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ATTRIBUTE ANALYSIS OF THE ARMOR MACHINE GUN CANDIDATES

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In May 74, the Army initiated a program to select an interim weapon from the existing world wide "off-the-shelf" hardware to replace the current 7.62mm M219 Coax Machine Gun. Since inception, the M219 has had a history of reliability problems in the field. Alternatives considered were the M219, the product improved M219, the M60E2, and foreign 7.62mm weapons. As part of the evaluation, an attribute analysis was conducted to compare the technical performance, RAM-D and physical characteristics of the candidates. Due to wide variability in test procedures, sample size quality, gathered data, and results available for the

20. ABSTRACT

candidate weapons, engineering experts were brought together to achieve a blend of data and opinion on each candidate weapon. Discussions ensued until a consensus was reached on ranking and scoring each candidate for 23 attributes. An analysis was then performed to establish a weapon ranking and dominance of ranking as a function of attribute weights.

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OBJECTIVE

The objective of this analysis is to compare the attributes of the Armor Machine Gun candidates.

INTRODUCTION

The current Armor Machine Gun is the US M219, a 7.62mm machine gun, designed to be mounted coaxially with the main tank armament and have applications to other armor vehicles. The operation/maintenance history shows that this weapon system has performance deficiencies which cannot be corrected by minor redesign.

A joint effort was initiated by AMC and TRADOC in May 74 to select a possible replacement for the M219 from the world-wide "off-the-shelf" hardware. The weapon candidates are presented in Table 1, all are 7.62mm systems.

This analysis compared each candidate based on TRADOC proposed attributes and quantitative weighting of these attributes. The following section describes the attributes considered in evaluating the candidate weapon systems.

ATTRIBUTES

The attributes are divided into three major categories, presented in Figure 1 and defined as follows:

1. Technical Performance: Hardware effectiveness and operation in actual field usage.

2. Physical Characteristics: Man-machine interface and weapon compatibility with the vehicle.

3. RAM-D: Reliability, availability, maintainability and durability of the weapon.

These major categories and the attributes which comprise each category are presented in Figures 2 through 4. Relative weights, assigned by TRADOC, indicate the importance of a weapon system having that attribute.

The ability of a weapon system to fulfill an attribute and the importance (weight) of that attribute were used to evaluate the candidate weapon systems. This attribute analysis was based on data collected from prior tests and studies performed on the candidate weapons.

TEST DATA

Recent tests have been conducted on all candidates; however, these tests performed were not directly comparable as to purpose and results. The tests used for data in this analysis are as follows:

1. The US candidate weapon systems (M219, M219PT, and M60E2) were tested at Ft Knox with modified armor mounts. The test results are still being evaluated and only limited data was available for this study.

2. The foreign candidates - Canadian C1, FRG MG3, Belgium MAG58, UK L8A1, and the French AAT52 were tested at Rodman Laboratories, Rock Island Arsenal to establish performance characteristics. These test results were still under evaluation and only limited data was available for this study. Armor mounted tests were not conducted.

3. The Soviet PKM candidate was tested at H.P. White Laboratories in accordance with MTP 3-2-045 except for variations noted in the test report[1]. The testing was limited by the availability of only one weapon and quantity and quality of ammunition (i.e., ammunition used was Soviet and Chinese 7.62mm). Armor mounted tests were not conducted.

The test results received from the US and foreign candidate systems were not directly comparable due to differences in testing procedures and conditions as follows:

1. The US candidate weapon systems were tested from armor mounts (modified for the M60E2). The foreign weapon systems were tested from both hard and soft mounts but not from armor mounts.

2. The US candidates were not limited in testing by the availability of weapons or hardware. In testing the foreign candidate systems, only one weapon each was available with limited amount of replacement parts.

3. The purpose of testing the Canadian C1, Belgian MAG58, UK L8A1, FRG MG3, and the French AAT 52 by Rodman Laboratories was to establish performance characteristics instead of determining or solving engineering problems. Therefore, exact causes of malfunctions or stoppages were not always actually determined.

4. The Soviet PKM Machine Gun was tested with Soviet and Chinese 7.62mm ammunition in various degraded and corroded conditions. Weapon modifications to fire US or NATO 7.62mm ammunition was not performed.

In summary, the foreign weapon tests were limited in both sample size and quality of hardware. Direct comparisons based on test results were not possible.

WEAPON/TANK INTERFACE STUDIES

Currently, only the M219 has been employed in an Armor Machine Gun role. The other candidates (the foreign systems and US M60E2) would require weapon modifications of various degrees and replacement of mounts

[1] Machine Gun, 7.62mm X 54R, Model PKM (Soviet) MCN 35764, FSTC-MX-17-25-75, December 1974, H.P. White Laboratory, Bel Air, MD.

TABLE 1. ARMOR MACHINE GUN CANDIDATES

Nomenclature	Nation	Remarks
M219	US	Current Armor Machine Gun
M219PI	US	A product improved version of the M219.
M60E2	US	A modified version of the M60 used in the infantry role.
C1	Canada	A modified M1919A4.
MG3	FRG	-
MAG58	Belgium	-
L8A1	UK	A modified MAG58.
AAT52	French	-
PKM	USSR	Without modification, fires only Soviet and Chinese 7.62mm ammunition.

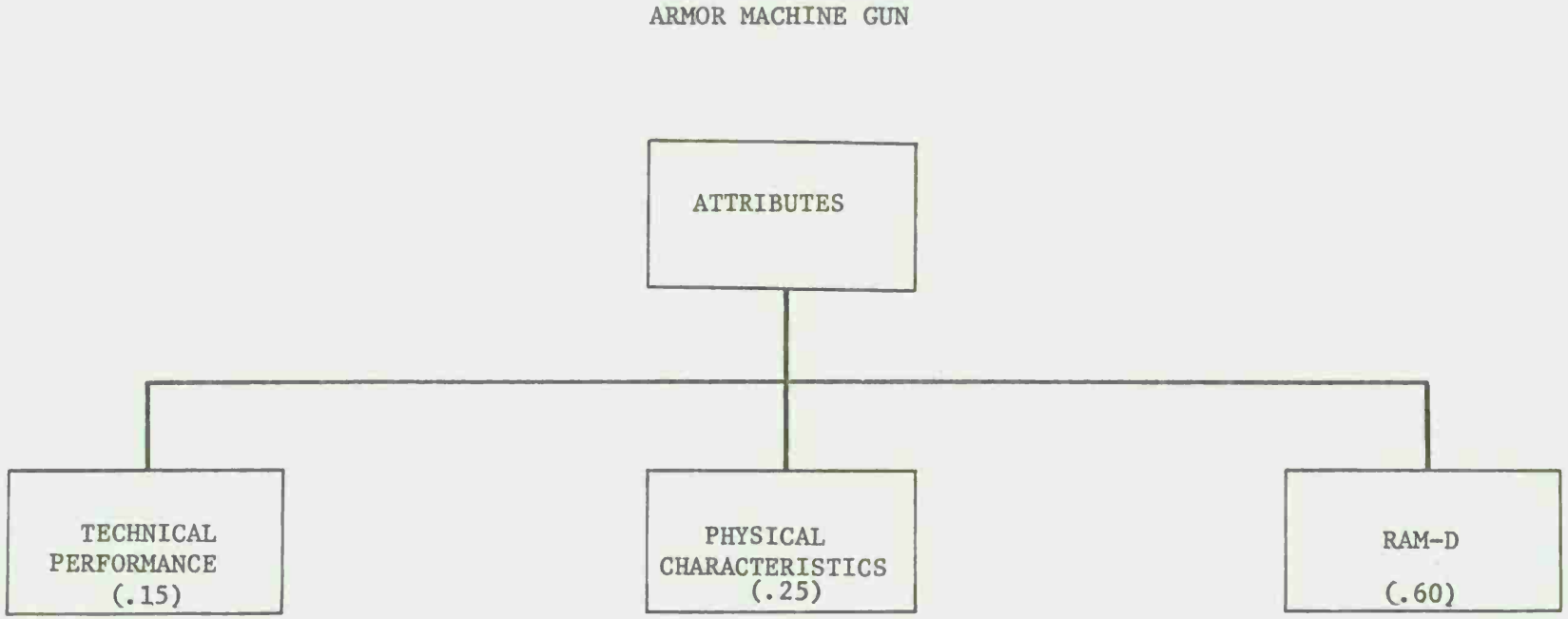


Figure 1. Major Attribute Categories

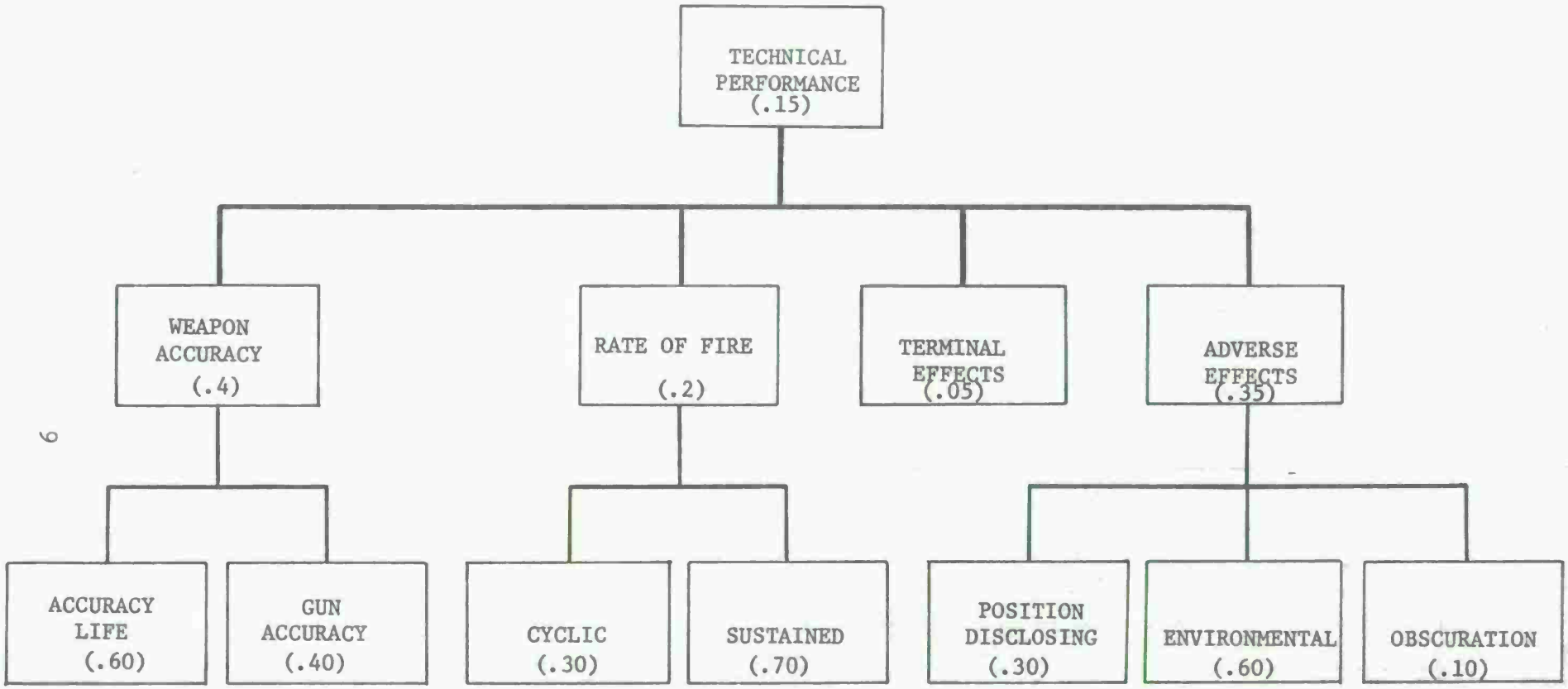
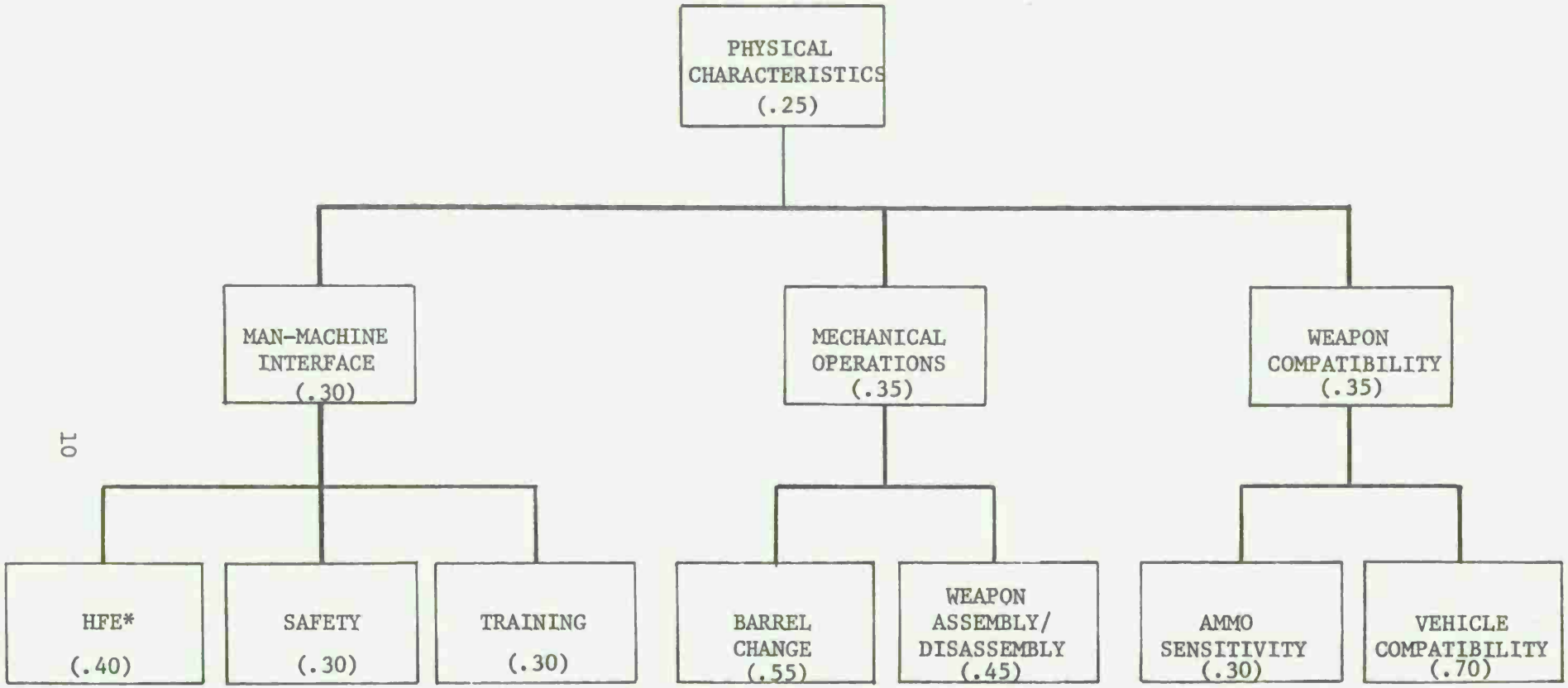
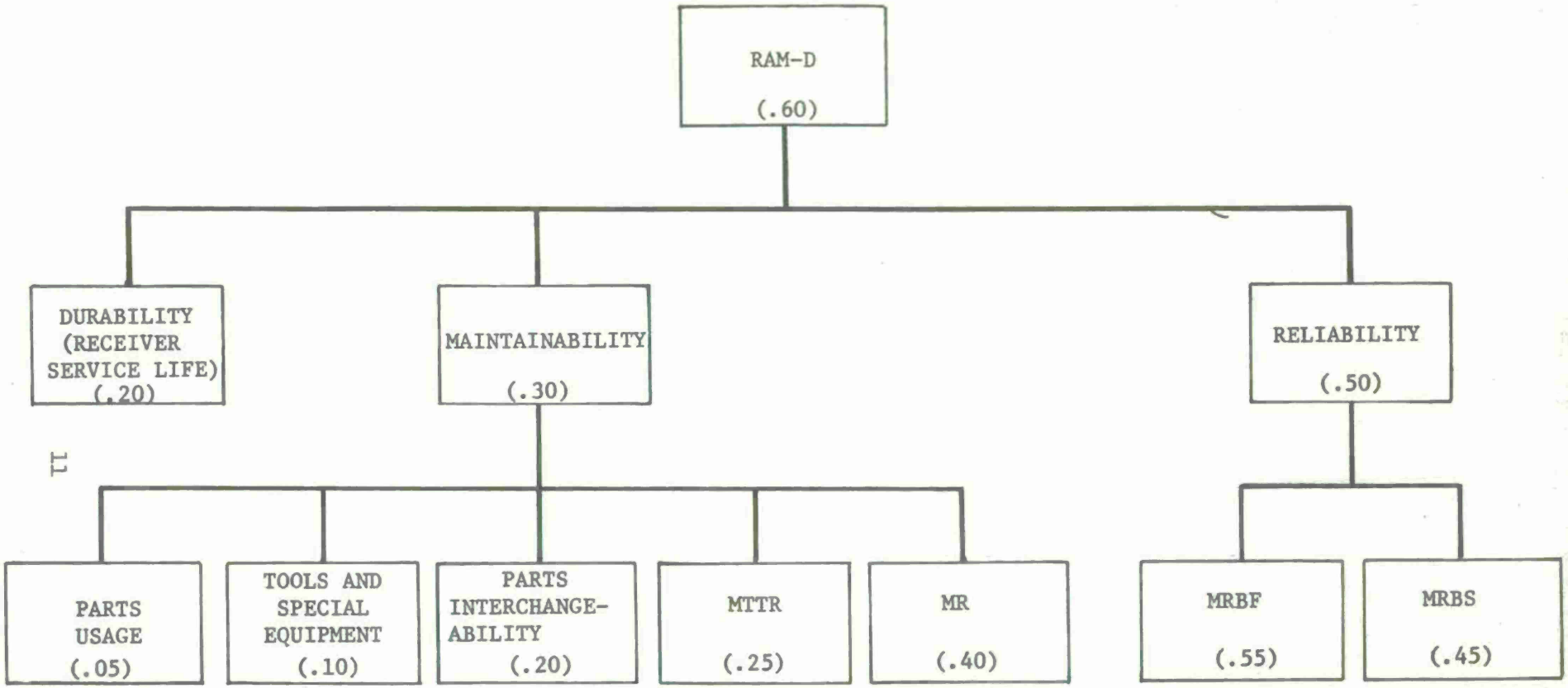


Figure 2. Technical Performance Attributes



*Human Factor Engineering

Figure 3. Physical Characteristic Attributes



LEGEND

MTTR - Mean-Time-To-Repair
MR - Maintenance Ratio
MRBF - Mean-Round-Between-Failure
MRBS - Mean-Round-Between-Stoppage

Figure 4. RAM-D Attributes

or procurement of kits to modify existing armor mounts.

A study performed by Rodman Laboratories in February 1975, to rank the Canadian C1, FRG MG3, UK L8A1, Belgium MAG58, and the French AAT52 as to their degrees of engineering difficulty in adopting them to a co-axial role in the M60A1 and M60A2 tanks and in the M551 AR/AAV[2] indicated that the C1 and the AAT52 presented the least problems (ranked high), and the MG3, MAG58, L8A1 presented the most problems (ranked low). The Soviet PKM and US M60E2, not included in the study, are considered to rank at least as high as the C1 and the AAT52. The Soviet PKM would require weapon modification from a right-hand feed to a left-hand feed (considered a moderate redesign effort). To use the M60E2 would require modifications to the M60A2 Tank Gun Rotor and ejection chute (considered moderate redesign effort).

ANALYSIS

An analysis comparing the attributes of each candidate was conducted utilizing the available test results and the consensus of judgments from engineering experts in their specialized areas.

The analysis was initiated by bringing together knowledgeable experts of the US and foreign weapon systems from Rodman Laboratories. These experts expressed their opinions and feelings about each candidate performance in a particular category. They supported their opinions and judgments by test results and data or drawing on past experience with the weapon system or comparable weapon systems. This discussion ensued until a consensus was reached as to the ranking of the weapons in order from 1 to 9. Ties were allowed (i.e., if two weapons were considered equal for an attribute category, they would both be given the same ranking). The assumptions and criteria used in ranking the candidate weapons for each attribute are presented in Table 2.

After an agreed ranking was achieved, the experts were asked to separate the ranked weapons as to relative performance in each category (i.e., how well did the "best" (ranked 1) weapon perform over the "second best" (ranked 2) and etc.). These scores were scaled from 0 to 10 with the top ranked weapon receiving a value of 10.

RESULTS

The scores are presented in Table 3 for each attribute. The product of each score with its corresponding attribute weight is presented in Table 4; the sum of these weighted scores was used to establish the weapon ranking. The weighted scores clustered into three groups. The high group contained the M60E2 and the MAG58 with scores of 8.3 and 8.1, respectively. The middle group contained the M219, M219PI, PKM, L8A1, AAT52, and the MG3. The scores ranged from 6.8 to 7.6. The low group contained only the C1 with a score of 5.6. The scores and groups are presented in Table 5.

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[2] DF from SARRI-LS to SARRI-LA-T, Subject: Interim Armor Machine Gun-Tank Interface Study, dated 13 February 1975.

TABLE 2. PERFORMANCE CHARACTERISTICS ASSUMPTIONS & CRITERIA

Category	
TECHNICAL PERFORMANCE	
Weapon Accuracy	
Accuracy Life	Based on barrel life data for US candidates and test experience with foreign candidates.
Gun Accuracy	Based on accuracy data at 1000 m.
Rate of Fire	
Cyclic	Based on cyclic rate test data.
Sustained	Rates that would not degrade weapon performance or safety operation, based on cook-off rate.
Adverse Effects	
Position Disclosing	Judged the same for all weapons.
Environmental	Based on available mud, cold, hot, sand and dust test results. The Russian PKM cold tests indicate problems with the splitting cartridge cases. Further tests are needed to determine the actual cause, either the weapon or ammunition.
Obscuration	Judged the same for all weapons.
PHYSICAL CHARACTERISTICS	
Man-Machine Interface	
Human Factors Engineering (HFE)	Based on operator-machine gun interface (i.e., amount of operator maintenance and control necessary for field use).
Safety	Based on safety hazards to the operator or maintenance personnel in performing basic tasks (e.g., cleaning, maintenance and operation).
Training	Based on number of manhours and cost to train personnel to operate or perform maintenance operations.

Table 2 (Cont'd)

Mechanical Operations	
Barrel Change	Based on test data and assumed ideal tank mounts.
Weapon Assembly/Disassembly	Based on test data and experience.
Weapon Compatibility	
Ammo Sensitivity	Based on test data. The Russian PKM is now being modified to fire US and NATO rounds for testing.
Vehicle Compatibility	Based on experience and studies conducted in machine gun/vehicle interfaces. Also, considered were ammo storage and fire control systems.
RAM-D	
Durability	Based on receiver life test data.
Maintainability	
Parts Usage	Based on parts usage data for US candidates and limited test experience on foreign weapon systems.
Tools and Special Equipment	Based on number of tools and special equipment needed for field and higher maintenance levels.
Parts Interchangeability	All weapons were rated the same except for the Russian PKM which requires serial numbered parts (i.e., limited or non-existence of part interchangeability).
Mean Time To Repair (MTTR)	Based on test data and experience.
Maintenance Ratio (MR)	Judged the same for all weapons as no information was available.
Reliability	
Mean Rounds Before Failure (MRBF)	Based on test data.
Mean Rounds Before Stoppage (MRBS)	Based on test data.

TABLE 3. ATTRIBUTE SCORE FOR CANDIDATE WEAPONS

Performance Category	Weapon								
	M213	M219PI	M60E2	PKM	MAG58	L8A1	C1	AAT52	MG3
ACCURACY LIFE	10.00	10.00	9.70	6.70	4.50	4.50	7.20	4.00	0.00
GUN ACCURACY	9.70	9.40	9.00	9.40	9.40	9.40	10.00	8.50	7.10
CYCLIC RATE	10.00	10.00	9.00	8.10	6.10	6.10	9.00	6.10	7.50
SUSTAINED RATE	10.00	10.00	9.60	7.10	6.10	6.10	7.10	3.90	3.90
TERMINAL EFFECT	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
POSITION DISC.	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
ENVIRONMENTAL	10.00	7.00	10.00	7.00	7.00	7.00	10.00	10.00	7.00
OBSCURATION	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
M.F.F.	10.00	10.00	7.40	7.40	10.00	10.00	6.60	7.40	10.00
SAFETY	8.30	8.30	6.00	6.00	10.00	10.00	2.60	9.10	8.30
TRAINING	6.10	5.80	7.60	6.10	7.60	7.60	6.10	10.00	9.00
BARREL CHANGE	9.20	9.20	6.40	5.00	6.40	6.40	1.00	6.40	10.00
ASM/DISASM	8.20	8.20	10.00	10.00	10.00	10.00	3.70	10.00	10.00
AMMO SENS.	5.70	7.20	10.00	7.20	10.00	5.70	10.00	10.00	10.00
VEHICLE COMPAT	10.00	10.00	7.30	2.30	2.30	2.30	9.40	8.90	6.00
PARTS USAGE	7.90	2.60	9.20	7.90	10.00	4.10	5.10	5.10	2.60
TOOLS/SPEC. EQ.	10.00	9.00	9.00	6.90	9.00	9.00	6.90	10.00	10.00
PART INTERCHG	10.00	10.00	10.00	0.00	10.00	10.00	10.00	10.00	10.00
MTTR	10.00	10.00	10.00	1.90	10.00	10.00	7.90	10.00	10.00
MR	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
MRBF	7.70	4.50	6.70	10.00	5.50	5.80	2.00	4.70	4.90
MRBS	1.80	2.10	6.50	4.90	10.00	3.70	0.00	4.00	2.40
DURABILITY	4.80	4.80	10.00	10.00	10.00	10.00	7.40	5.10	10.00

TABLE 4. WEIGHTED ATTRIBUTE SCORE FOR CANDIDATE WEAPONS

Performance Category	Weapon								
	M219	M219PI	M60E2	PKM	MAG58	L8A1	C1	AAT52	MG3
ACCURACY LIFE	0.36	0.36	0.35	0.24	0.16	0.16	0.26	0.14	0.00
GUN ACCURACY	0.23	0.23	0.22	0.23	0.23	0.23	0.24	0.20	0.17
CYCLIC RATE	0.09	0.09	0.08	0.07	0.05	0.05	0.08	0.05	0.07
SUSTAINED RATE	0.21	0.21	0.20	0.15	0.13	0.13	0.15	0.08	0.08
TERMINAL EFFECT	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
POSITION DISC.	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
ENVIRONMENTAL	0.31	0.22	0.31	0.22	0.22	0.22	0.31	0.31	0.22
OBSCURATION	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
H.F.F.	0.30	0.30	0.22	0.22	0.30	0.30	0.20	0.22	0.30
SAFETY	0.19	0.19	0.13	0.13	0.22	0.22	0.06	0.20	0.19
TRAINING	0.14	0.13	0.17	0.14	0.17	0.17	0.14	0.22	0.20
BARREL CHANGE	0.44	0.44	0.31	0.24	0.31	0.31	0.05	0.31	0.48
ASM/DISASM	0.32	0.32	0.39	0.39	0.39	0.39	0.15	0.39	0.39
AMMO SENS.	0.15	0.19	0.26	0.19	0.26	0.15	0.26	0.26	0.26
VEHICLE COMPAT	0.61	0.61	0.45	0.14	0.14	0.14	0.58	0.55	0.37
PARTS USAGE	0.07	0.02	0.08	0.07	0.09	0.04	0.05	0.05	0.02
TOOLS/SPEC. EQ.	0.18	0.16	0.16	0.12	0.16	0.16	0.12	0.18	0.18
PART INTERCHG	0.36	0.36	0.36	0.00	0.36	0.36	0.36	0.36	0.36
MTTR	0.45	0.45	0.45	0.09	0.45	0.45	0.36	0.45	0.45
MR	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72
MRBF	1.27	0.74	1.11	1.65	0.91	0.96	0.33	0.78	0.81
MRBS	0.24	0.28	0.88	0.66	1.35	0.50	0.00	0.54	0.32
DURABILITY	0.58	0.58	1.20	1.20	1.20	1.20	0.89	0.61	1.20
TOTAL	7.52	6.89	8.34	7.17	8.12	7.15	5.58	6.93	7.09

TABLE 5. RANKED CANDIDATE WEAPONS

GROUP	RANK	NATION & NOMENCLATURE	ATTRIBUTE VALUE
1	1	US-M60E2	8.34
	2	Belgium-MAG58	8.12
2	3	US-M219	7.52
	4	Soviet-PKM	7.17
	5	UK-L8A1	7.15
	6	FRG-MG3	7.09
	7	French-AAT52	6.93
	8	US-M219PI	6.89
3	9	Canadian C1	5.58

SENSITIVITY ANALYSIS

A sensitivity analysis was conducted on the weights assigned to the three major categories - Technical Performance, Physical Characteristics and RAM-D. Variations of these weights affect the scores and the ranking of the candidate weapons. The scores attained by the candidate weapon in each of the three categories are presented in Table 6. These scores, when multiplied by the respective category weights and summed, produce the weighted performance scores used to establish the weapon ranking.

Analysis of these scores indicates that if each category is assigned a weight above 0.07, then the M60E2, MAG58, and the M219 constitute a dominate set of weapons, i.e., at least one of them will rank higher than the other 6 candidates. For example, the M219 dominates the M219PI unless RAM-D and Technical Performance are assigned weights less than 0.07. Weights below 0.07 were not considered appropriate as these would effectively eliminate the attribute category from having an impact on the decision; therefore, all candidates except for the M219, MAG58, and M60E2 were excluded from further analysis.

Figures 5 and 6 present a mapping of the three candidates (i.e., M60E2, MAG58, and the M219) as a function of weight assignment. Figure 5 presents this information in terms of Physical Characteristics versus RAM-D; whereas, Figure 6 is in terms of Technical Performance versus RAM-D. The procedure used in mapping the dominant domains as a function of weights is presented in Appendix A.

Interpretation of the sensitivity analysis follows:

1. The candidate weapons Soviet PKM, UK L8A1, FRG MG3, French AAT52, US M219PI and Canadian C1 were considered dominated by either the Belgium MAG58, US M60E2 or the US M219 for the three major attribute categories: Technical Performance, Physical Characteristics, and RAM-D.

2. The Belgium MAG58 dominated the M60E2 and M219 for high RAM-D weight assignments.

3. The US M219 dominated the M60E2 and MAG58 for low RAM-D weight assignments.

4. The US M60E2 dominated the MAG58 and M219 for RAM-D weight values between 0.33 and 0.55 and generally dominated both between the high and low extremes for the three categories.

TABLE 6. MAJOR CATEGORY ATTRIBUTE SCORES

	CANDIDATE WEAPONS								
CATEGORY	M60E2	MAG58	M219	PKM	L8A1	MG3	AAT52	M219PI	C1
TECHNICAL PERFORMANCE	9.65	7.17	9.95	7.96	7.17	5.51	7.24	9.27	8.86
PHYSICAL CHARACTERISTICS	7.75	7.19	8.61	5.83	6.74	8.77	8.64	8.74	5.69
RAM-D	8.26	8.73	6.45	7.52	7.30	6.78	6.14	5.53	4.71
DOMINATING WEAPONS	NONE	NONE	NONE	M60E2	M60E2 MAG58	M60E2	M219	M219	M60E2 M219

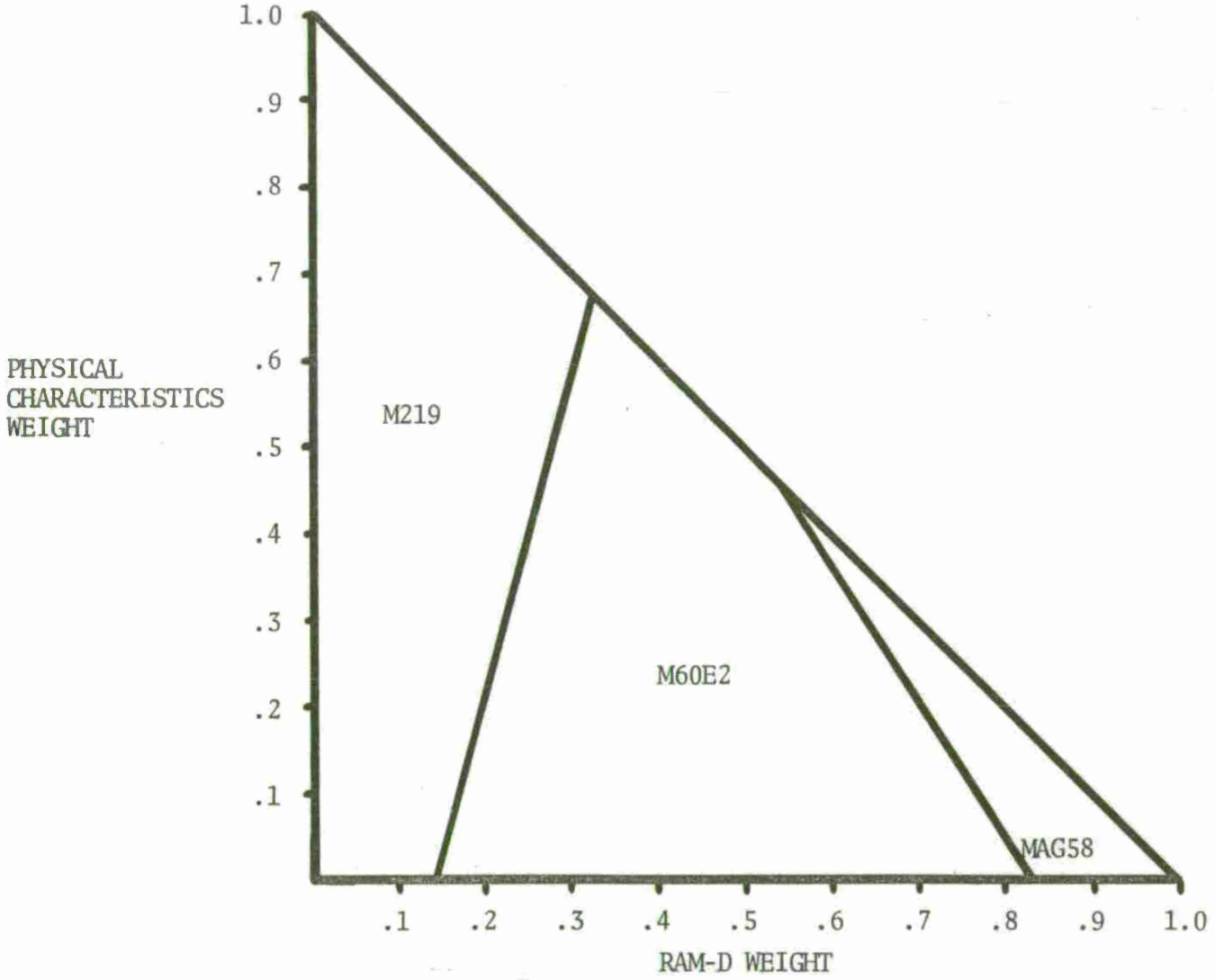

Figure 5. Preferred Candidate for Physical Characteristics And RAM-D Weight Assignments

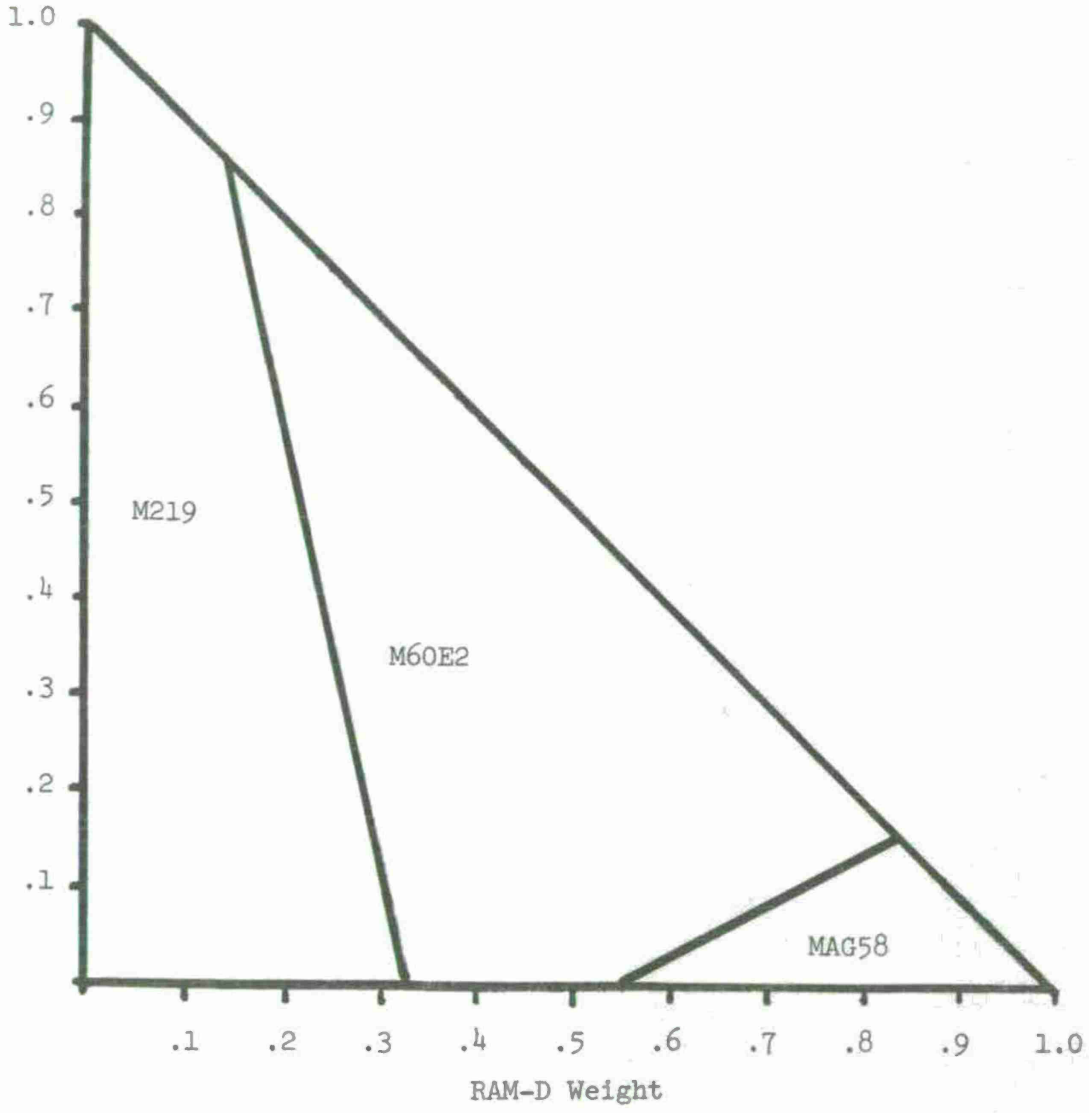

Figure 6. Preferred Candidate for Technical Performance and RAM-D Weight Assignments

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APPENDIX A. SENSITIVITY ANALYSIS METHODOLOGY

The system used to rank each weapon consisted of adding the weighted scores for each candidate at each level depicted in the dendritic tree shown in Figures 1 through 4. The weapons were ranked in decreasing order, i.e., the weapon with the largest sum-of-weighted scores was ranked number one. This section addresses the question: how sensitive is the ranking to the weights applied to each of the major categories, Technical Performance, Physical Characteristics, and RAM-D?

The M60E2, MAG58, and M219 constitute a dominant set of weapons. That is, at least one of them will be ranked number one for any weights assigned above 0.07. To determine the sensitivity of the ranking among these three candidates let $\vec{\lambda}$ be a vector of weights assigned to each major category and $\vec{S}_i$ be the score vector for the ith candidate. Then the weighted score for weapon i can be expressed as $WS_i = \vec{\lambda} \cdot \vec{S}_i$ where

$$\vec{\lambda} = \begin{bmatrix} \lambda_1 \\ \lambda_2 \\ \lambda_3 \end{bmatrix} \qquad \vec{S} = \begin{bmatrix} S_1, S_2, S_3 \end{bmatrix} = \begin{bmatrix} 9.65 & 7.17 & 9.95 \\ 7.75 & 7.19 & 8.61 \\ 8.26 & 8.73 & 6.45 \end{bmatrix}$$

A feasible $\vec{\lambda}$ is defined as $\Sigma\lambda_i = 1$ and $\lambda_i > 0$. This states that all weights contribute positively to the ranking. Setting $WS_i = WS_j$ $i,j = 1, 2, 3$ $i \neq j$, we find there exists a set of feasible weights which will result in equal weighted scores. This set of equal scores is defined by a line. On one side of the line one weapon dominates and on the other side the remaining weapon dominates. These lines can be solved for each weapon pair.

The following equations describe the weighted scores for each weapon:

$$9.65\ \lambda_1 + 7.75\ \lambda_2 + 8.26\ \lambda_3 = WS_1 \quad \text{(M60E2)}$$

$$7.17\ \lambda_1 + 7.19\ \lambda_2 + 8.73\ \lambda_3 = WS_2 \quad \text{(MAG58)}$$

$$9.95\ \lambda_1 + 8.61\ \lambda_2 + 6.45\ \lambda_3 = WS_3 \quad \text{(M219)}$$

$$\lambda_1 + \lambda_2 + \lambda_3 = 1$$

Setting $WS_i = WS_j$ $i \neq j$ and solving in terms of λ_1 and λ_3 results in the following equations:

$$\lambda_1 = 1.54 - 4.77\ \lambda_3 \qquad \text{(B.1)}$$

$$\lambda_1 = 1.04 + 2.73\ \lambda_3 \qquad \text{(B.2)}$$

$$\lambda_1 = -.292 + .536\ \lambda_3 \qquad \text{(B.3)}$$

Since $\Sigma\lambda_i = 1$, an assignment of two weights specifies the third. The space of assignable weights can be illustrated graphically with any two of the weights as the primary axes. The Equations (B.1), (B.2), and (B.3) correspond to lines A, B, and C, respectively, in Figure B-1. Line A defines the set of weights where the weighted scores for the M219 and M60E2 are equal. To the right of this line, the M60E2 will dominate and to the left the M219 will dominate. Likewise, line B and C define the set of weights where the M219 vs MAG58 and M60E2 vs MAG58 are equal. Since the M60E2 dominates the MAG58 to the left of line C and also dominates the M219 to the right of line A, the M60E2 dominance region lies between lines A and C as shown in Figure 6. The M60E2 occupies 51% of the feasible space, the M219 occupies 42%, and the MAG58 occupies the remaining 7%.

Since the three lines do not intersect within the feasible region, it can be concluded that no feasible set of weights exist such that all three weapons would be ranked equally.

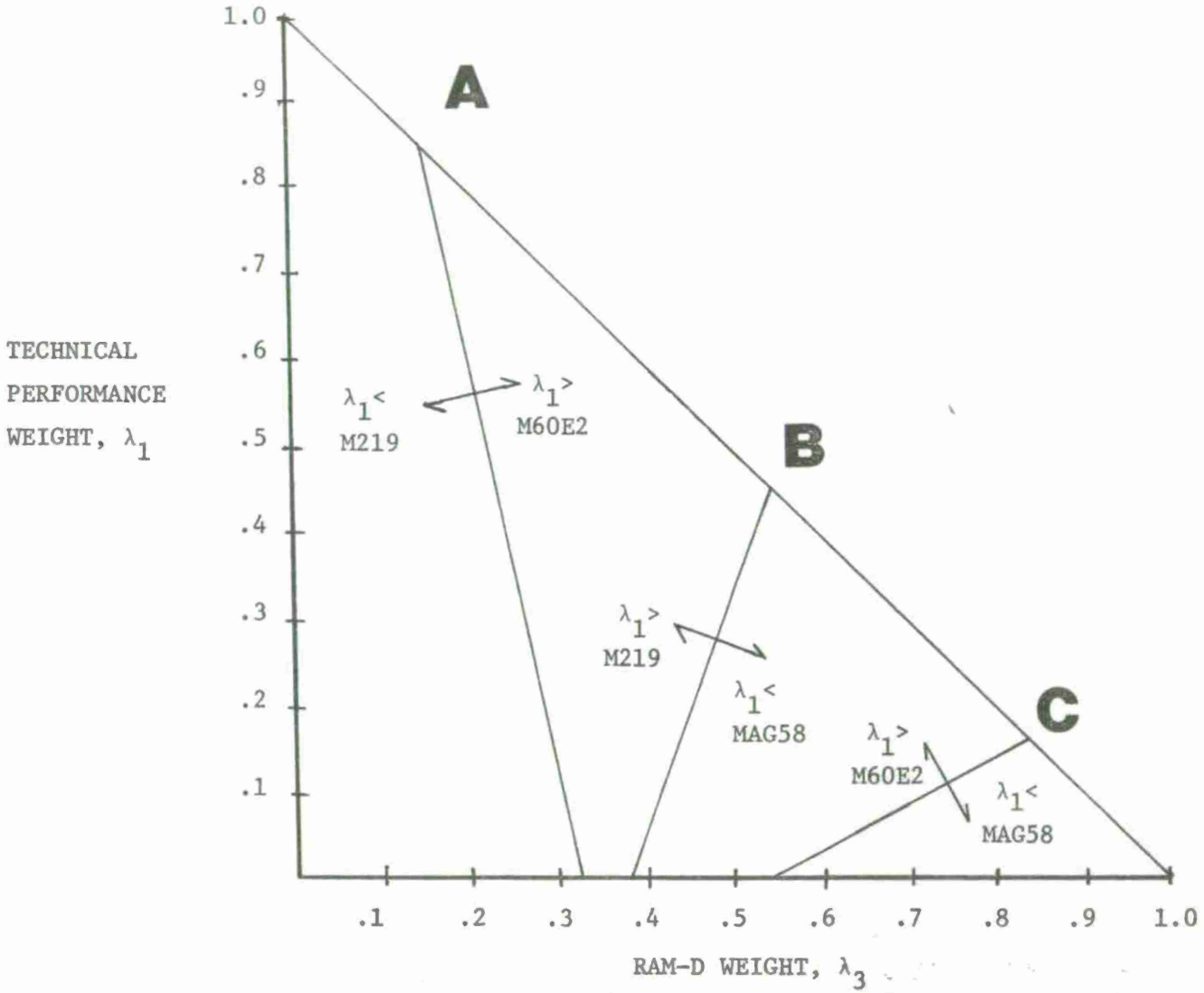

Figure A.1. Dominance Space of Candidate Weapons: Analytical Description of Feasible Regions

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