20 percent over the original price. Additionally, due to the fluctuation in price tied to the availability of aluminum and steel, 50 percent of the time the unit was not able to produce the required number of lots. In an extreme case, the production was short five lots, which would indicate that five active-duty brigade combat teams or twenty reserve brigade combat teams would not have the ammunition necessary to train. This model also does not consider the Air Force and Navy demands for the same caliber and cartridge case, which would likely result in further delays in meeting ammunition demand.

Bottlenecks in the production of medium caliber rounds. As seen in the above analysis, access to metals for casings results in a bottleneck for the casing materials for medium caliber rounds, resulting in likely cost overruns or shortfalls. Even without these issues, there are issues on the production side. The ammunition facilities are operating at a steady state with the amount of equipment and personnel necessary to provide the required number of target practice rounds per year. However, the system is not resilient to perturbations in demand.

Take for example the ammunition that has been supplied from the United States to Ukraine. U.S. defense officials state that these rounds are not drawn from its own contingency stockpiles. Therefore, they are manufactured specifically for Ukraine. Although these rounds are primarily tactical cartridges, they are produced in the same facilities as the target practice rounds with many of the same materials, including the casings, as illustrated in figure 7. The ammunition plants have not been able to produce enough to meet the demand signal while maintaining the steady production of training rounds. Given the necessity of arming Ukraine, the production of training rounds had to be cut back. Since there is not a stockpile of training rounds, there will be a shortfall that would not allow military units to practice gunnery with.

The U.S. government has appropriated millions of dollars through tranche and congressional supplemental appropriation to modernize these bottlenecks. Further, in two years, a fifteen-year industrial base modernization

plan will kick off and invest $16 billion to $18 billion from FY 2024 to FY 2038.[13] Unfortunately, these future planned efforts do little to help manage the supply chain and bottlenecks developed in producing weapons now. The lack of modern tooling and processes only exacerbates the supply chain problems and has even led to the U.S. seeking to purchase weapons from other nations to supply to Ukraine.

Conclusions and Recommendations

This article set out to explain the impact that supply chain shortages will have on military training. The constant flow of materiel necessary for realistic training is not very resilient to supply chain perturbations. A case study is also presented for medium caliber ammunition to demonstrate the impact that the global metal market and foreign military aid will have on procuring training rounds.

While many of the supply chain issues will eventually resolve themselves, the shortages associated with the COVID-19 pandemic provide an important lesson for the need for resilient supply chains for military goods, especially those related to training. Militaries and their associated defense industrial bases, as they rebuild themselves from the pandemic, should consider and address these issues. Many of these issues can be resolved by ensuring that there are persistent mechanisms for procuring the necessary raw materials. Additionally, manufacturing facilities need to be upgraded, leveraging the advances in the commercial sector. ■

Notes

1. National Defense Industrial Association, *Vital Signs 2022: The Health and Readiness of the Defense Industrial Base* (Arlington, VA: National Defense Industrial Association, March 2022), 6, https://www.ndia.org/-/media/vital-signs/2022/vital-signs_2022_final.pdf.

2. Ibid.

3. Ibid.

4. Ibid., 4, 16.

5. Mark Ashby et al., *Defense Acquisition in Russia and China* (Santa Monica, CA: RAND Corporation, 2021), vi, accessed 28 April 2023, https://www.rand.org/pubs/research_reports/RRA113-1.html.

6. Dan Steinbock, *The Challenges for America's Defense Innovation* (Washington, DC: Information Technology & Innovation Foundation, November 2014), accessed 12 April 2023, https://itif.org/publications/2014/11/21/challenges-america%E2%80%99s-defense-innovation/.

7. Thomas Baumgartner, Yogesh Malik, and Asutosh Padhi, "Reimagining Industrial Supply Chains," McKinsey, 11 August 2020, accessed 12 April 2023, https://www.mckinsey.com/industries/industrials-and-electronics/our-insights/reimagining-industrial-supply-chains.

8. David Vergun, "Critical Supply Chain Task Force Releases Recommendations," DOD News, 30 July 2021, accessed 17 April 2023, https://www.defense.gov/News/News-Stories/Article/Article/2714084/critical-supply-chain-task-force-releases-recommendations/.

9. Heiner Lasi et al., "Industry 4.0," *Business & Information Systems Engineering* 6, no. 4 (2014): 239–42, accessed 13 April 2023, https://aisel.aisnet.org/bise/vol6/iss4/5.

10. Field Manual 7-0, *Training* (Washington, DC: U.S. Government Publishing Office, 2021).

11. Training Circular 3-22.9, *Rifle and Carbine* (Washington, DC: U.S. Government Publishing Office, 2016).

12. U.S. Bureau of Labor Statistics, "Producer Price Index by Commodity: Metals and Metal Products: Cold Rolled Steel Sheet and Strip," Federal Reserve Bank of Saint Louis, accessed 12 April 2023, https://fred.stlouisfed.org/series/WPU101707.

13. Jen Judson, "US Army Document Details Plan to Update WWII-Era Ammo Plants and Depots," Defense News, 18 April 2022, accessed 12 April 2023, https://www.defensenews.com/land/2022/04/18/us-army-document-details-plan-to-update-wwii-era-ammo-plants-and-depots/.