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Identifying Potential Supply Chain Bottlenecks Within the Ammunition Manufacturing Process for the Optionally Manned Fighting Vehicle

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Abstract: The U.S. Army is developing the Optionally Manned Fighting Vehicle (OMFV) to replace the Bradley Fighting Vehicle (BFV). The OMFV is slated to replace the BFV's 25mm caliber gun with a 30mm or 50mm caliber gun. This analysis seeks to help inform the OMFV program's decision on round size by evaluating the supply chain aspects of each round. From stakeholder analysis, the primary supply chain concern is related to the casing material, with the 30 mm round using aluminum and the 50 mm round using steel. The manufacturing process for each round type was modeled in ProModel, including the supply chain issues related to steel and aluminum. The results indicated that both types of rounds are bottlenecked by steel limitations, since both rounds use steel projectiles. The study also indicated a larger variability in round cost for 50 mm rounds given the volatility of the steel market.

Keywords: Supply Chain, Medium Caliber Ammunition, OMFV

1. Introduction

The 21st Century operational environment has become extraordinarily complex for the United States Army. As a result, the Army has emphasized the need to rapidly modernize its force after decades of counterinsurgency to preserve dominance. One of the programs borne from this need was the Optionally Manned Fighting Vehicle (OMFV). Aimed at replacing the Bradley Fighting Vehicle, the OMFV development process has provided "companies with an unprecedented amount of latitude in their designs" (Mittal, 2020). The major difference between this acquisition program and those of the past lay in the fact that the Army has simply requested a list of technical requirements that the vehicle should have. One of these requirements – lethality – factors heavily into the weapon system to be utilized by the OMFV.

There exists a key consideration for companies competing for the OMFV contract: the caliber of the main weapon platform. Currently, the M2 Bradley utilizes a turreted 25mm chain gun as its primary weapon. On the OMFV, the design decision to utilize a similar 30mm medium caliber round would give the design more flexibility towards other technical requirements. However, using a larger 50mm caliber weapon would increase the range and overall lethality of the weapon, and hence that of the vehicle. Using a larger round may lead to tradeoffs in other vehicle requirements and within the supply chain itself.

Within the scope of this analysis, it was deemed essential to determine the potential impacts towards the industrial base that may occur should the client decide to utilize 30mm or 50mm ammunition on the OMFV. This study presents an overview of 30mm and 50mm ammunition with a focus on the manufacturing process. It then presents a discrete event simulation that models the supply chain issues related to the manufacturing of these rounds. The paper concludes with results that look at how supply chain uncertainty can affect the availability and cost of ammunition based on the round caliber.

2. Background

2.1 The Optionally Manned Fighting Vehicle

The Army has been in the market for a replacement to the M2 Bradley Fighting Vehicle for several years, as the platform has become increasingly obsolete in the rapidly evolving 21st Century operating environment. To address this need, the OMFV program was born. This program is nested within the Next Generation Combat Vehicle (NGCV) DoD modernization priority, which is an initiative to develop combat vehicles that effectively operate in the 21st Century battlefield with an advantage in "firepower, speed, and survivability" (Posture of the United States Army, 2021). However, initial attempts at developing a prototype, which followed a strict acquisitions process, faltered. This was due to the inability for industry to adequately fulfill a multitude of program requirements within the Army's aggressive timeline. On January 16, 2020, the program was canceled (Feickert, 2021). Despite these initial setbacks, the Army recognized that the need to replace the M2 Bradley to maintain parity on the 21st Century battlefield was essential for the warfighter. Thus, the DoD restructured its approach. Months after cancelling the project, the DoD released new criteria that gave industry an unprecedented amount of freedom towards the ultimate design of the vehicle.

One of the key measures of effectiveness for the program is lethality. In the modern battlefield, the OMFV must be able to face a range of threats – mounted or dismounted – and have the capability to achieve dominance and win. One of the key factors relating to lethality for this vehicle pertains to the caliber of the ammunition that it will shoot. The decision to utilize 30mm ammunition, or to upgrade to 50mm, is one that is currently being assessed within the different companies competing for the OMFV contract. The decision to utilize one caliber over the other influences the weapons platform that the OMFV will utilize, therefore influencing the vehicle's lethality, as observed in Figure 1. However, this decision also heavily influences the existing manufacturing base due to increased demand for ammunition.

Figure 1. OMFV Lethality Decision Factors

2.2 30mm and 50mm Caliber Munitions

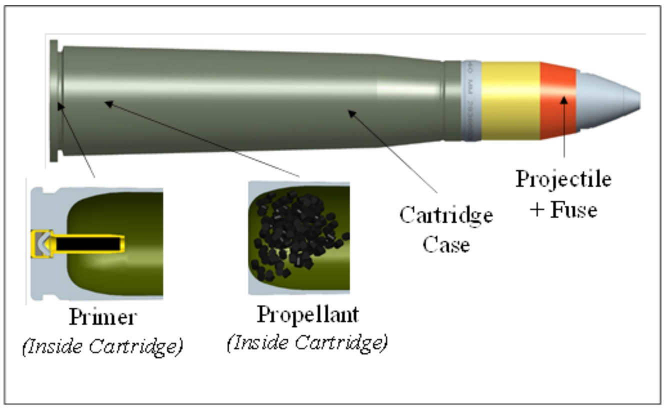
Generally, ammunition is classified by its caliber, and is grouped into three main categories. The first are small caliber rounds, used in the small arms weapons carried by soldiers such as the M4 Carbine or the AK-47. Meanwhile, medium and heavy caliber rounds are typically used in weapon mounted vehicles. There is currently a wide variety of medium and heavy caliber ammunition utilized across a multitude of platforms within the American military arsenal. The caliber of the rounds within the medium caliber program range in scale from the 20mm rounds that service the cannons of aircraft such as the F-15 Eagle or F-22 Raptor to the formidable 30mm rounds that are utilized by the A-10 Warthog or AH-64 Apache. Heavy caliber rounds are greater than 45mm in caliber and are used on numerous American ground and air vehicles as well. In discussion with the Program Manager of Medium Caliber Ammunition, it was learned that the goal of medium and heavy caliber ammunition is to damage and destroy other vehicles or buildings and are not intended to use against human targets (personal communication, 19NOV21). As such, medium and heavy caliber rounds are substantially more complicated than small caliber rounds, as these larger caliber rounds have the capability to include an explosive payload within the projectile.

Medium and heavy caliber ammunition is comprised of five main components, as shown in Figure 2. First is the primer, which is struck by the weapon system and sparks the chemical reactions needed to begin to 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 towards the target. All these components are held together by the cartridge case. The fifth component, the fuse, is only included in High Explosive (HE) and Armor Piercing (AP) rounds. In these rounds, the fuse provides a time delay for the explosive material in the projectile to detonate. However, Target Practice (TP) rounds do not include a fuse.

The main type of round produced for military applications are TP rounds (P. Santamaria, personal communication, 19NOV21). Typically, the program managers procure a stockpile of the necessary HE and AP rounds for combat operations.

They also ensure that they have access to a supply chain that can rapidly produce them in the event of a war. However, TP rounds are used for annual weapon qualification and for training exercises. As such, they must be replenished annually.

Although different in size, 30mm and 50mm rounds are comprised of many of the same components and materials. The primary difference between the 30mm and 50mm rounds are the cartridge case material. While the 30mm rounds use aluminum, the 50mm rounds use steel (Cortese, 2021). Ammunition suppliers procure the raw metals to produce the cartridge case. They also procure steel for the projectile. To complete the round, propellant, primers, cases, and projectiles are shipped from distributors across the country and are imported to a centralized Load, Assemble, Pack (LAP) facility that combines these components to form rounds. The rounds are then grouped together into lots of 100,000 rounds. The process for developing these rounds is shown in Figure 2.



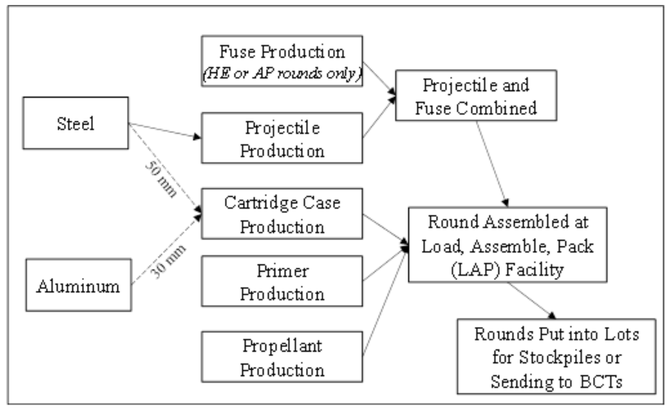


Figure 2. Components of a medium/heavy caliber rounds (left) (US Army DEVCOM – Armament Center, 2021) and medium/heavy caliber round manufacturing process (right)

3. Supply Chain Issues

3.1 Identifying Manufacturing Vulnerabilities

It is prudent to identify trends that exist regarding the current defense supply chain if one wants to determine potential vulnerabilities within the medium and heavy caliber ammunition industrial base. Currently, the aftershocks of the COVID-19 pandemic have drastically strained the financial performance of defense supply chains across the country, as manufacturers struggle to deal with extraordinarily volatile supply and demand (Vital Signs 2022: The Health and Readiness of the Defense Industrial Base, 2022). This has caused prices for many commodity goods to drastically increase, among which include the raw materials used to manufacture medium and heavy caliber ammunition.

In the same vein, the raw materials that comprise the components of each round are subject to the same volatility. Further decomposition of the vulnerabilities associated with the raw materials with each component can be found in Table 1. One can observe from the table that the projectile and cartridge case both rely on the same raw materials, especially as it pertains to the creation of TP rounds. The effects on the market of unforeseen circumstances such as the COVID-19 pandemic or a potential war can drastically influence the demand for these raw materials, such as steel or aluminum. This can subsequently influence their costs and availability, which has a direct effect on the number of rounds produced and cost per round. The stakeholders indicated that the primer and propellant supply chains are robust and are unlikely to undergo any shortages. This is because there are not competing with other industries vying for these components. These components are specialized for this usage, so they can be assumed to be available.

Table 1. Components Vulnerability Analysis

Components	*Raw Materials*	*Potential Vulnerability*
Primer	Lead, Antimony, Composite (Ellis, 2007)	None
Projectile	Steel	Steel market is very volatile with large cost fluctuations (U.S. Bureau of Labor Statistics, 2022).
Cartridge Case	Steel (50mm) Aluminum (30mm)	Although, both steel and aluminum markets are volatile, cost fluctuations and availability for aluminum is less than steel (International Monetary Fund, 2022).
Propellant	Chemical Composites (e.g., Nitrocellulose)	None

3.2 Raw Material Shortages

The COVID-19 pandemic and its effects on the supply chain for different commodity goods have had repercussions for a multitude of industries, among which include ammunition. The availabilities of steel and aluminum as a function of cost were gathered using monthly historical data of the Producer Price Index (PPI) for each raw material from 2000 to the present. By plotting the prices of the two raw materials over time, one can observe one significant trend. The volatility between steel and aluminum are almost identical up for a long period of time. Despite the relative differences in the cost per ton between steel and aluminum, when there was a price increase in one raw material, there was a similar movement in the market price of the other one.

Per Figure 3, despite the relative similarity between both price and volatility between steel and aluminum, it is evident that within the last few months alone that the price of steel has skyrocketed relative to the price of aluminum. This can be attributed to the drastic supply chain shortages caused by the COVID-19 pandemic, which struggled to meet increased demands from various markets. The surge in cost for raw materials will lead to subsequent increases in total cost for the purchase of lots of medium or heavy caliber ammunition.

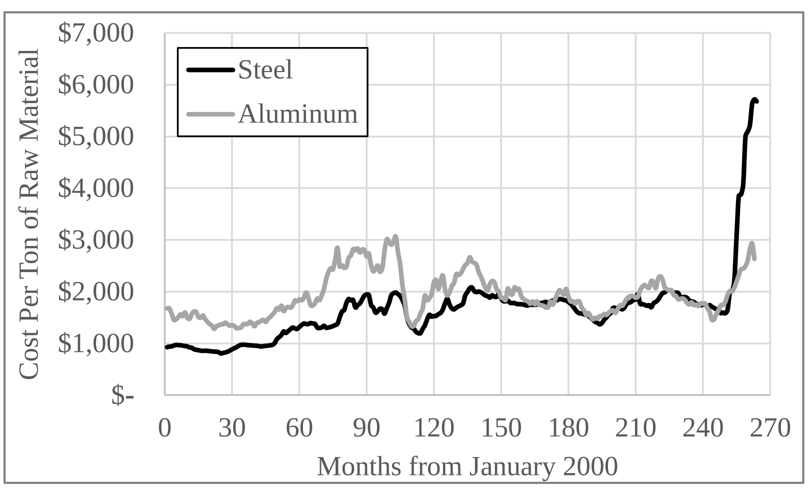


Figure 3. Steel and aluminum prices over time based on data from (U.S. Bureau of Labor Statistics and International Monetary Fund, 2022).

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4. Methodology and Model

The availability and cost of 30mm and 50mm caliber rounds for the OMFV depends 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 within the software *ProModel*. This software allows for the simulation of discrete events to help improve "existing manufacturing, logistics, and operational systems," thereby making it an ideal candidate to assess the overall efficacy of the medium and heavy caliber ammunition manufacturing process (*ProModel - Better Decisions Faster*, n.d.). It provides the ability to fully ascertain the complexity of the supply chain through simulation.

Using an input file from Excel, which can be readily reviewed and updated by stakeholders, it was possible to numerate different aspects of the process to then be analyzed in concert. As shown in Figure 4, this input file would then feed into the model itself using a slate of editable parameters. The input parameters for the model can be referenced in Table 2. The large number of parameters allows for greater nuance in capturing the complexities of the medium/heavy caliber ammunition industrial base. The numbers for each parameter were assessed based off research of current production processes for medium caliber ammunition, then confirmed by subject matter experts on ammunition manufacturing. It was necessary to make assumptions towards other key input variables to ensure an accurate simulation was conducted in the forms of a viable QAQC rate, the component assembly times, and raw material pricing and availability.

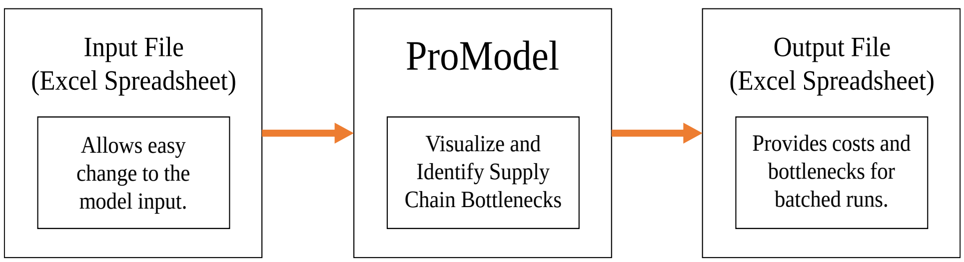

Figure 4. Model Architecture

Table 2. Current Input File Parameters for Model Simulation

Input Parameter	***Value***
Number of Vendors	Dependent on the Component and Stakeholder Analysis
Stock on Hand	Function of the Total Rounds Produced
Lot Size	Function of the Stock on Hand divided by the Number of Vendors
Lot Frequency (Days)	20
Scrap Percentage	0.0 to 0.5 (Dependent on the Component)
Assembly Time (Parts/Day)	Total Rounds Produced divided by the Workdays per Year
Pass Rates	Assigned based off Stakeholder Analysis
Actual Lot Size	100,000 Rounds
Lot Size for Model	1,000 Rounds
BCT (Active and Reserve)	Accounts for the number of active and reserve Brigade Combat Teams in the Army and the number of lots of ammunition they would use.
Total Rounds	Function of the number of different brigades multiplied by the lot size
Workdays per Year	Assumed to be 240 days
Resolution	100 rounds/unit

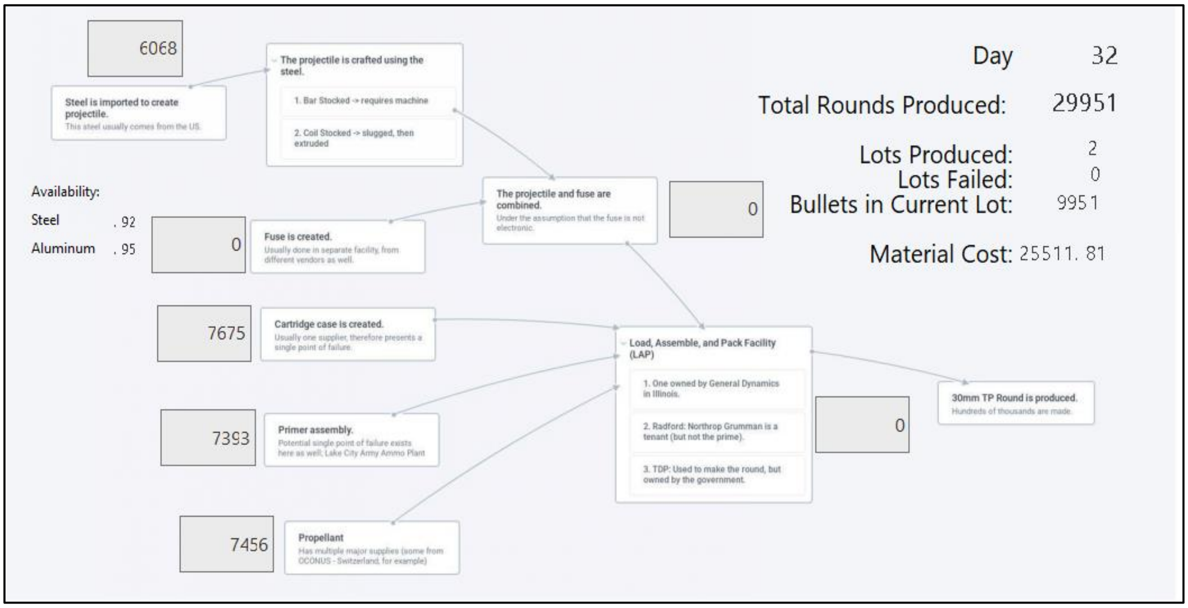

Figure 5. Screenshot of the Medium and Heavy Caliber Ammunition Industrial Base Model in ProModel

Figure 5 provides a screenshot of the model. The model consists of two primary assembly areas. The first area handles the assembly of the projectile and fuse. Note that this assembly stage was included in the model for modeling non-TP rounds, since TP rounds do not have fuses, so this step can be skipped. The second area is the LAP, which packages the rounds together. The LAP pulls cases, projectiles, propellant, and primer from different stockpiles. The stockpiles are replenished each month based on the availability of raw materials.

The model uses a random number generator to select a month from Figure 3 to start running, such that the cost and availability of steel and aluminum replicates the real-world patterns. Additionally, the model uses a series of random numbers for accounting for rounds and lots passing quality assurance. As such, the model is stochastic and must be run many times to account for this variability. Following a batch run, ProModel outputs an Excel file that provides the total number of rounds and lots produced along with the cost.

5. Analysis and Results

Since the model is stochastic, it must be run multiple times to capture the range of possible results. A desired relative precision of 5 percent requires at least 420 runs. As such, the model was set to batch run for 500 iterations for both 30 mm and 50 mm rounds. Upon completion of this simulation, there were four primary outputs from the model for each ammunition caliber: the total number of rounds produced, the number of failed lots, the overall material cost, and the cost per lot. Table 3 contains descriptive statistics of 30mm rounds, and Table 4 contains that of 50mm rounds upon completion of the simulation.

Table 3. Descriptive Statistics of 30mm Rounds (Aluminum)

Descriptive Statistics	**30mm Rounds**					
	Starting Month	**# of Rounds**	**# of Lots**	**# Failed Lots**	**Material Cost**	**Cost per Lot**
Average	123.4	6,005,089	58.5	1.1	$6,057,173.5	$103,587.85
Standard Deviation	59.8	91,707	1.4	1.0	$922,144.30	$15,786.28
Minimum	24	5,818,700	54	0	$3,678,228.48	$62,803.81
Maximum	224	6,157,000	61	5	$7,274,237.74	$129,527.40

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Table 4. Descriptive Statistics of 50mm Rounds (Steel)

Descriptive Statistics	50mm Rounds					
	Starting Month	# of Rounds	# of Lots	# Failed Lots	Material Cost	Cost per Lot
Average	123.4	6,005,089	58.5	1.1	$5,653,246.40	$96,610.51
Standard Deviation	59.8	91,707	1.4	1.0	$944,681.0	$16,578.60
Minimum	24	5,818,700	54	0	$3,237,536.30	$53,958.94
Maximum	224	6,157,000	61	5	$6,865,250.46	$120,656.67

One can observe from these tables two key takeaways. First, from a descriptive statistic standpoint, most of the data remains similar regarding each parameter's average, standard deviation, minimum, and maximum. This is because of the comparable price of both steel and aluminum over time and that the same random number seeds were used for both sets of runs. Furthermore, both round types required steel for the projectile and supply chain shortages of steel served as the primary bottleneck in the model.

The second key takeaway is that it is noticeable that 30mm round's cost is greater than that of 50mm round's cost due to the higher cost of aluminum. However, it has considerably lower standard deviation. This is due to the skyrocketing price of steel in recent times due to COVID-19.

The cost per lot provides additional insight as it gives an indication of the amount of money a stakeholder would need to pay per 100,000 rounds of ammunition. A comparison of results for this parameter can be referenced from the box plot in Figure 6. From this, we can observe that – on average – the cost per lot for 30mm ammunition is greater than that of 50mm. This indicates that 30mm ammunition would be more expensive for both the stakeholder and the Army, were they to use that caliber of ammunition on the OMFV. However, the range of values is smaller for 30mm rounds than the 50mm rounds due to the difference in volatility between the steel and aluminum markets.

These trends were further reinforced after conducting a t-test between the cost per lot for 30mm and 50mm ammunition. After this analysis, it was found that the standard deviation for 30mm was $15,786.28, whereas it was $16,578.60 for 50mm. The p-value for the two-tailed t-test was 1.63×10^{-11}, indicating statistical significance between the two costs per lot. This variation in price can create issues with budget allocations and procurement contracts, so it should also be considered in deciding the round size for the OMFV.

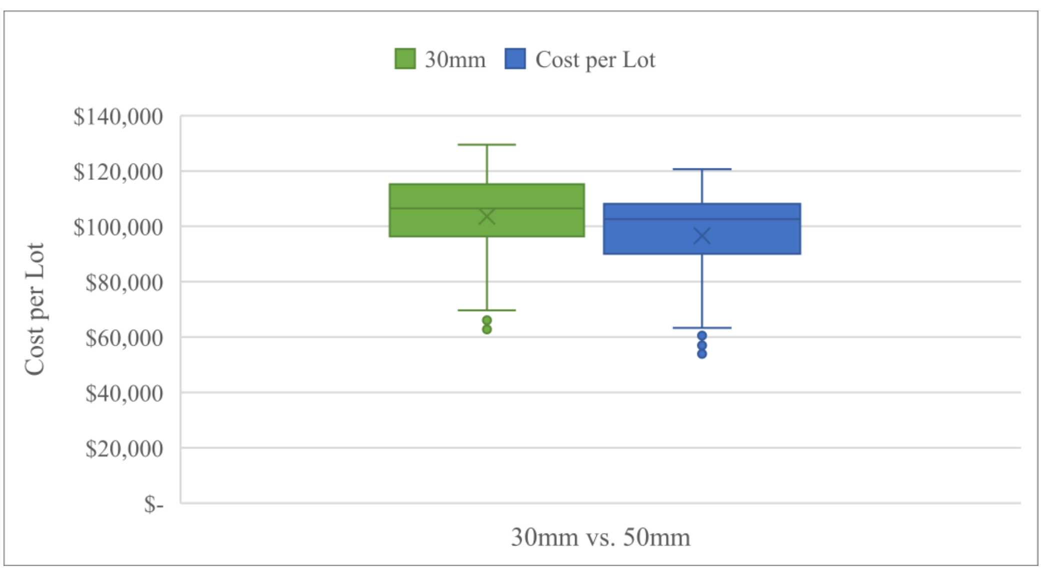

Figure 6. 30mm vs. 50mm Ammunition Cost per Lot

6. Conclusions

Steel and aluminum prices have been on par for a long period, and fluctuations in prices for one material have often led to similar shifts in the other. However, because of extraordinary volatility in recent years, due in part to COVID-19's impacts on the supply chain, the price of steel has skyrocketed compared to that of aluminum. This should be a consideration for key stakeholders as they decide whether to implement a 30mm or 50mm cannon for use on the OMFV. The decision to use a 50mm cannon, which uses steel as its primary base material, would significantly increase its lethality. This is essential in the modern, near-peer fights which the United States may find itself in during the 21st Century. However, as observed from the simulation ran in ProModel, a decision to use steel would lead to more volatile prices. While steel may be cheaper than that of aluminum, the increased volatility may lead stakeholders to paying more over time than that of a less volatile material. This stands in contrast to aluminum in the 30mm round. While more expensive, the material is subject to less volatility than that of steel. However, it is also less lethal than that of 50mm. Ultimately, the decision lay with the values found important to the stakeholder: is it prudent to minimize costs at the price of lethality, or is lethality the ultimate factor of consideration for the new OMFV, at greater expense to the taxpayer?

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