120mm Mortar System Accuracy Analysis

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Committed to Excellence

120mm Mortar System

M120 Towed Mortar System

120mm Mortar Cartridge Family
<u>(from left to right):</u>
M934/M934A1 HE
M929 WP Smoke
M930/M983 Illumination
M931 Practice

M121 Carrier Mounted
Mortar System

➢ The M120/M121 Battalion Mortar System (BMS) was initially fielded in 1995.

  ◆ It replaced the 4.2 mortar system.

➢ The M121 is the carrier mounted system in the M1064 Armored Personnel Carrier (M113 family of vehicles).

120mm Mortar System

System Characteristics	
Maximum Range	7,200 m
Minimum Range	200 m
Maximum Rate of Fire	16 rounds / minute (first minute)
Sustained Rate of Fire	4 rounds / minute

There are 3 primary methods for firing mortars:

◆ Predicted Fire – This method utilizes information about ammunition characteristics, weapon location, target location, and meteorological conditions to compute a ballistic solution for hitting the target.

◆ Observer Adjusted Fire – This method relies on having one or more Forward Observers within sight of the target area, to visually estimate how far the rounds miss the target and then provide feedback to the fire control unit, to reduce this error.

◆ Registration/Transfer **–** In this method one or more rounds are fired to a designated location for aiming purposes. Adjustments are made until the system error is reduced to an acceptable amount. Then these adjustments can then be "transferred" to hit other nearby targets more effectively.
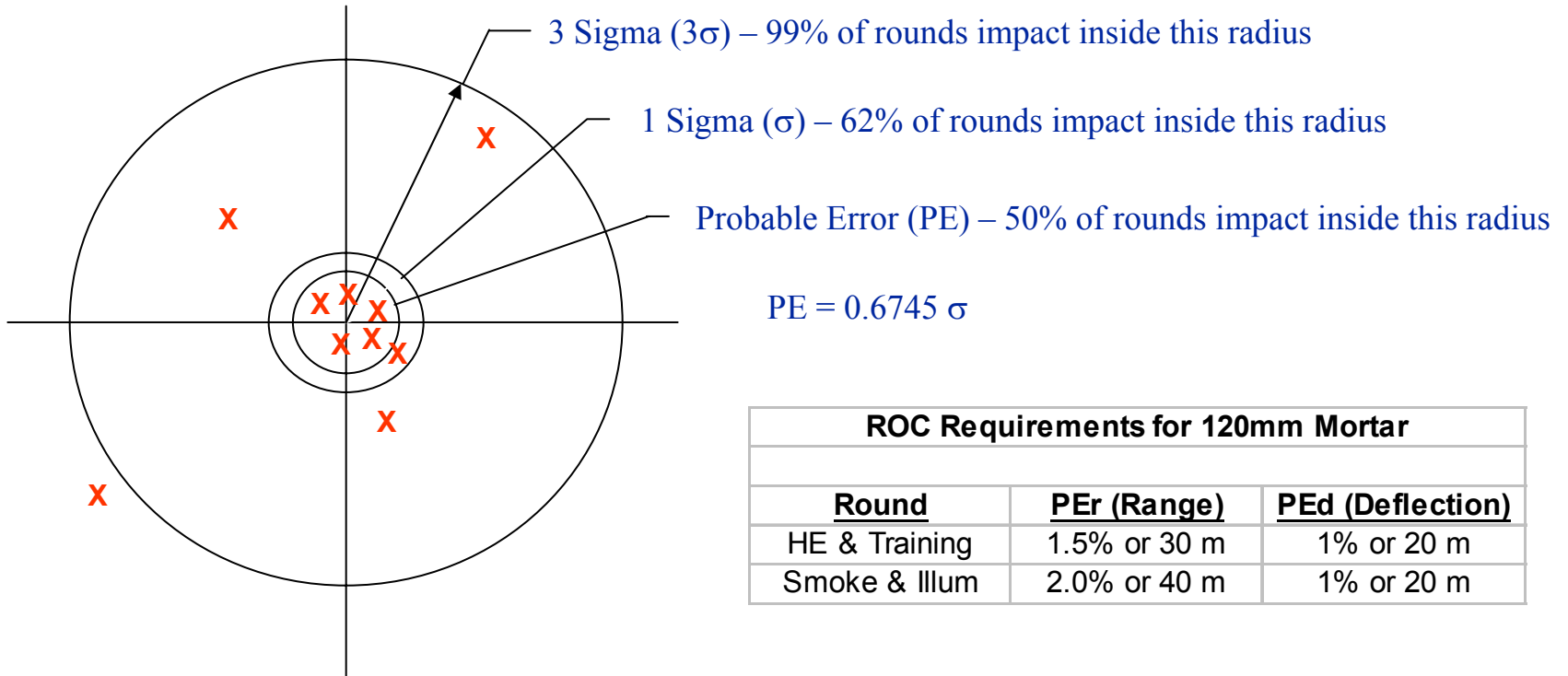
Objectives of this Study

➢ To provide examples of how the accuracy of the 120mm mortar system can be improved for evolutionary block upgrades or future programs such as the Stryker, Brigade Combat Team (BCT) or Future Combat System (FCS).

➢ Reduction in the number of rounds required to hit the target.

➢ Provide more accuracy for mortar fires, especially for coordinated fires from two or more mortars with different lots of ammo.

120mm Mortar Accuracy Requirements

3 Sigma (3σ) – 99% of rounds impact inside this radius

1 Sigma (σ) – 62% of rounds impact inside this radius

Probable Error (PE) – 50% of rounds impact inside this radius

PE = 0.6745 σ

ROC Requirements for 120mm Mortar		
Round	**PEr (Range)**	**PEd (Deflection)**
HE & Training	1.5% or 30 m	1% or 20 m
Smoke & Illum	2.0% or 40 m	1% or 20 m

Notes:
PEr for HE @ max range is
1.5 % of 7,200 m = 108 m
1 σ = 160 m
3 σ = 480 m
Rounds could land as far at 1 km from each other.

Notes:
PEr for Smoke @ max range is
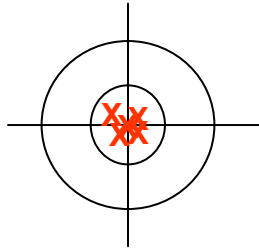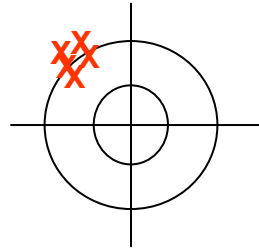2 % of 7,200 m = 144 m
1 σ = 213 m
3 σ = 640 m
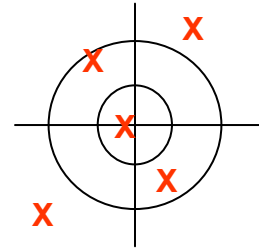Rounds could land more than 1 km from each other.

Precision vs Bias Errors

Good Precision
& Good MPI

Good Precision
but Poor MPI

Good MPI but
Poor Precision

➢ Fundamentally accuracy is described in terms of precision and bias.

   ◆ The mean point about which the rounds impact, is called the Mean Point of Impact (MPI).

   ◆ If the MPI is close to the center of the target, then the pattern is said to have a small MPI error or a small bias error.

   ◆ If the rounds impact very close to each, then the pattern is said to have a small precision error.

Root Sum Square Analysis

Once all the major sources of error have been identified, the overall effect can be evaluated statistically by taking the Root Sum Square of all the Component Errors:

$$\sigma = \sqrt{\sum_i \left(u_i \times \sigma_i\right)^2}$$

σ represents the standard deviation of the system characteristic being evaluated.
It could represent precision error, the bias error or a combination of both.
In this example let σ represent the total system error in range.

σ_i represents the standard deviation of each individual source of error.
For example test data may show that the muzzle velocity for a given lot of ammunition
has a standard deviation of 2.5 m/sec, in which case σ_{MV} = 2.5 m/sec

u_i represents sensitivity of σ to σ_i
This value represents how much σ is affected by a unit change in σ_i
For example if a variation of 1 m/sec in muzzle velocity can affect range by 14.4 m,
then u_{MV} = 14.4 m / (m/sec)
These values are also referred to as a unit effects or partial effects.

The product of $u_i \times \sigma_i$ represents the component error, or the effect that each individual source of error will have on the total system error.

System Error Analysis

Source of Error	Unit Effects	Standard Deviation	Component Error
Muzzle Velocity	14.4	2.5	36.0
Wind Velocity	8.4	4.9	41.2
Air Density	15.1	0.5	7.6
Air Temp	1.4	0.5	0.7
Form Factor	15.1	1.0	15.1
Weapon Location	15.0	1.0	15.0
Aiming Error	7.2	0.5	3.6
Jump	7.2	1.0	7.2
Root Sum Square			**59.7**
3 Sigma			**179.1**

➢ The effect of all the error components on the overall system error, is obtained by taking the root sum square of all the component errors.

➢ In this example the resulting system error in range will have a standard deviation of σ = 59.7 m.

➢ The 3σ error is 179.1m.

◆ This means that with the given standard deviations and unit effects of all the individual sources of error, there is a 99% probability that the rounds will impact within 179.1 meters of the center of the target.

➢ The unit effects and standard deviations used above, are representative nominal values for illustrative purposes.

◆ Note that Muzzle Velocity and Meteorological conditions (Wind Velocity, Air Density and Air Temp) have the greatest affect on overall error.

Effect of MET Improvements

➢ Meteorological (MET) data is used to characterize the atmosphere that the mortar round will fly through. This includes:

- ◆ Wind Velocity
- ◆ Air Density
- ◆ Air Temperature

Source of Error	Unit Effects	Base Case Standard Deviation	Base Case Component Error	On-board MET Standard Deviation	On-board MET Component Error
Muzzle Velocity (m/sec)	14.4	2.0	28.8	2.0	28.8
Range Wind (knots)	8.4	**4.9**	41.2	**4.2**	35.0
Air Density (%)	15.1	**0.5**	7.6	**0.4**	6.4
Air Temp (%)	1.4	**0.5**	0.7	**0.4**	0.6
Form Factor (%)	15.1	1.0	15.1	1.0	15.1
Weapon Location (m)	15.0	1.0	15.0	1.0	15.0
Quadrant Elevation (mils)	7.2	0.5	3.6	0.5	3.6
Jump (mils)	7.2	1.0	7.2	1.0	7.2
Root Sum Square			**55.7**		**51.1**
3 Sigma			**167.0**		**153.3**
% Improvement					**8.2%**

➢ To illustrate how an improvement is MET accuracy can affect the total system accuracy, assume that MET could be improved at least 15%, by methods such as interfacing cost effective meteorological sensors with the on-board fire control system.

- ◆ The resulting standard deviation in range would be reduced from 55.7 m to 51.1 m.
- ◆ Therefore the 15% reduction in MET error, reduced the total system error by 8.2%.

Methods of Reducing Errors in MET

The following recommendations are offered, for future Fire Control System upgrades to help reduce the error associated with Meteorological (MET) uncertainty:

1. Wind Velocity Error
    ◆   Integrate a digital anemometer into the Fire Control System
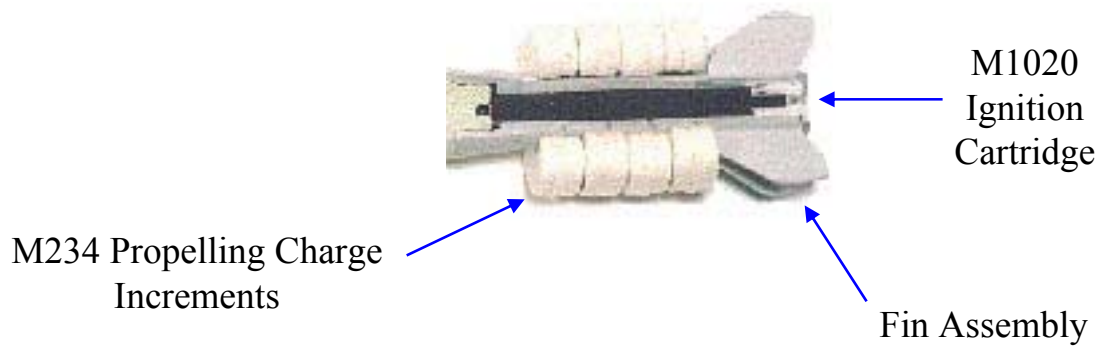
2. Air Density Error
    ◆   Integrate a digital barometer into the Fire Control System

3. Air Temperature Error
    ◆   Integrate a digital thermometer into the Fire Control System

120mm Propulsion System

M1020 Ignition Cartridge

M234 Propelling Charge Increments

Fin Assembly

Firing Table Data for M929		
Charge	Muzzle Velocity (m/sec)	Max Range (m)
0	102	999
1	168	2,527
2	224	4,124
3	274	5,711
4	322	7,121

Specification Requirements & Specifications

➢ **System Accuracy Requirement (Ref. ORD for 120mm Mortar System dated May 1985)**

◆ For M929:   PEr < 2 % for ranges > 2,000 m

◆ For M934A1: PEr < 1.5 % for ranges > 2,000 m

➢ **M1020 Ignition Cartridge Acceptance Requirements**

◆ Muzzle Velocity @ Charge 0 & 70 ºF: Mean 101 +/- 3 m/s, Max σ = 1.6 m/sec

➢ **M234 Propelling Charge Increments Acceptance Requirements**

◆ Muzzle Velocity @ Charge 1 & 70 ºF: Mean 168 +/- 5 m/s, Max σ = 1.6 m/sec

◆ Muzzle Velocity @ Charge 4 & 70 ºF: Mean 320 +/- 4 m/s, Max σ = 2.5 m/sec

Muzzle Velocity at Charge 4

	M234 Specification (m/sec)	M929 Stockpile (m/sec)	M929 Individual Lot Averages	M929 Firing Table
Mean	320 +/- 4	320.8	321.1 +/- 2.8 *	322
Standard Deviation	2.5	2.0	1.0	N/A
* The Mean Muzzle Velocities for the individual lots ranged from 318 m/sec to 323.6 m/sec.				

➢ The variation within each individual lot is significantly less than the variation across the current stockpile of 19 lots of M929 mortar rounds.

➢ The specification allows the mean muzzle velocity of any lot to vary from 324 m/sec to 316 m/sec.

➢ The actual mean muzzle velocities measured during lot acceptance testing have ranged from 318 m/sec to 323.6 m/sec (Mean of 321.1 and tolerance of +/- 2.8 m/sec).

➢ The standard deviation of the stockpile is 2.0 m/sec.

➢ The average standard deviation for a lot is 1.0 m/sec.

➢ Therefore the standard deviation in muzzle velocity can be reduced by 50%, by using muzzle velocity data for a specific lot, rather than using an average across all 19 lots of the M929 stockpile inventory.

Effects of Muzzle Velocity Improvement

Source of Error	Unit Effects	Base Case		Lot # ID	
		Standard Deviation	Component Error	Standard Deviation	Component Error
Muzzle Velocity (m/sec)	14.4	**2.0**	28.8	**1.0**	14.4
Range Wind (knots)	8.4	4.9	41.2	4.9	41.2
Air Density (%)	15.1	0.5	7.6	0.5	7.6
Air Temp (%)	1.4	0.5	0.7	0.5	0.7
Form Factor (%)	15.1	1.0	15.1	1.0	15.1
Weapon Location (m)	15.0	1.0	15.0	1.0	15.0
Quadrant Elevation (mils)	7.2	0.5	3.6	0.5	3.6
Jump (mils)	7.2	1.0	<u>7.2</u>	1.0	<u>7.2</u>
Root Sum Square			**55.7**		**49.8**
3 Sigma			**167.0**		**149.3**
% Improvement					**10.6%**

➢ Reducing the standard deviation of muzzle velocity from 2 m/sec to 1 m/sec, reduces the total system standard deviation is from 55.7 m to 49.8 m.

➢ Therefore reducing the standard deviation of muzzle velocity by 50%, reduces the total system error by 10.6%.

Methods of Reducing Muzzle Velocity Errors

The following recommendations are offered for Future Fire Control Software upgrades to help reduce the error associated with Muzzle Velocity uncertainty:

➤ 1. Incorporate lot specific propulsion system data into the Fire Control software to improve the accuracy of the ballistic solution

  ◆ Muzzle velocity data is already being collected, for each lot of ammunition, during various life cycle tests, such as:

    • Lot Acceptance Testing (LAT)
    • Stockpile Surveillance Testing
    • Firing Tables Updates

➤ 2. Measure actual propellant temp and input into the Fire Control System

  ◆ The muzzle velocity is very sensitive to the temperature of the propellant
  ◆ The Firing Tables include corrections to adjust the expected Muzzle Velocity based on the temperature of the propellant
  ◆ The temperature of the propellant in the packaged configuration, could be significantly different from the ambient air temperature.

    • Providing an inexpensive means to measure the temperature of the propelling charge increments, would reduce the the Muzzle Velocity error.

Effects of Combined Improvements

Source of Error	Unit Effects	Base Case		On-board MET		Lot # ID		Combined	
		Std Dev	Comp Error	Std Dev	Comp Error	Std Dev	Comp Error	Std Dev	Comp Error
Muzzle Velocity (m/sec)	14.4	2.0	28.8	2.0	28.8	**1.0**	14.4	**1.0**	14.4
Range Wind (knots)	8.4	4.9	41.2	**4.2**	35.0	4.9	41.2	**4.2**	35.0
Air Density (%)	15.1	0.5	7.6	**0.4**	6.4	0.5	7.6	**0.4**	6.4
Air Temp (%)	1.4	0.5	0.7	**0.4**	0.6	0.5	0.7	**0.4**	0.6
Form Factor (%)	15.1	1.0	15.1	1.0	15.1	1.0	15.1	1.0	15.1
Weapon Location (m)	15.0	1.0	15.0	1.0	15.0	1.0	15.0	1.0	15.0
Quadrant Elevation (mils)	7.2	0.5	3.6	0.5	3.6	0.5	3.6	0.5	3.6
Jump (mils)	7.2	1.0	7.2	1.0	7.2	1.0	7.2	1.0	7.2
Root Sum Square			55.7		51.1		49.8		44.6
3 Sigma			167.0		153.3		149.3		133.9
% Improvement					8.2%		10.6%		19.9%

➢ The MET errors are reduced 15% by integrating cost effective on-board meteorological equipment into the Fire Control System.

➢ The standard deviation in Muzzle Velocity is reduced by 50% by identifying the specific lot number of the ammunition being fired and using the Muzzle Velocity for that specific lot to compute a more accurate ballistic solution.

◆ Using more accurate propellant temperature would also further reduce the uncertainty of muzzle velocity.

➢ The standard deviation of the total system error is reduced by 19.9%.

◆ Note that the combined effect is greater that the individual improvements.

Summary

➤ The objectives of this study were:
  ◆ To identify how its accuracy can be improved to meet future requirements such as the block upgrades for the Brigade Combat Team (BCT) and the Future Combat System (FCS).
  ◆ To provide an estimate of how much the system accuracy can be improvement by the recommendations made.

➤ The ballistic trajectory will be significantly affected by the meteorological conditions, such as wind velocity, air temperature and air density.
  ◆ Methods for reducing the uncertainty of meteorological data include interfacing electronic instruments into the fire control system for measuring the temperature, humidity and wind velocity and the gun location.

➤ Another significant source of error is the uncertainty associate with the muzzle velocity of the round when it leaves the weapon. The muzzle velocity error is a function of the variability of the propulsion system components and the temperature of the propellant when fired.
  ◆ The variability in propulsion system components can be reduced by using muzzle velocity data on each production lot of mortar rounds which is being collected during life cycle tests such as lot acceptance testing and stockpile surveillance testing.
  ◆ More accurate measurement of the propellant temperature would further reduce the errors associated muzzle velocity.

➤ The combined effects of these recommendations, are estimated to improve the system accuracy by as much as 20%.