Impact of Ammunition Performance On Weapon Reliability & Life Cycle Cost

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SUMMARY & CONCLUSIONS

Since all weapons and ammunitions operate as one system, the reliability of one affects the reliability of the entire system. Deficiencies in new ammunition design and development can severely reduce a weapon’s reliability by shortening weapon part life or decreasing the Mean Rounds Between Stoppages (MRBS).

The reliability of a system is directly related to the life cycle cost of a system. A highly reliable system requires less maintenance and less spare parts. Sustainment cost would be reduced with less need for maintenance action and less spare parts. Since historically, sustainment cost constitutes more than 50% of the life cycle cost of any system, changes in the sustainment cost affect the life cycle cost. The amount of increase in the overall life cycle cost can help determine whether the cost is beneficial to pursue further failure analysis and corrective action implementation.

Aside from cost, other factors affect the decision to perform further fixes on a system to increase reliability. A highly reliable system also increases soldier moral and soldier safety, increases the mission success rate and possibly shortens the mission completion time.

A new ammunition that causes shortened barrel and bolt life, decreased reliability and increased sustainment cost of its host weapon system may be acceptable depending on other benefits this new ammunition may provide. A thorough reliability and life cycle cost analysis can help determine the advantages and disadvantages of a new ammunition from a statistical perspective.

1 INTRODUCTION

Most, if not all, products nowadays can be considered to be a complex system composed of numerous subcomponent assemblies. Each subcomponent assembly contains its own subcomponents. More likely than not, each of these subcomponent assemblies is developed and produced separately. The assembly of the final product occurs after all the subcomponents are tested and packaged. As a result, the reliability of the final product is not only dependent on the reliability of each of its subcomponents but also on the reliability of the interface between these subcomponents. In the small arms branch of the Department of The Army, complex systems, such as weapon and ammunition, go through many iterations of advanced research and development. Each iteration may only address one subcomponent of the entire system. Therefore, interface problems needs to be addressed early in the development phase through cycles of test-fix-test.

For the purpose of this paper, the top level system includes the weapon, ammunition and necessary belt/magazine. The subcomponent assemblies are the weapon subassembly, ammunition subassembly and belt/magazine subassembly.

Weapons and ammunitions have always been developed, tested and manufactured as separate programs within the Department of The Army. However, since weapons and ammunitions cannot function as intended independently, the reliability of weapons and ammunitions is not mutually exclusive. This dependency results in the reliability of one to affect the reliability of the other, either positively or negatively. Newly developed ammunition should not only meet its own reliability requirement while firing from its intended host weapon(s) but it should also not degrade the reliability of the host weapon(s). Even ammunition with a high demonstrated reliability may reduce the reliability of its host weapon(s) by causing more part failures, more weapon-related stoppages, more frequent unscheduled cleaning/maintenance, more jamming, more failure to eject, etc.

The reliability of ammunitions, like any other program, should be designed into the program from its initial concept drawings and tested throughout the research and production process, prior to reaching full up system government development test to demonstrate a reliability requirement. The initial test of new ammunition should be able to characterize the affect of the ammunition on the reliability of the weapon(s). Historical data may be leveraged for test planning. Failure trend analysis of both the ammunition and the host weapon(s), combined with historical knowledge, can lead to a quantitative analysis of the degree of reliability degradation of the weapon(s) as a result of firing the new ammunition. Life cycle cost can then be generated based on known supply and maintenance costs.

2 TEST PLANNING

Planning a test for new ammunition requires deliberate control of test conditions and variables such that the data collected can be analyzed with statistical confidence.
Independent factors that may impact test result but cannot be controlled by the test facility or the ammunition developer should be limited and documented. These factors may include unforeseen changes to test location or failures in test support equipment, etc.

Environment, temperature and conditions between the new ammunition and the baseline ammunition should be as consistent as possible throughout the duration of the test. This eliminates variables that are environmentally and thermally induced. All ammunition should come from one continuous production lot. This eliminates variables in production quality. This assumes good quality assurance at the production site such that the differences from one lot to another are within tolerance of the specification of the ammunition.

Planning an ammunition test should also take into consideration any impact the ammunition may have on its host weapon(s). The test should be long enough for the long term cumulative effects of the ammunition on the host weapon(s) to manifest. The test should also be conducted side by side against a baseline ammunition. This type of test produces a more accurate impact of the new ammunition on a weapon’s performance and, ultimately, life cycle cost. The baseline ammunition being used should already have an extensive set of test data or an established and accepted reliability based on historical knowledge.

The quantity of weapons used for both the new ammunition and baseline ammunition should be the same. The sample size of the test ammunition should be large enough to demonstrate any cumulative effects on the performance of the host weapon(s). Factors affecting this sample size include the life of essential weapon parts, such as the bolt, the receiver or the barrel, the amount of by-product produced by firing the new ammunition, and the length of a realistic mission. The test should also be long enough to cover several repetitions of the standard full cleaning cycles of the weapon. If the weapons are magazine-fed, the test should also be long enough to be able to rotate the magazines throughout the weapons so that each weapon fires out of each magazine for a set number of cycles. This type of rotation can help identify possible failure modes unique to a particular magazine.

The test should be designed such that commonly seen failure modes are given enough time to surface. For the purpose of this paper, the failure modes addressed for test planning are those that account for the majority of the failures surfaced from historical data. These failure modes are:

- Foiling
- Stress and fatigue cracks possibly due to high port and chamber pressure
- Frequency of light indents (insufficient pressure indentation on the cartridge primer) indicating possible low port and chamber pressure and/or an abundance of residue causing an increase in friction

The resulting data from this test should provide an extensive list of failure modes, failure parts, and maintenance logs. Quantitative weapon and ammunition reliability measures can be derived from the failure rate and sample size. Failure trend plot can be generated from the failure modes collected. Spare part data and maintenance frequency feed into the derivation of sustainment cost and life cycle cost.

3 DATA COLLECTION

Consistency in data collection is important. If the test requires the use of both new ammunition and baseline ammunition, then the same type of data measures should be collected on each type of ammunition. The measures needed should be discussed, determined and agreed upon by all stakeholders prior to the start of test. These measures need to provide sufficient information for data analysis post test. Examples of these measures include, but are not limited to, the number of stoppages and the round the stoppage occurred, the condition of the weapon at the time of stoppage, the possible cause of the stoppage, the type and condition of the round that was involved in the stoppage, the indentation depth of any light indents, the number of refires (a manually ejected round from a previous failure to fire is reloaded and fired for a second time), the number of successful refires, the frequency of unscheduled cleaning, the part failures and frequency, etc.

4 DATA ANALYSIS & LIFE CYCLE COST ESTIMATE

Sustainment costs have historically dominated most systems’ life cycle costs, and this is true for weapons. The cost for spare part replacement and maintenance increases as the weapon’s part life decreases and requires more cleaning to sustain a low frequency of stoppage. Increased stoppages due to firing or unscheduled cleaning negatively affect reliability. Essentially, reliability and sustainment cost have a proportional relationship.

The reliability and performance of a weapon change depending on the ammunition it fires. Ammunitions can have an effect on the service life of certain components of a weapon, cleaning cycle and MRBS. Ammunitions which produce a large amount of byproduct from burning off propellant cause more build up within the weapon chambers. This buildup causes bolt jamming and light indents. Light indents often occur when the forward momentum of the bolt is insufficient to cause enough indentation to ignite the primer and fire the round. This loss of momentum can result from the bolt not returning all the way from the previous fire or a buildup of byproducts that may jam the bolt as it moves forward.

Based on historical data, the most common failure modes that cause decreased reliability are the following:

- High port and chamber pressure inducing stress on the bolt
- Low port and chamber pressure inducing light indents, increasing stoppage frequency
- Foiling causing increased stoppage frequency
- Failure to feed to the magazine or belt incompatibility or quality control during production
- Other significant weapon part life degradation

Examples of these measures include, but are not limited to, the number of stoppages and the round the stoppage occurred, the condition of the weapon at the time of stoppage, the possible cause of the stoppage, the type and condition of the round that was involved in the stoppage, the indentation depth of any light indents, the number of refires (a manually ejected round from a previous failure to fire is reloaded and fired for a second time), the number of successful refires, the frequency of unscheduled cleaning, the part failures and frequency, etc.
For the purpose of this paper, each of the first 4 failure modes will be analyzed further. The effect of each failure mode on life cycle cost will also be addressed.

4.1 High Port and Chamber Pressure

High port and chamber pressure is a result of discharging a round of ammunition. A high port and chamber pressure being emitted from a discharged round of ammunition can cause stress on the bolt as it is cycled back to recharge for the next round. Port and chamber pressure emitted by the propellant burning pushes the bolt back to its original starting position. The high explosion of pressure causes a high speed return of the bolt. The bolt doesn’t stop until it impacts the buffer which is located in the buttstock of the weapon. The higher the pressure released by a discharged round, the faster the bolt travels and the harder the impact when the bolt hits the buffer. Stress accumulates in the bolt every time it impacts the buffer. This type of cyclic stress can lead to bolt cracking and bolt lug shearing. The higher the pressure, the higher the stress and the sooner the bolt fails. If collected, this bolt failure and replacement data can be used to develop a Maximum Likelihood Estimate (MLE) of the bolt life for a particular type of weapon firing a specific type of ammunition.

For the purpose of this paper, a sample data of 10 weapons is used to illustrate how an MLE of the bolt life can be derived from test data. Table 4.1.1 below shows the bolt life of 10 weapons firing a new type of ammunition. 5 weapons are of Weapon Type 1 (WT1) and 5 weapons are of Weapon Type 2 (WT2). The unit for the bolt life column is in terms of the number of rounds fired. If a bolt failed during test and was replaced, the bolt life represents the number of rounds fired by that particular bolt until it failed. This is considered a 0 censored data in the 3rd column of Table 4.1.1. If a bolt did not fail then the bolt life represents the number of rounds fired by that particular bolt until the end of test. This is considered a 2 censored data in the 3rd column of Table 4.1.1.

The MLEs for WT1 and WT2 firing this new ammunition are derived based on the values in Table 4.1.1. A similar set of sample data for 10 weapons firing baseline ammunition is used to calculate the MLEs for WT1 and WT2 firing baseline ammunition. The percent bolt life degradation caused by firing the new ammunition is calculated for WT1 and WT2. Degradation is defined as negative deviation from the bolt life of a weapon firing the baseline ammunition. The difference between the bolt life MLEs of a weapon firing the new ammunition and the same weapon firing baseline ammunition is divided by the MLE of that same weapon firing baseline ammunition. Table 4.1.2 below depicts this information.

Bolt life of both weapons types decreased from firing the new ammunition. This decrease in bolt life indicates a possible increase in cost for supplying spare parts and maintenance time of the weapons. As bolt life shortens, the number of bolts and the maintenance time needed to complete a mission of a specified length will increase, resulting in an increase to sustainment cost. Since sustainment cost takes up a significant part of the life cycle cost, an increase in sustainment cost directly increases the life cycle cost of the weapons.

<table>
<thead>
<tr>
<th>Table 4.1.1</th>
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<tbody>
<tr>
<td>weapon</td>
</tr>
<tr>
<td>WT1 Weapon1</td>
</tr>
<tr>
<td>WT1 Weapon2</td>
</tr>
<tr>
<td>WT1 Weapon3</td>
</tr>
<tr>
<td>WT1 Weapon4</td>
</tr>
<tr>
<td>WT1 Weapon5</td>
</tr>
<tr>
<td>WT2 Weapon1</td>
</tr>
<tr>
<td>WT2 Weapon2</td>
</tr>
<tr>
<td>WT2 Weapon3</td>
</tr>
<tr>
<td>WT2 Weapon4</td>
</tr>
<tr>
<td>WT2 Weapon5</td>
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</tbody>
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<th>Table 4.1.2</th>
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<tr>
<td>Weapon</td>
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<tr>
<td></td>
</tr>
<tr>
<td>WT1</td>
</tr>
<tr>
<td>WT2</td>
</tr>
</tbody>
</table>

4.2 Low Port and Chamber Pressure

Low port and chamber pressure is a result of discharging a round of ammunition. When a round is fired, the pressure from the dispersed energy travels through a gas tube back to the bolt to push it into the buttstock. A low port and chamber pressure of the ammunition being fired does not provide enough pressure to propel the bolt all the way back home where it is charged to fire the next round. When the bolt travels forward to strike the next round, it doesn’t gain enough speed to indent the primer far enough for this next round to fire. This type of failure is often called a light indent due to the small indentation left on the round of ammunition that failed to fire. This small indentation can sometimes cause enough damage to the primer such that the round will not be able to fire again. In the test community, there are two ways to identify whether a light indent round is still functional. One method is to disassemble the ammunition primer in a laboratory. However, once the round is pulled apart, it can’t be fired again. Another method is to reload the light indent round and refire it. If the round does not fire after three attempts, the round is considered non-functional and
Increased light indent count decreases the Mean Rounds Between Stoppage (MRBS) of the host weapon. A lower MRBS is an indication of degraded weapon reliability. However, this type of reliability degradation is induced by the ammunition. Comparison between the MRBS of a weapon type firing the new ammunition against a weapon firing baseline ammunition can accurately show how much the new ammunition affects a specific weapon type or a family of weapons. The underlying assumption is that all test weapons are representative of the entire lot of weapons produced. This also implies that not one weapon incurred significantly more stoppages than any other weapon during the test. Table 4.2.1 below shows the MRBS at 80% lower confidence bound of WT1 and WT2 firing the new ammunition and baseline ammunition. The percent degradation caused by firing the new ammunition is calculated for WT1 and WT2. Degradation is defined as negative deviation from the MRBS of a weapon firing the baseline ammunition. The difference between the MRBS of a weapon firing the new ammunition and the same weapon firing baseline ammunition is divided by the MRBS of that same weapon firing baseline ammunition.

Table 4.2.1

<table>
<thead>
<tr>
<th>Weapon</th>
<th>MRBS</th>
<th>% degradation</th>
</tr>
</thead>
<tbody>
<tr>
<td>WT1</td>
<td>857.9</td>
<td>26%</td>
</tr>
<tr>
<td>WT2</td>
<td>903.9</td>
<td>77%</td>
</tr>
</tbody>
</table>

The MRBS for both weapon types decreased due to firing the new ammunition. This indicates that the new ammunition negatively affects the reliability of the entire weapon and ammunition system. Given a fixed number of rounds, a low MRBS means a higher number of stoppages. This increased number of stoppages can cause a high risk for soldier safety and maintenance time needed to complete a mission.

4.3 Fouling

Fouling occurs when the chemical residue left behind by burning the propellant of a fired round of ammunition sticks to the surface areas inside the host weapon. The residue builds up after each discharged round of ammunition. Standard cleaning procedure is not enough to remove all the residue in a weapon. Over a period of time, the remaining residue gets thick enough to become an obstruction and cause friction as the bolt travels back and forth. This obstruction leads to ammunition induced stoppages. The majority of these stoppages appear as a series of light indents. An inspection of the condition of the weapon can help verify the amount of existing fouling. Should the light indent frequency lessens or stops after a scheduled or unscheduled cleaning, it is reasonable to deduce that the stoppages leading up to the cleaning are induced by fouling. Since fouling is a build-up of the byproduct of ammunition firing, the ammunition is negatively affecting the weapon reliability.

Table 4.3.1 below shows the total stoppages occurred for a test consisting of five WT1 weapons and five WT2 weapons. The number of stoppages due to fouling is listed. The 80% lower confidence bound reliability of the new ammunition firing from WT1 and WT2 and the 80% lower confidence bound reliability of baseline ammunition firing from WT1 and WT2 are listed. The reliability for small arm ammunition is often very high. For this test example, the reliability requirement for the new ammunition is .9999 at 80% lower bound confidence.

Table 4.3.1

<table>
<thead>
<tr>
<th>Weapon</th>
<th>Fouling w/ new ammo</th>
<th>Fouling w/ baseline</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td># stoppages</td>
<td>MRBS</td>
</tr>
<tr>
<td>WT1</td>
<td>8</td>
<td>.99981</td>
</tr>
<tr>
<td>WT2</td>
<td>15</td>
<td>.99968</td>
</tr>
</tbody>
</table>

The stoppages caused by fouling can affect the ammunition reliability significantly. For this example, implementing a corrective action to decrease the amount of residue left behind by the new ammunition can be the difference between meeting and not meeting its reliability requirement.

Fouling causes a high risk for soldier safety. The equipment needed to completely clean out the chemical residue is not carried by soldiers in the field. The longer maintenance time needed to send the weapon to a cleaning shop and the increase in cleaning frequency drives up the sustainment cost of the weapon as well as decreases the availability of the weapon.

4.4 Barrel Life

The part life of a weapon is often a good indication of a positive or negative effect on the life cycle cost. A shorter part life requires more maintenance and more spare replacement parts to be available. An increase in need for spare parts, maintenance time and frequency increase sustainment cost, and therefore, increase life cycle cost.

Analyzing the major part life of a weapon can also reveal possible failure modes used in failure analysis and corrective action implementation. Table 4.4.1 below shows an example of shortened barrel life due to firing the new ammunition from WT1, WT2 and Weapon Type 3 (WT3). The percent barrel life degradation caused by firing the new ammunition is calculated for all 3 weapons. Degradation is defined as negative deviation from the barrel life of a weapon firing baseline ammunition. The difference between the barrel life of a weapon type firing the new ammunition and the barrel life of the same weapon firing baseline ammunition is divided by the barrel life of that weapon firing baseline ammunition.

The barrel life of all three weapon types decreased firing the new ammunition compared to the barrel life of all three weapon types firing baseline ammunition. WT1 and WT2 are rifles. WT3 is a semi-automatic machine gun. The large percent degradation of the barrel life of WT3 could be attributed to the type of weapon.
A shortened barrel life leads to an increase in spare barrel supply. Soldiers will be required to change out the barrel more frequently. The impact on sustainment cost of a shortened barrel life is direct and immediate.

4.5 Life Cycle Cost

The life cycle cost estimation is derived from inputting reliability dependent metrics into the Consumption, Holding, Repair, and Transportation (COHORT) Cost Program. This program determines the budget needed to supply and sustain a weapon system at its intended operational performance target throughout its intended usage life. Inputs to this program include the reliability metrics such as MRBS, spare part quantities based on part life, cost of each spare part, shipping cost and shipping time.

The example below shows the impact to life cycle cost due to shortened usage life of a weapon’s bolt and barrel. The inputs to the COHORT program for this analysis are the degradation in bolt and barrel life of WT1 and WT2. Table 4.5.1 below shows the output over a 20 year life span.

The COHORT output is conducted for three different alternatives:

1. Bolt is replaced when it fails. Bolt and barrel replacement is assumed to be independent
2. Bolt and barrel are replaced when the bolt fails. This assumption is highly dependent on shortened bolt life since both bolt and barrel are replaced at the end of a given bolt life. This alternative would be used if barrel life is slightly longer than the bolt life.
3. Bolt is replaced when the bolt or barrel fails. This assumption assumes that the barrel life is shorter than the bolt life.

Based on the output of the COHORT program, there is an increase in the sustainment cost of both WT1 and WT2 weapons firing the new ammunition for all three alternatives. This information can be used to decide whether it is worthwhile to conduct further failure analysis, implement possible corrective actions to increase reliability and decrease sustainment cost or to accept the predicted increase in sustainment cost. Other factors that can affect this decision include the level of risk to soldier safety, soldier morale, and mission completion requirements.

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BIOGRAPHIES

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