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Evaluating Different Power Solutions for Medium Caliber, Counter-Drone Rounds

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Author Note: The views expressed herein are those of the authors and do not reflect the position of the United States Military Academy, the Department of the Army, or the Department of Defense.

Abstract: Drones are a growing part of the battlefield; they are becoming easier to produce and have growing capabilities that make them dangerous. There are many different ways to counter drones and a new medium caliber round may prove to be the best solution. The biggest issue in building this round is finding a power source that is cost-effective while also meeting stakeholder requirements. This study seeks to solve this issue by using a value modeling approach that scores each power source alternative based on metrics that are key to the stakeholder. The first step was to research power source alternatives that met stakeholder requirements. Each alternative was then given a value score based on their respective characteristics. The next step was to create a value versus cost trade space analysis, which provides insight into the tradeoff between value and cost. The analysis shows four feasible alternatives with low costs, and one alternative with a significantly higher cost and value.

Keywords: Counter-Drone Technology, Value Modeling, Medium Caliber Ammunition.

1. Introduction

Drones have become common in today's world and are a growing problem on the battlefield. Enemies are weaponizing drones on the battlefield, posing new threats to friendly forces, who need an immediate solution to counter these threats. The
U.S. Army is currently developing effective ways to counter drones. While there are electromagnetic and laser options, the best near-term counter-drone solution is a 30mm, medium caliber round with advanced capabilities (Vincent, Mittal, & Morales, 2021). Currently, the supply chain for these rounds is limited by the availability of the power source required to power its electronics. The power source is very specialized to meet the long shelf-life needs of the round; this requirement results in a manual assembly process that is time consuming and expensive.

This study seeks to evaluate alternatives for this power source that could potentially alleviate the supply chain bottleneck. These alternatives are evaluated using a value modeling approach which scores each power system alternative based on metrics that are key to the stakeholders. This paper presents an overview of the problem, the value model, a set of alternatives, and a trade-space analysis for these alternatives.

2. Problem Definition

Drones are increasingly available at a low cost and are easily weaponized. In the article *Defending U.S. Forces Against Enemy Drones*, Steven Aftergood states "Enemy use of unmanned aerial systems (UAS) is a growing threat to U.S. forces because of their low cost, versatility, and ease of use, according to a recent U.S. Army doctrinal publication" (2016). In the past, drones were mainly used for surveillance; however, they are now taking on a more deadly role on the battlefield. As drone technology advances, drone defense technology needs to advance just as rapidly. There are kinetic and non-kinetic ways to combat drones, with non-kinetic means relying on jamming, hacking, or directed energy. While non-kinetic options are useful, drones have increasingly better defenses against these systems. On the other hand, a drone has little defensive capabilities against a kinetic system like a 30mm round that can destroy it with a single shot. This growing problem is outlined in Figure 1.

Within the range of kinetic counter-drone technology, the Army is exploring the use of existing weapon systems, such as a 30mm chain gun, to be repurposed for counter-drone applications (Peri, 2015). Medium caliber munitions have emerged as a frontrunner for a kinetic counter-drone solution. In particular, the 30x113mm round was fielded “to provide lethality while not increasing vehicle weight significantly” (Tani & Amoroso, 2021).

Though medium caliber ammunition could be effective for dealing with drones, there are many risks still associated with it. For example, any fired projectile can miss its target, and land beyond its desired location. Alternatively, the drone could be programmed to detect incoming rounds and take evasive actions. To limit these risks, advanced counter-drone rounds can include tracking systems, proximity detonation, or self-destruct features. For these rounds to have these functions, it requires an energy source to power the necessary electronics. However, these rounds also have a required shelf life of 20 years. With the need for such a long shelf life, a liquid reserve battery seems to be the only viable energy source currently for the rounds production.

The liquid electrolytes in the liquid reserve batteries are isolated until the cell is activated. As a result, the batteries can lay dormant for multiple years and still maintain full functionality. This, along with their ability to withstand extreme temperatures, has resulted in liquid reserve batteries being the primary power source for munitions (Jacobs, 2018). However, the current liquid reserve battery for 30x113mm rounds has supply chain issues and is costly. The issues in the supply chain are due to the complex manufacturing process of these liquid reserve batteries, which requires significant assembly work to be done by hand, hence driving up the cost.

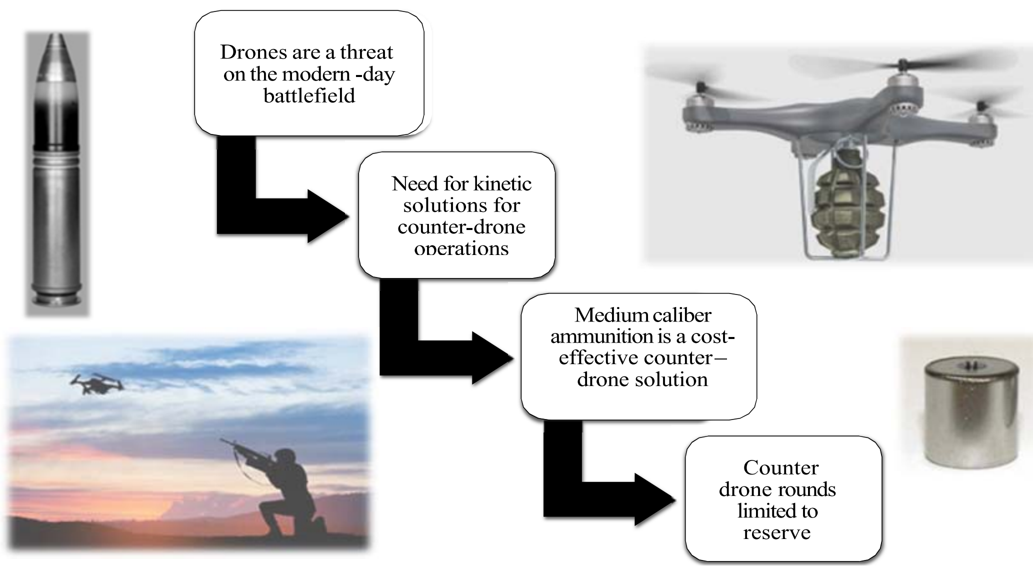

Figure 1. Overview of the problem and its possible solutions/bottlenecks

3. Methodology

The methodology used in this analysis is outlined in Figure 2. The overall focus of this study is to evaluate alternate power sources for counter-drone medium caliber rounds, due to cost and availability issues with the current liquid reserve battery. The first step involved conducting a stakeholder analysis to determine which specifications of the power sources were most important in powering the round, and which variables had the most positive impact on production logistics. The primary stakeholder was the Office of the Project Manager for Maneuver Ammunition Systems (PMMAS), who defined the scope and goals of the research. The key issues were identified as finding a cost-effective power source that could produce substantially more quantities per month to increase ammunition production.

The study then identified feasible options by conducting a market survey, which explored a variety of power sources such as liquid reserve batteries, primary cells, active cells, and coin cells. Each alternative was evaluated based on its ability to meet voltage and current criteria and stacked in series or parallel if necessary. For feasible alternatives, raw data was collected for each value measure, which was used later to determine a total value score using a value model based on the stakeholder analysis. These value scores were then plotted on a value vs. cost curve, which provided a visual representation of how the alternatives compared to each other.

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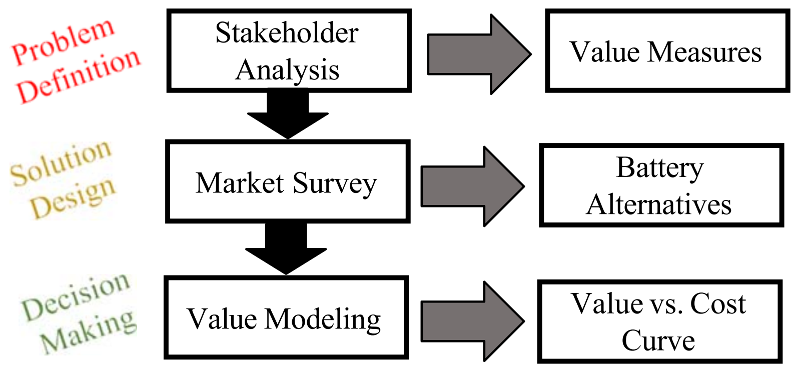

Figure 2. Methodology followed for this analysis.

4. Value Model

Stakeholder analysis was conducted to discover the necessary variables of power sources to find the best possible alternative. The eight identified variables, termed as value measures, are shown in Table 1. First, shelf life is important because it needs to last at least a decade before the round may be used but ideally last 20 years. The diameter and length are based off the current power source, but it must fall within the round dimensions to meet the requirement. It must be able to maintain functionality in the coldest temperatures because power sources tend to operate the worst in the cold. The power source must have the required voltage and minimum current to give the round smart capabilities in flight and reach these values quickly after being shot from the weapon system. The power source must also be produced in large quantities each month to be bought by the Army, ideally around 15,000 batteries per month for the duration of the ammunition testing and production.

Using the requirements for each of the value measures, value functions are created to give uniform quantifiable values to each input of raw data. The value function for the project is a linear equation derived for each measure, validated by the stakeholders, connecting the maximum and minimum raw data values, and relating the raw data to value scores (Parnell, Driscoll, & Henderson, 2001). The value scores for voltage and current are either 0 or 100 because the round will not function if the power source does not meet the required volts or amps. For the other value measures, linear equations connect the raw data to value scores. For example, the zero-value point for shelf life is 10 years and the 100-value point is 20 years. Using the maximum and minimum, the equation is created, $yy = 10xx - 100$, where yy equals the value and xx equals the raw data. For each alternative, the data was inputted for xx to find the value, and this same process is used for the rest of the value measures.

Table 1. Table showing each of the value measures, their maximum and minimum data points, and their associated swing weights in rank order.

Value Measures	Zero Value	Maximum Value	Swing Weight
Shelf Life	10 years	20 years	100
Availability	1,000 qty/month	15,000 qty/month	65
Diameter	30 mm	6.985 mm	50
Length	11.3 mm	8.255 mm	50
Temperature	-28 C	-53 C	50
Voltage	$\neq$ 3.6 V	3.6 V	25
Current	< 20 mA	20 mA	25

After identifying the value measures, swing weights were added. The swing weights seen in Table 1 are used to show which value measures are more important than others to give a greater contribution to the total value of each alternative (Parnell, Driscoll, & Henderson, 2001). Shelf life has the highest swing weight with a value of 100. Shelf life is weighted highly because the army has certain requirements on how long a round can be stored and if the battery cannot last in the round, then it will be useless. Availability is the next most important with a value of 65 because one of the problems currently is acquiring enough batteries due to supply chain issues. Then, diameter, length, and temperature have swing weights of 50, as it is important that the power source fits in the round and operates in the elements, but it is not the main problem. Since the round is still in its early stages, the packaging for the battery could be changed if the right alternative was found. Lastly, voltage and current have a swing weight of 25 because they have specific requirements for the round to function, and alternatives that do not meet this requirement are thrown out early in the research process. The value model provides a score that allows for a quantitative comparison between the alternatives.

5. Power Source Alternatives

The value measures discussed in the previous section were used to give each power source alternative a value score. Table 2 displays the list of power source alternatives for use in medium caliber counter-drone round, including the battery type and usage. It is worth noting that some of these alternatives are commonly used for military application, while others are not. This must be taken into consideration during the decision-making process, as some alternatives have been tested more thoroughly than others.

Alternatives 1 and 2 are liquid reserve batteries. These batteries separate the active chemicals of the cell until they are needed, which in this case is when the round is fired. The separation of these chemicals significantly increases the shelf life (Jacobs, 2018). One of the most common types of liquid reserve batteries is a lithium thionyl chloride (Li-SoCl2) battery. For this cell, thionyl chloride acts as both the electrolyte solvent, and the cathode material, with the electrolyte commonly being lithium tetra chloroaluminate (Lithium Thionyl Chloride Cell, 2023). As seen in Table 2, liquid reserve batteries tend to be used for military purposes. The two batteries are similar in type (i.e., liquid reserve) and chemistry, with the only major difference being the manufacturer of the batteries.

Alternatives 4, 5, and 6 are button cells. Button cells are small, single cell batteries that take on the shape of a small cylinder, like a button. Common anode materials for button cells are zinc or lithium, with common cathodes being manganese dioxide, silver oxide, and others (Galligan & Morose, 2004). Devices that utilize button cells typically require a long service life. For this reason, it has been considered for the counter-drone medium caliber round. However, it is important to note that button cells are not often used militarily, as they are typically limited to small electronics such as watches and thermometers.

Table 2. Table of each power source alternative, to include its current uses, value score, and cost per unit.

Alt	Type of Battery	Chemistry	Uses	Value Score	Unit Cost
1	Liquid Reserve	Lithium Thionyl Chloride	Medium Caliber Munitions, Guided Projectiles	82.18	$180
2	Liquid Reserve	Lithium Thionyl Chloride	Sub-munitions (MLRS, etc.)	81.76	$200
3	Primary Cell	Lithium Wafer	Utility Meters, Tracking Sensors	66.24	$3
4	Button Cell	Nickel Cadmium	Rail & General Transit, Telecom Backup Power	47.18	$0.26
5	Button Cell	Alkaline	Laser Sights, Watches, Clocks	44.55	$1.50
6	Button Cell	Silver-Oxide	Small Electronics, Calculators, Thermometers	51.94	$2
7	Primary Cell	Lithium Thionyl Chloride	Aerospace & Vehicle Industry	68.03	$5

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Alternatives 3 and 7 are primary cells. Primary cells are small, light, and non-rechargeable, meaning that they are to be discarded after use (University of Washington, 2021). Both alternatives 3 and 7 use a lithium thionyl chloride chemical system. Most notably, these alternatives have a high value score and relatively low unit cost. Although these alternatives have high value scores, they have never been used for military applications. As a result, more in-depth testing with these battery types may be needed to ensure proper functionality.

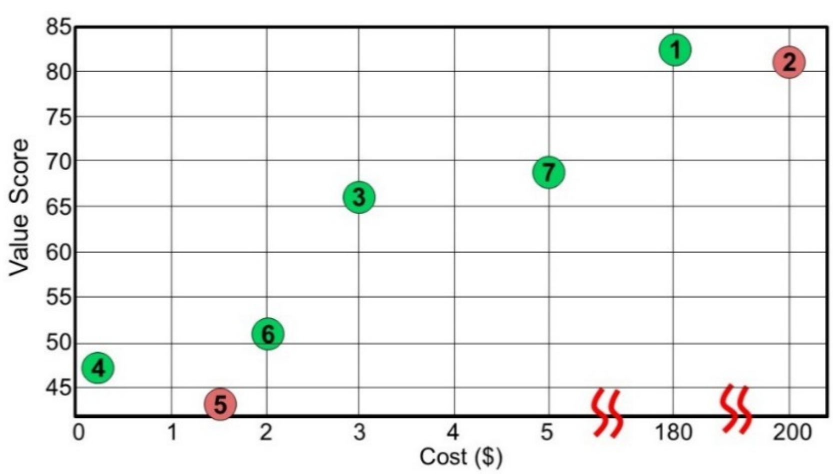
Several technologies were not considered for this analysis. One of these alternatives was a setback generator. While a setback generator could be used to power a round, they are typically made custom to specific projects. As a result, they are expensive and have limited availability. Another considered alternative was a radioactive isotope battery. A radioactive isotope battery uses decay from a radioactive isotope to generate electricity. This type of battery is not only expensive but is also not commonly used to power medium-caliber ammunition. As a result, it was not considered for this analysis. Additionally, rechargeable batteries were not considered for this analysis due to their short shelf-life and relative volatility.

6. Analysis and Results

For the analysis, it is critical to include the cost of each battery because the stakeholder wants to find the cheapest alternative. After compiling the value scores for each alternative, they were plotted against their respective costs, as shown in Figure 3. The value vs. cost curve shows that two of the alternatives are dominated. A dominated alternative is one that produces a lower value score while having a higher cost than another alternative. For the liquid reserve alternatives considered in this study, Alternative 1 dominates Alternative 2. It is important to note that Alternative 1 is the battery power source currently used. Alternative 5, the alkaline button cell, is dominated by Alternative 4, the nickel-cadmium button cell.

There are tradeoffs between the value scores and prices of alternatives, which can be attributed to differences in technology. Better technology can result in higher value scores but also in higher costs. Additionally, there are tradeoffs between the size and performance of batteries, with larger batteries often performing better but not fitting in the current system or the round. Cheaper batteries may have a shorter shelf life, which does not meet stakeholder requirements. Ultimately, the stakeholders will need to consider the tradeoffs between the battery performance, especially shelf life, and the cost.

The study found that the current system is expensive and can only be made in small batches, which greatly affects the availability of the round. While the study considered another liquid reserve batteries, it was outperformed in the value model by the current alternative which has a better size and shelf life. Many of the active cell batteries have reasonable value scores, but they have a decreased shelf life, typically in the range of ten years. This shorter shelf-life violates a current acquisition regulation for rounds, which are required to have a twenty-year shelf-life. However, the specific application of these rounds for counter-drone purposes could justify a shorter shelf-life. Militarized drone technology is a rapidly evolving field which will likely be significantly different in ten years. As such, current counter-drone rounds would likely be obsolete well before the twenty-year shelf-life.



#	Type of Battery
1	Liquid Reserve (Currently Used)
2	Liquid Reserve
3	Lithium Wafer-Based Primary Cell
4	Nickel-Cadmium Button Cell
5	Alkaline Button Cell
6	Silver-Oxide Button Cell
7	Lithium-Based Primary Cell

Figure 3. Value vs. Cost curve.

It is important to note that these value scores are based solely on the value measures shown in Table 1. However, since all of the alternatives are different sizes, they will require modifying the layout of the round to accommodate the power source. As such, the solutions with higher value scores may not be feasible given other constraints in the round design. Additionally, modifying the round's internal configurations could potentially increase cost or introduce bottlenecks, which would be counterproductive to the goals of this study. Future work will consider these implications of changing the power sources.

7. Conclusion

Drones and counter-drone technology are currently playing a critical role on the battlefield. As such, the U.S. Army needs to develop a counter-drone solution. The frontrunner is a 30mm round that includes advanced electronics to allow for tracking, proximity detonation, and self-destruction. However, these rounds are currently limited by the availability of the thermal batteries that power them. This paper presented a value model that analyzed different alternatives to the current thermal batteries. This study included other liquid reserve batteries, button cells, and primary cells. These alternatives were evaluated in terms of their shelf life, cost, availability, size, minimum operating temperature, voltage, and current. The study identified that the current solution has the highest value but also has the largest cost which could create issues acquiring the power sources from the manufacturer. The primary cell power sources have significantly better availability and a decreased cost, while also able to provide comparable voltages and currents as the current systems. However, the primary cell systems do have a reduced shelf-life, which can be justified by the specific application of these rounds. The twenty-year shelf life achieved by the current rounds may not be necessary given the rapidly evolving field of drones.

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