United States Military Academy
West Point, New York 10996

Future Main Battle Tank Analysis for Louisiana Maneuvers

CPT (P) Mark E. Tillman

Cadet David Coslin
Cadet Robert Walker
Cadet Thomas White
Cadet Todd Tarantelli
Cadet Mark Bernetti
Cadet Michael Torreano
Cadet Dennis Bodgan
Cadet Michael Pratt
Cadet Brodie Hodges
Cadet Met Oktay

19990325 007

OPERATIONS RESEARCH CENTER
TECHNICAL REPORT NO. FY93/93-9.1

15 June 1993

The Operations Research Center is supported by the Assistant Secretary of the Army for Financial Management.

The sponsor for this project is the Armament Research, Development and Engineering Center (ARDEC), Picatinny Arsenal, NJ.

DTIC QUALITY INSPECTED 4

DISTRIBUTION STATEMENT A
Approved for Public Release
Distribution Unlimited

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	15 JUNE 1993	TECHNICAL REPORT

4. TITLE AND SUBTITLE

FUTURE MAIN BATTLE TANK ANALYSIS FOR LOUISIANA MANEUVERS

5. FUNDING NUMBERS

6. AUTHOR(S)

CPT MARK E. TILLMAN, CADETS COSLIN, WALKER, WHITE,
TARANTELLI, BERNETTI, TORREANO, BODGAN, PRATT, HODGES, OKTAY

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

USMA OPERATIONS RESEARCH CENTER
WEST POINT, NEW YORK 10996-1779

8. PERFORMING ORGANIZATION REPORT NUMBER

TECH RPT # FY93/93-9.1

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION / AVAILABILITY STATEMENT

DISTRIBUTION STATEMENT A.
APPROVED FOR PUBLIC RELEASE; DISTRIBUTION IS UNLIMITED.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

THIS REPORT SUMMARIZES THE METHOD AND DOCUMENTS THE RESULTS OF CADET DESIGNS AT THE UNITED STATES MILITARY ACADEMY DURING SPRING TERM, 1993. THE FOCUS OF THESE DESIGNS WAS THE ANALYSIS OF A FUTURISTIC SYSTEM: THE FUTURE MAIN BATTLE TANK (FMBT). ALL THE CADETS DECLARED SYSTEMS ENGINEERING AS THEIR MAJOR AREA OF STUDY. OUR PURPOSE WAS ACADEMIC: TO PROVIDE THE CADETS WITH A REAL ARMY DESIGN PROBLEM WHICH WOULD SERVE AS A CAPSTONE EXERCISE, DRAWING ON THE WIDE BSE OF THE KNOWLEDGE GAINED DURING THEIR FOUR YEAR CURRICULA.

14. SUBJECT TERMS

FUTURE MAIN BATTLE TANK ANALYSIS FOR LOUISIANA MANEUVERS

15. NUMBER OF PAGES

220

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	

Future Main Battle Tank Analysis for Louisiana Maneuvers

CPT (P) Mark E. Tillman

Cadet David Coslin
Cadet Robert Walker
Cadet Thomas White
Cadet Todd Tarantelli
Cadet Mark Bernetti
Cadet Michael Torreano
Cadet Dennis Bodgan
Cadet Michael Pratt
Cadet Brodie Hodges
Cadet Met Oktay

A TECHNICAL REPORT
OF THE
OPERATIONS RESEARCH CENTER
UNITED STATES MILITARY ACADEMY

Directed by
Lieutenant Colonel James E. Armstrong, Jr. Ph.D.
Director, Operations Research Center

Approved by
Colonel James L. Kays, Ph.D.
Professor and Head
Department of Systems Engineering

15 June 1993

The Operations Research Center is supported by the Assistant Secretary of the Army for Financial Management.

The sponsor for this project is the Armament Research, Development and Engineering Center (ARDEC), Picatinny Arsenal, NJ.

Vitae

CPT(P) Mark E. Tillman

Born in May, 1960, CPT Tillman graduated in 1982 from the US Military Academy, and has served in field artillery units in both CONUS and Europe. While assigned to the 82d Abn Division, CPT Tillman participated in "Operation Urgent Fury" as a fire direction officer for the initial assault elements of the division. Later, while serving with the 42d FA Brigade in Europe, he commanded a nuclear capable, 8 gun, 8 inch battery for nearly 20 months. In 1991 he was awarded a Masters of Science Degree in Mathematics (OR) from the Colorado School of Mines. His thesis, A Method for Force Ratio Reduction, has drawn wide acclaim. Since then, as an Assistant Professor of Systems Engineering, he has served as director of the Military Academy's Combat Simulation Laboratory and is responsible for the instruction and development of three separate courses in combat modeling and combat system design. CPT Tillman directs cadet and faculty research in the following areas: The Enhanced Integrated Soldier System, The Future Main Battle Tank, The Future Light Helicopter, Reconnaissance, Historical Reenactments of the Battle of Gettysburg and Revolutionary War. He has been selected for attendance at the Command and General Staff College and his military awards include the Bronze Star Medal, the Meritorious Service Medal, the Army Commendation Medal (2 OLCs), the Army Achievement Medal (3 OLCs), the Ranger Tab, and the Senior Parachutist Badge.

Cadets Dave Coslin, Michael Torreano, Robert Walker, Dennis Bodgan, Thomas White, Michael Pratt, Todd Tarantelli, Brodie Hodges, Mark Bernetti, and Met Oktay

The cadets were all seniors majoring in Systems Engineering at the United States Military Academy. They were all enrolled in Systems Design II (Systems Effectiveness) for the Spring Term, 1993 while conducting this analysis. All the cadets graduated in May, 1993. Subsequently, each was commissioned as a 2LT in the Regular Army of the United States except for Cadet Oktay who was commissioned into the Turkish Army. As 2LTs, they have been assigned to a variety of posts in the branches of Infantry, Armor, Field Artillery, and Transportation.

Acknowledgments

This report benefited from the wisdom of several experienced officers.

First, we wish to thank MAJ George Stone, III. MAJ Stone provided continuous guidance throughout the past year. Busy with CGSC, he assisted us from Ft Leavenworth, and made several trips to West Point to lend advice and much needed help during critical phases of the analysis. Further providing his editorial comments during the compilation of this report, we are indebted to him from start to finish.

We also wish to thank MAJ Joeseph Waldron. He took on a time-consuming task when he volunteered to assist in the creation of this report. He literally redefines the the term "word-processing" with his wizardry. Also, the marvelous figures throughout this report are his skillful craft. MAJ Waldron also volunteered to help present this analysis at MORS 93. We were fortunate to have him assist us.

We further thank MAJ David Pride and Julie Chu of ARDEC. Both were instrumental in providing a lot of the required data on P(H) and P(K|H) from AMSAA. MAJ Pride acted superbly as a data hunter both within and outside of ARDEC. Julie Chu filled the liaison role wonderfully between West Point and ARDEC by channeling information and data. They each provided a lot of guidance on the configuration of FMBT weaponry as well.

Table of Contents

List of Tables

List of Figures

Executive Summary

This report focuses on the results of cadet designs performed in support of ARDEC analysis requirements for Louisiana Maneuvers. The study focuses on the analysis of the Future Main Battle Tank (FMBT). Our goal was to conceptualize and design a future tank and evaluate its effectiveness on tomorrow's battlefield under several different scenarios and missions. The cadets, through a top-down approach to system design, initiated this study by validating needs, developing goals and objectives to meet the needs and specifying performance parameters as part of a Feasibility Study. The results of this first phase indicate that there seems to be a need for a lighter, more deployable, more lethal, more survivable tank to fight our future wars.

After conducting limited maintainability and reliability analyses, each cadet conceptualized and built a tank in Janus (A). Next, they conducted operational testing on Janus (A) to ensure their systems were modeled correctly. Then, we evaluated several main gun alternatives on Janus (A). Trade-offs of other system parameters were performed analytically. We conducted multiple replications of each cadet's design matrix to test for significance of different factors or alternatives as part of a trade-off determination on each cadet's preliminary system design. In this phase of the study we used a Task Force defense scenario at the National Training Center with FMBT systems integrated. The results of this phase indicate the following: The most effective enhancement to the block II design is to increase the system's ability to hit a target. Interestingly, the combined enhancements of hit, kill, and recognition did not provide a significant improvement over P(H) alone. The electric tank recommendation remains mostly classified.

Finally, in the detailed design phase, we conducted multiple replications of yet a different design matrix to test for significance of factors of further interest. Among these were force mix levels and day verses night operations. Successfully integrating the FMBT systems into a brigade attack scenario in Southwest Asia, the results of this phase indicate the following: a mix of block II (enhanced) tanks and electric tanks improves the effectiveness of the force (integration of just block II (enhanced) tanks or just electric tanks did not fare as well as the mix); block II (enhanced) tanks with their thermal sensors performed better at night than the electric tanks; the electric tanks perform better in daytime.

Further, using response surface methodologies (a predictive method), and without conducting further simulation, the study concluded that a mix of tanks seems to be an optimal strategy for both day and night combat. The response surface leads us to replacing the force with either block II (enhanced) or electric systems depending on whether night or day conditions are expected.

Future Main Battle Tank
Analysis for
Louisiana Maneuvers

1. Background

1.1. Purpose

This report summarizes the method and documents the results of cadet designs at the United States Military Academy during Spring Term, 1993. The focus of these designs was the analysis of a futuristic system: The Future Main Battle Tank (FMBT). All the cadets declared Systems Engineering as their major area of study. Our purpose was academic: to provide the cadets with a real Army design problem which would serve as a capstone exercise, drawing on the wide base of knowledge gained during their four year curricula.

1.2. Scope

The analysis of the FMBT was integrated into the Systems Design II course. This course is required of all Systems Engineering majors. The course enrollment was 16 senior cadets, ten cadets choosing the FMBT as the subject of their design. The other six cadets selected the future light helicopter (Comanche). The course consisted of 40 lessons with 3.5 attendances each week (12 lectures and 28 laboratory periods). Course lectures centered on integrating the systems engineering design process into the study of the FMBT. The lab periods in the Department of Systems Engineering Combat Simulation Laboratory involved conducting database research, operational testing of system prototypes, trade-off analyses of system parameters, and full scale, battle simulation.

To gain proper perspective, it must also be mentioned that cadets are typically stressed in many aspects of life at the Military Academy beyond the requirements of this study. This course is one of 5 or 6 in which a cadet might be enrolled. Moreover, there are physical education requirements such as intramural or intercollegiate athletics, and military requirements such as parade drill and chain-of-command duties. One can visualize the hectic pace cadets experience during the academic year while studying the FMBT.

1.2.1. Scope of Feasibility Study

During this first phase of engineering design, the cadets focused on a primitive need which described a battlefield deficiency. Using a number of source documents, the cadets refined this need to an operational one and began to describe system expectations to meet this need. The end result of this phase was establishing:

1. System goals which address the need.
2. Functional objectives for the system which if met satisfy these goals.
3. System operating parameters such as environmental conditions expected.
4. A set of alternatives.
5. A set of screening criteria followed by selection of feasible alternatives.
6. A recommendation of four feasible alternatives for use in the next design phase.

1.2.2. Scope of Preliminary Design

During the second phase of the engineering design process, we integrated a client need into the analysis. This phase focused on further describing the alternatives and conducting performance trade-offs of systems design specifications. The result, a "Type A" system specification, would later become the cornerstone document to guide all ensuing engineering design regardless of discipline. Our role as systems engineers, then, would be to test and evaluate concepts derived from the feasibility study, and attempt to align these in an optimal way from a systems performance perspective. Specifically, our client, the Armament Research, Development, and Engineering Center, Picatinny Arsenal (ARDEC), wanted to know if enhancing the Block II tank's P(H), P(K|H), and Sensor P(recognition) would be worthwhile. They further wanted us to determine the contribution, if any, of the Electromagnetic Gun (EMG) and other futuristic weapons that are currently being considered in lieu of the EMG.

To accomplish this analysis, each of the five tank groups was assigned an analysis need. To keep the exercise within the scope of cadet work levels, we built the weapons and sensors derived from current weapons and sensors to enhance the probabilities in question. Next, the cadets built their tank concept inside the Janus database and then linked already configured futuristic weapons to their systems. A fully defined system in the Janus database may require input of 10 thousand or more parameters. We streamlined this procedure for the cadets by developing a Combat Systems Generator (CSG) for their use. The CSG is a computer program operating in DOS that queries the user for applicable performance parameters which define a combat system. The output of this program is a set of tables in the necessary form for input into the Janus database.

After conducting operational testing to ensure their systems were modeled correctly, they conducted multiple replications of their design matrix to test for significance of factors or alternatives which addressed the analysis needs of ARDEC. The Block II (enhanced) groups conducted four replications of their matrix (a factorial design) for a total of 16-20 Janus runs. The Electric Tank groups conducted six replications of their matrix (comparison of alternatives) for a total of 18 Janus runs. The tables below are examples of each design matrix.

Design Point	System Name[1]	P(H)	P(K)	Sensor
1	W	–	–	–
2	X	+	–	–
3	Y	–	+	–
4	Z	+	+	–
5	W	–	–	+
6	X	+	–	+
7	Y	–	+	+
8	Z	+	+	+

Table 1.1 Design Matrix for Block II (enhanced) Preliminary Design

SYSTEM X	SYSTEM Y	SYSTEM Z
WPN NAME[2]	WPN NAME	WPN NAME
IIA	IIB	IIE
None	IIC	IIC
None	IID	IID

Table 1.2 Design Matrix for Electric Tank Concept Preliminary Design

[1]Each system would have weapon A and B mounted with the appropriate level of enhancements.

Wpn A is capable of defeating only tanks out to 3 km. Basic load is 27 rds.

Wpn B is capable of defeating all targets except tanks out to 3 km. Basic load is 13 rds.

[2]A brief description of each weapon follows:

Wpn A is capable of defeating all known targets out to 4 km. Basic load is 38 rds.

Wpn B is capable of defeating only tanks out to 4 km. Basic load is 24 rds.

Wpn C is capable of defeating all targets except tanks out to 4 km. Basic load is 10 rds.

Wpn D is capable of defeating tanks from 2.5-4 km and is the preferred weapon over B in this range. Basic load is 6 rds.

Wpn E is a possible replacement for B and is capable of defeating only tanks out to 4 km. Basic load is 24 rds.

After completing the required simulation runs, each group compiled results and made appropriate conclusions about the system design.

This phase of the analysis did not consider life cycle system costs:

1.2.3. Scope of Detailed Design

The cadets continued their analysis in a detailed design. After making appropriate changes to system parameters derived from results of the preliminary design analysis and incorporating a recommended design of another cadet group, each group integrated the designs into a larger force using a more aggressive scenario. The cadets then conducted three replications (for a total of 12-15 runs) of their design matrix (a factorial design) to test the significance of factors, such as the affect of limited visibility conditions (night) and sensors.

Design Point	Factor 1	Factor 2
1	−	−
2	+	−
3	−	+
4	+	+

Table 1.3 Design Matrix for Detailed Design (all groups)

After completing the required simulation runs, each group compiled results and made appropriate conclusions about the system design.

Further, each group used response surface methodologies to explore the affect of varying the quantity of futuristic systems in the detailed design scenario. The results are very revealing and not always what was expected.

This phase of the analysis included life cycle system costs. The costs were obtained from the U.S. Army Concepts Analysis Agency and were used in their Value-Added Analysis model. Shown below is a system cost summary :

System	Life Cycle Cost (in millions)
M1A1 Tank	$3.15
Block II Tank	$3.68
Electric Tank	$6.36

Table 1.4 Summary of System Life Cycle Costs

2. Integrated Engineering Design Methodology Used

The overall analysis of FMBT was partitioned into sizable parts for each group of two cadets. The process described below is a carefully orchestrated effort which attempts to keep the analysis academic and creative; allows completion within the time frame of a semester; and addresses the client analytical needs. The figure below (figure 2.1) illustrates the three phase engineering design process used.

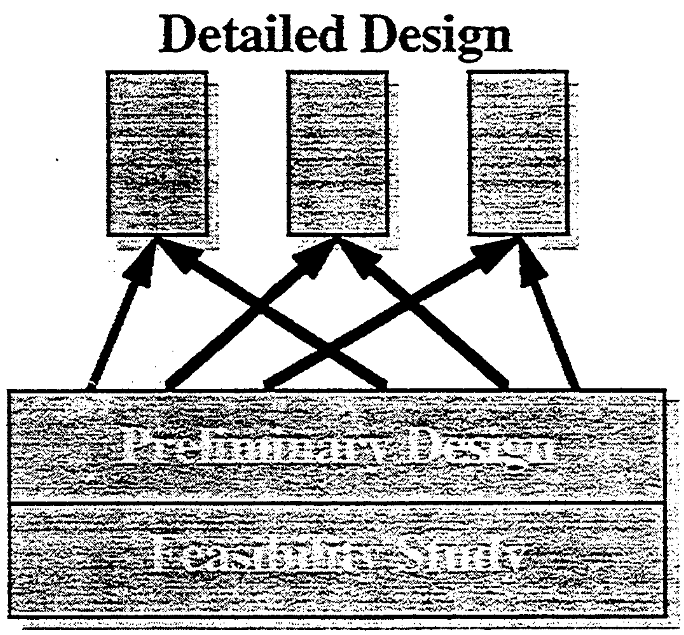


Figure 2.1 The Three Phase Engineering Design Process

2.1. Feasibility Study Integrated Methodology

In this first phase the cadets were given a primitive need to begin their study. Each group worked independently of the others (see figure 2.2). The process is further illustrated in figure 2.3. The process causes the cadets to ideate in a very broad, unlimited sense, in a quest for ways to address this need. In one case, a cadet group combined different subsystem alternatives to develop, in theory, over 403 million alternative system configurations. Screening criteria were developed and the field narrowed to several thousand feasible alternatives. Technology limitations as well as social and environmental impacts were among the screening criteria used. Realizing we could not narrow the field any further without considerable research, I asked the cadets to recommend four of the best alternatives to use in the next design phase. Further guidance required the cadets to diversify the technologies used in each alternative.

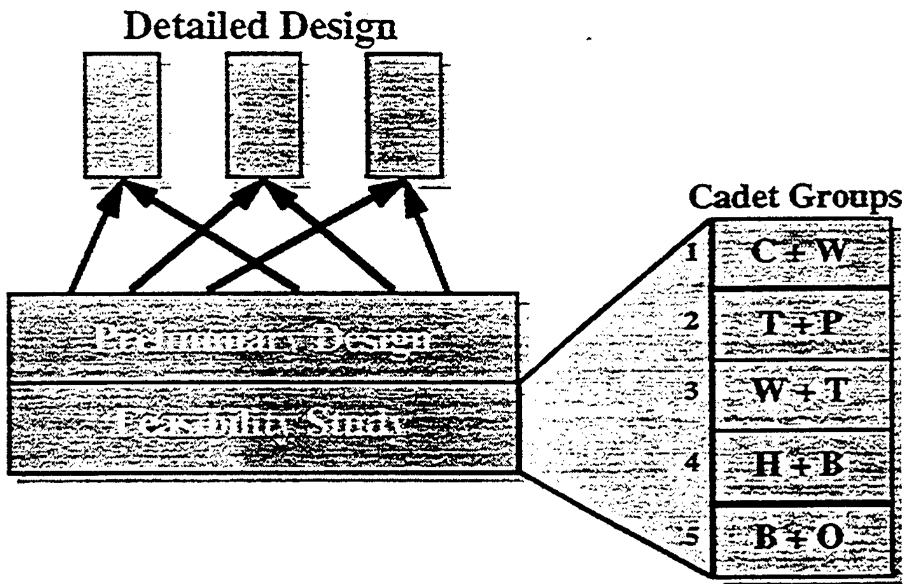


Figure 2.2 Feasibility Study Assignments

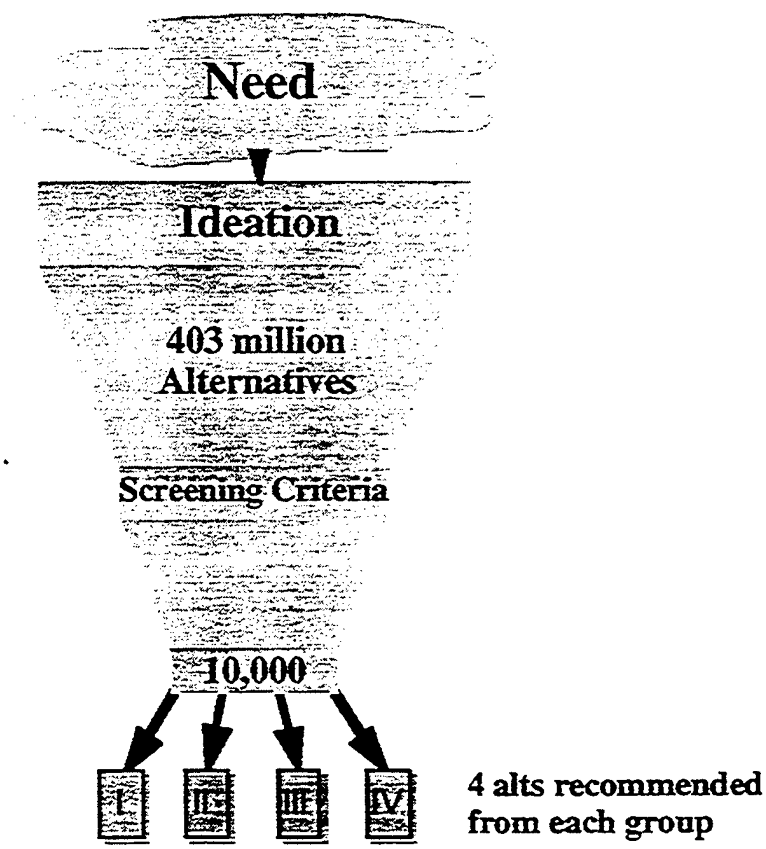


Figure 2.3 Feasibility Study Process

2.2. Preliminary Design Integrated Methodology

In the preliminary design, we directed the cadets to focus on a particular generation of tank. After reviewing the feasibility studies of each group, it appeared that the alternatives were centered on "near future" (yr 1997), and "far future" (yr 2015), technologies. The near future groups would focus on enhancing the Block II M1 series Tank (Block II (enhanced)). The far future groups would focus on the concept of the Electric Tank. The figure below (figure 2.4) illustrates the group assignments.

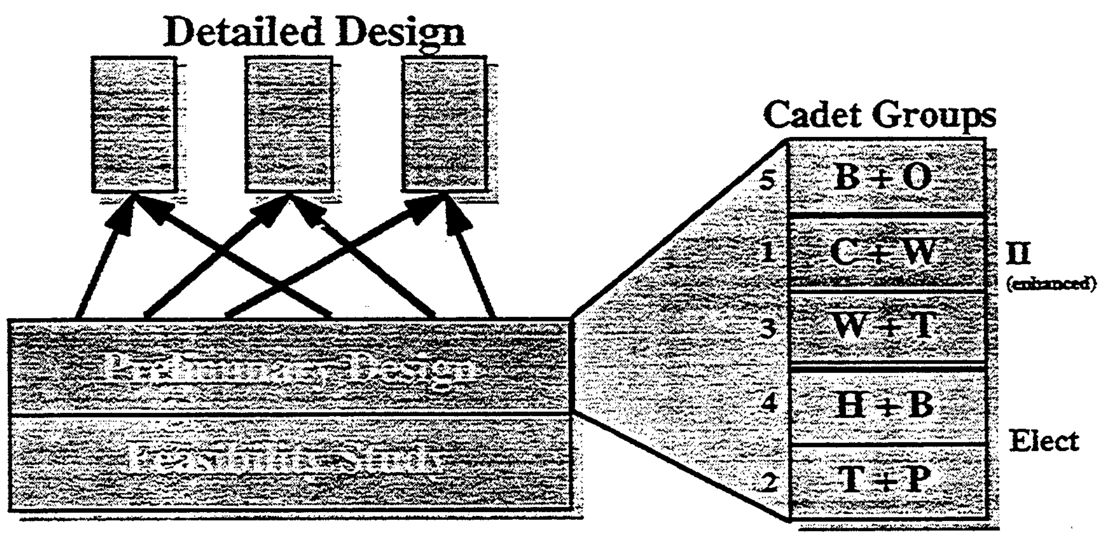


Figure 2.4 Preliminary Design Assignments

Further limiting the scope of analysis, we focused each group's analysis during this phase on a single recommended alternative from the group's feasibility study (see figure 2.5). In aggregate, the analysis of the five groups provided repetition of results and breadth of analysis which meet the client analysis needs. At conclusion of this phase, each group recommended a single alternative to be used in the detailed design phase. Most of the groups used a multi-attribute utility (MAU) model. Some cadets employed a relative worth model, while other groups used a MAU software package, HIPRE3+, to construct the decisional framework, perform utility computations, and sensitivity analysis of the ensuing recommendation.

2.2.1. Block II (enhanced)

The Block II (enhanced) groups each performed a fractional factorial design. The factors represented the enhancement or lack of enhancement to the P(H), P(K|H), P(Recognition) for the system. The resulting design points each represented an alternative configuration of the main tank gun or the system's sensor. Each system carried two types of main tank rounds (see Appendix A for system names, rounds assigned, and enhancements). Figure 2.5 illustrates this design methodology for one of the three groups detailed to this system analysis requirement.

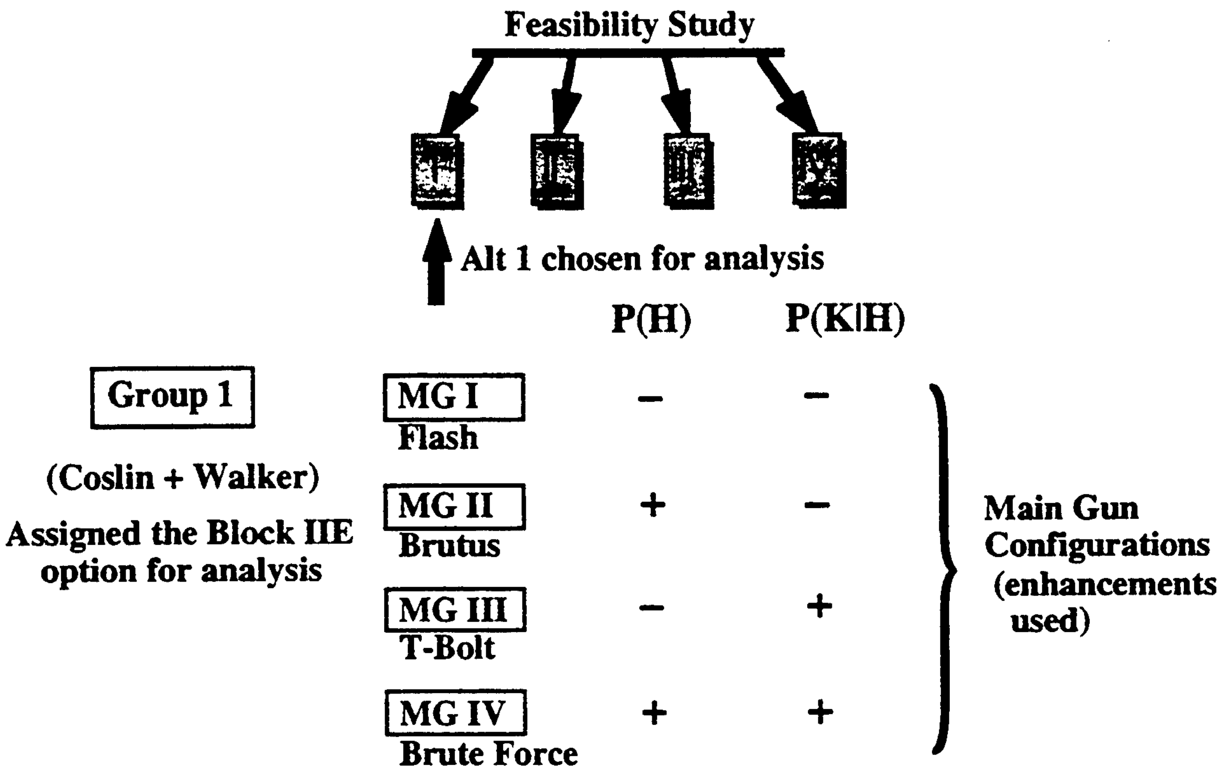


Figure 2.5 Preliminary Design Methodology (Block II (enhanced))

The scenario chosen was a static defense at the National Training Center, Ft Irwin, California. In this scenario, a Task Force (TF) defends against a Motorized Rifle Regiment (MRR). Each of the cadet systems, representing the different configurations of main guns and sensors, was integrated into identical missions for the simulation replications.

This methodology enabled a thorough analysis of the main tank gun and tank sensor without regard to the system chassis characteristics. We argue, in this context, that the chassis characteristics were not relevant to each factor's effectiveness. At conclusion, each group analyzed one of their chassis alternatives (that of an M1 series) with varied combinations of enhancements, and recommended the best system or course of action.

2.2.2. Electric Tank

The Electric Tank groups performed a comparison of alternatives design. The alternatives represented a different basic load of main tank rounds. Five different rounds were used in this analysis. Figure 2.6 illustrates this design methodology for one of the two groups who worked on this systems analysis requirement.

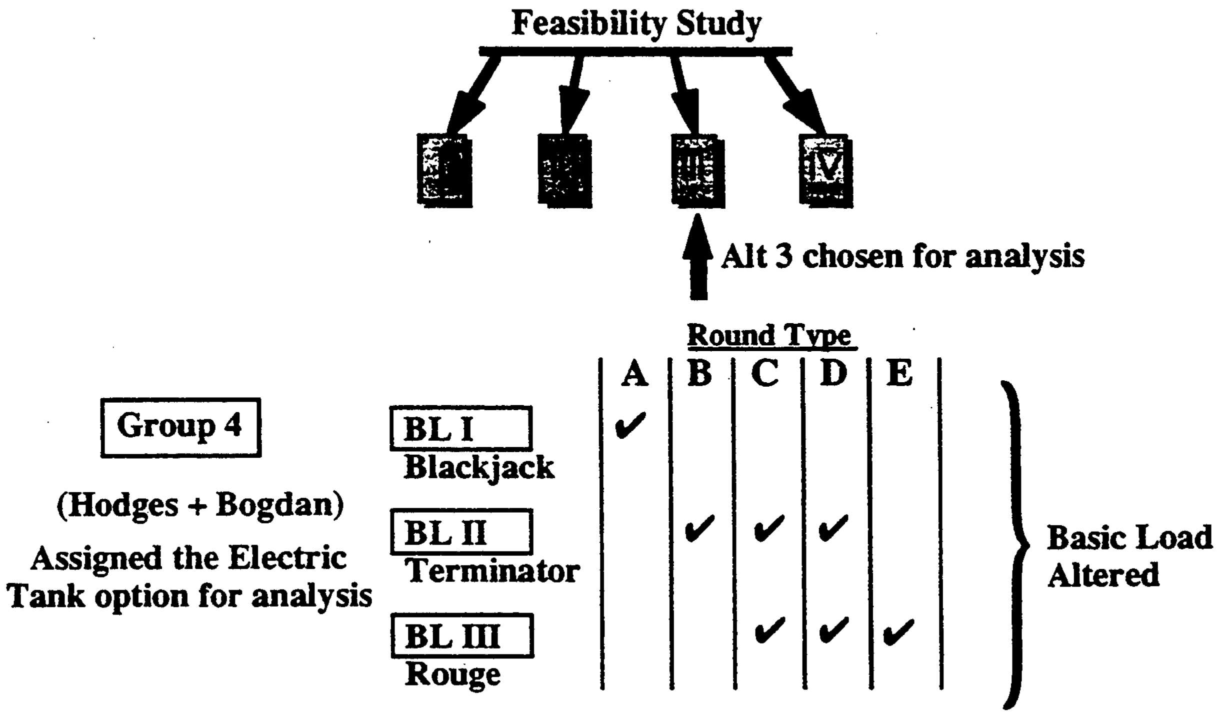


Figure 2.6 Preliminary Design Methodology (Electric Tank)

The scenario chosen was identical to the Block II (enhanced) which used a static defense. Cadet systems, representing a different configuration and number of main tank gun rounds, were integrated into identical missions for the Janus simulation.

This methodology enabled a thorough analysis of the main tank gun without regard to the system chassis characteristics. We argue, in this context, that the chassis characteristics were not relevant to round effectiveness. At conclusion, each group analyzed one of their chassis alternatives (that of an electric concept) coupled with three basic loads of five main gun rounds and recommended alternatives.

2.3. Detailed Design

In this final analysis, the Block II (enhanced) was mixed with the Electric Tank and each system's contribution to force effectiveness measured. This phase of the design process allowed the groups to further refine their system specifications as well as "open up" their systems in a larger, more aggressive scenario. Each group entered this phase with their recommended system from the previous phase. Each group was also assigned the recommended alternative of another group to use in the force mixing. We constructed a 2 factor, 2 level, full-factorial design to focus the analysis. The first factor dealt with the force mix and the second factor was the group's choice. Figure 2.7 illustrates these assignments along with the force mix factor level assignments. If a group's preliminary design focused on the Block II (enhanced), then an Electric alternative was assigned to augment force mix, and vice-versa. The "+" level (the level in which we suspect a numerically higher response from the simulation) was reserved for that group's recommended alternative from the previous phase. We understand that this would later create counter-intuitive logic in the response surface if the "+" level failed to outperform the "-" level. The "-" level was the system mix of Block II (enhanced) and Electric Tanks.

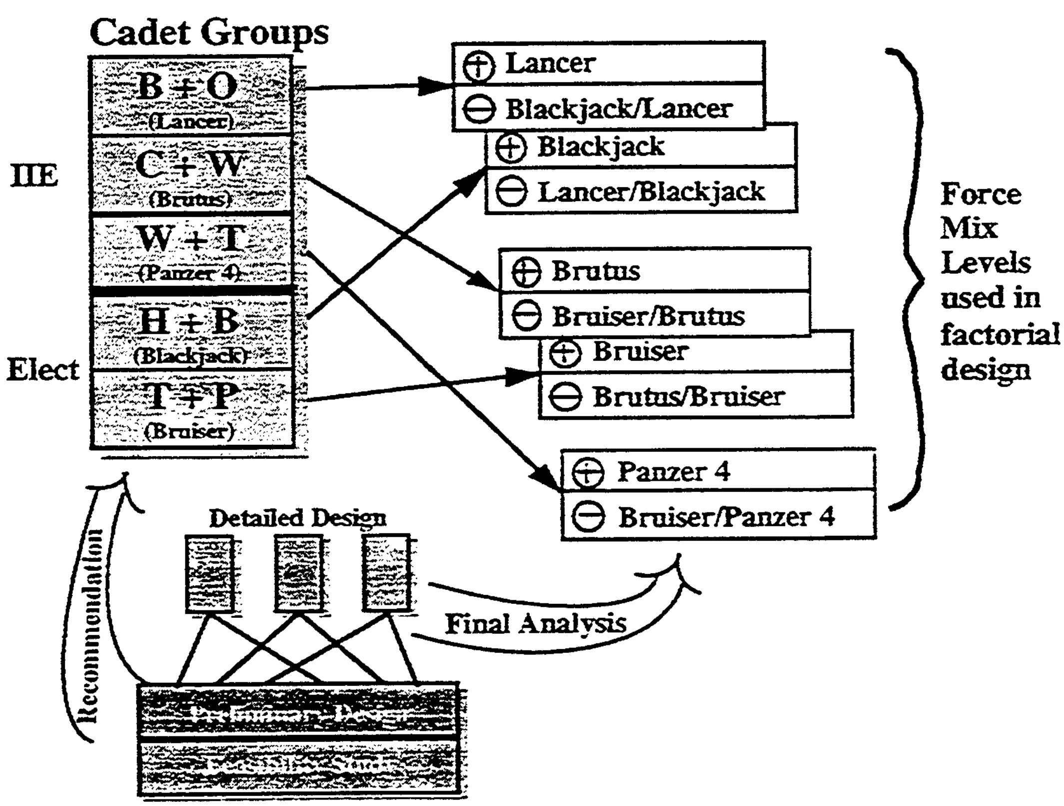


Figure 2.7 Preliminary Design Recommendations and Detailed Design Set-Up

We integrated the designs into the tactical force structure of a maneuver brigade. Figure 2.8 illustrates the task organization of the brigade and the units affected by the system integration. The two tank companies chosen for system integration were selected primarily for the enormous impact they had on battle outcome.

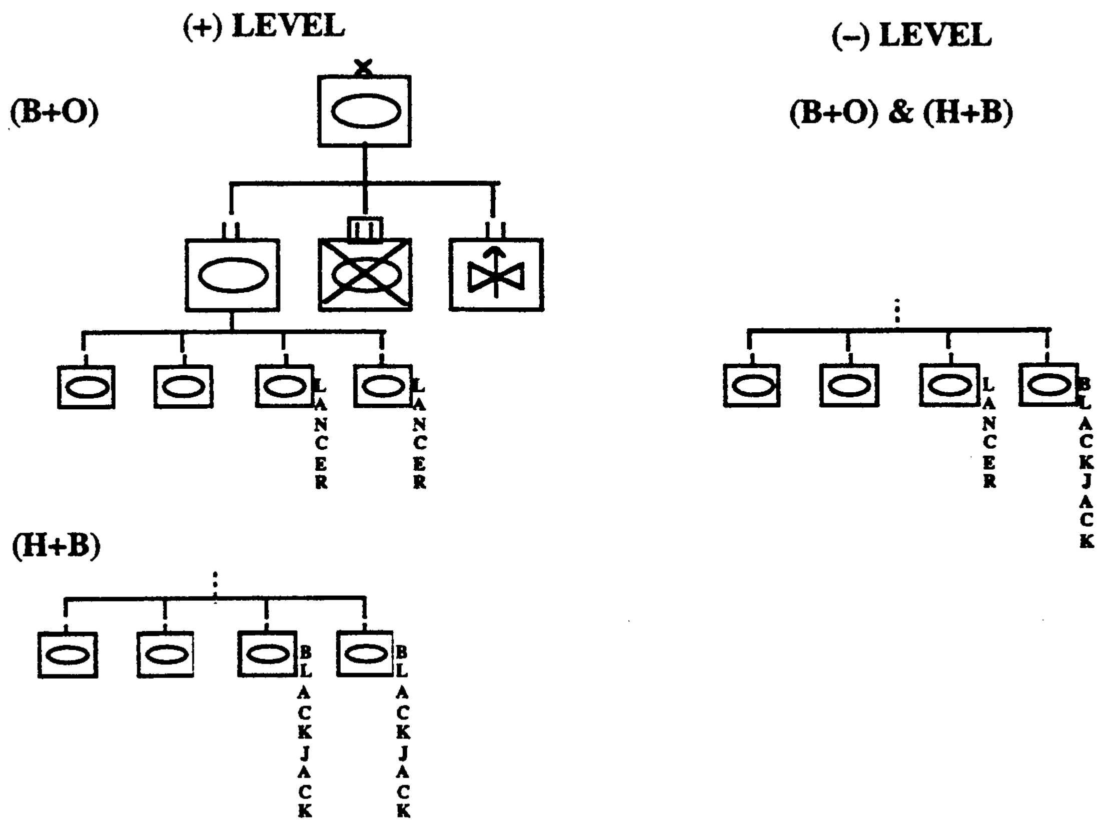


Figure 2.8 Task Organization of Force Mix

Each of these two companies play a pivotal role in force effectiveness because of the important flanking maneuver they conduct as part of the double envelopment of the enemy force (see figure 2.9).

Speed, lethality, survivability are only a few of the critical attributes of a successful system in this mission role. Interestingly, the M1A1 tank does not fare very well in this capacity. We had hoped to see an improvement in system's effectiveness as well as an improvement in the effectiveness of the futuristic brigade force.

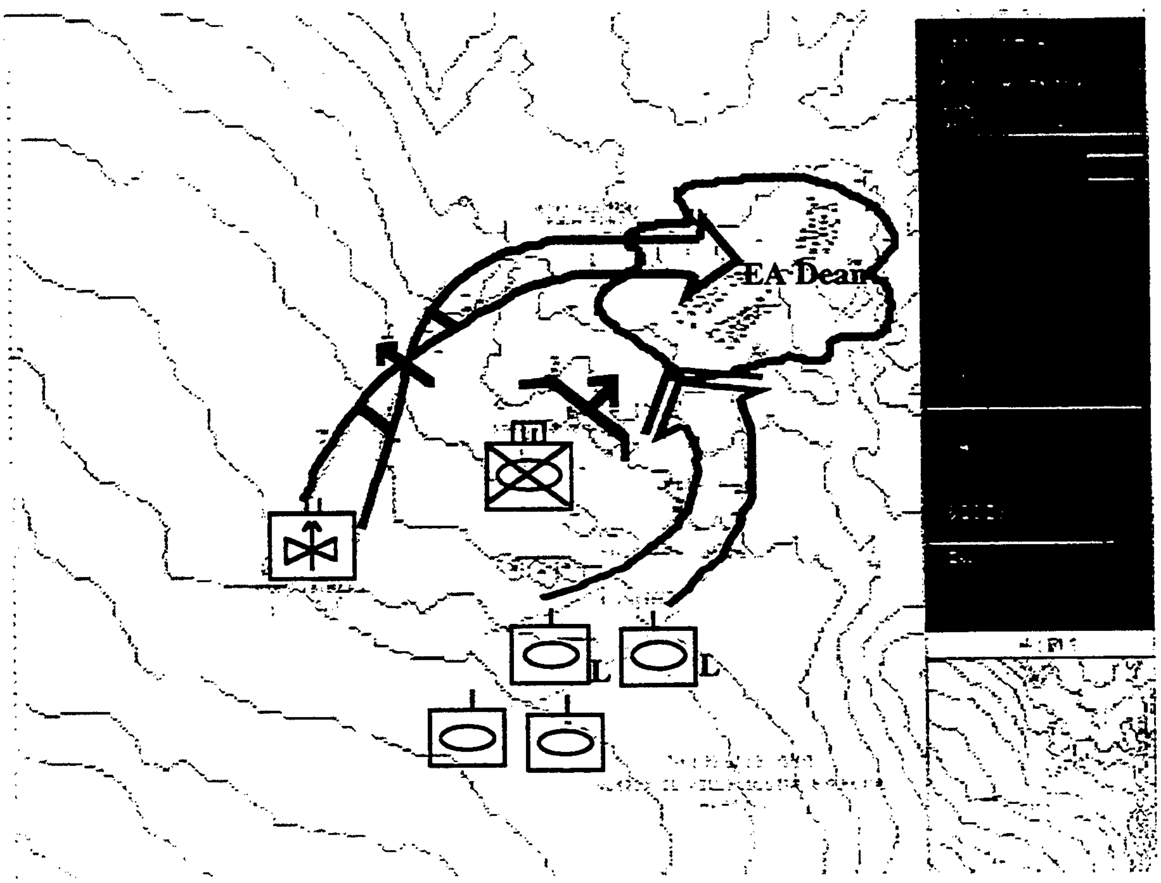


Figure 2.9 Scheme of Maneuver

The design level assignments allowed for repetition as well as diversity of analysis. We hoped, again, to see commonality among appropriate conclusions from each of the groups.

3. Summary of Needs Analysis/Feasibility Study Results

Appendix C contains samples of the cadet work. The five sets of results revealed:

1. An operational need for an improved system is valid and justifiable. The current system, the M1A2, is inadequate for the near and far future. The main deficiency is the deployability restrictions on the current system of tanks. Both inter-theater and intra-theater requirements are not met with the M1 series tank.

2. This new or improved FMBT system should perform several combat roles.

a. Anti-Armor
b. Anti-Aircraft
c. Nuclear/Chemical/Biological Detection
d. Reconnaissance

3. Goals: The highest level system goal is: Meet Demands of the Future Battlefield. Inherent to this goal are the following:

a. To be more lethal
b. To be more deployable
c. To be more survivable
d. To reduce logistical needs
e. To be more combat effective
f. To be more economically attractive

4. Cadet teams branched these goals further down into five to ten additional levels. The end result is a set of objectives to measure system performance. Examples of system objectives are:

a. Be at least 95% reliable as a system over a 96 hour operational period.
b. Reduce size to allow transport of three systems in a single C-17 aircraft.
c. Weigh less than 60 tons.
d. Be able to defeat 14" of depleted uranium armor.
e. Be equipped with laser protection for crew.

5. A functional breakdown of subsystems includes:

a. Power Supply
b. Armament
c. Main Gun Type
d. Passive Targeting System
e. Communications System
f. Mobility System
g. Projectiles
h. Anti-Air System
i. Anti-Personnel System
j. NBC Protective System
k. Laser Protection System
l. Camouflage/Stealth System
m. Sensor Package
n. Crew
o. Projectile Loading and Residue Disposal System

5. Using tools such as Zwicky's Morphological Box, some of the groups enumerated millions of alternatives. In one case, over 403 million alternatives could have been generated for consideration.

6. Some of the screening criteria used to narrow the field of alternatives were:

a. Weight
b. Size
c. Availability of Technology
d. System Complexity
e. Estimated Costs and Economical Realisability
f. Social Acceptability

7. Some of models that could be used in further analysis include:
   a. *Janus*. Janus would be used to conduct operational certifications, system performance trade-offs, and force integration analysis.
   b. *Queueing Models*. Queueing models are analytical tools to determine such parameters as rate of fire and method of fire control for the main gun. Networking and deployability issues could be explored with queueing models as well.
   c. *Integer and Linear Programs*. IPs and LPs could be used to determine optimal basic loads of tank rounds as well as the weight, cost, and volume trade-offs between subsystems.
   d. *Maintainability Models*. These models could be used to trade-off repair time parameters to meet stated objectives.
   e. *Reliability Models*: These models could be used to trade-off system failure parameters and system backup configurations to meet stated reliability objectives.

4. Summary of Preliminary Design Results

Appendices F and G contain two samples of work for this phase. The design work of cadets Coslin and Walker (cite appendix F) focuses on the Block II (enhanced) tank. Whereas the work of cadets Torreano and Pratt (cite appendix G) focuses on the Electric Tank. The charts below (Tables 4.1 through 4.2) summarize cadet work in this phase by cadet group. The "Sig Level Used" refers to the α level of a two tailed test conducted on a null hypothesis. This hypothesis asserted that the means of the responses for a given MOE associated with each factor level (or the alternative) are equal. The alternative is that they are not equal, indicating a significant difference between the factor levels. If a difference is detected, we could further identify which factor level provides a more favorable response from each MOE. The MOE in this analysis should closely relate to the achievement of the functional objectives for the main gun.

4.1. Block II (enhanced) System

Cadet Group	MOEs * indicates used in decision model	Sig Level Used	Decision Model Used	System Utility Scores ✓ indicates recommendation	Enhance-ment Recom-mended
Bernetti and Oktay	SER* FMBT Kills/Fires* Detection Range*	.35	Rel Eff MAU	Knight NA Lancer Goliath **C-D✓** Knight NA **Lancer✓** Goliath **C-D✓**	P(H), P(K|H) and P(Recog)
Tarantelli and White	Tank Killing Efficiency[3]* Combat Effectiveness[4]* # of Detections by FMBT* Kills at Max Ranges[5]* % Contribution* Main Gun Lethality[6]*	Varied[7]	MAU	Pzr 1 .269 Pzr 2 .417 Pzr 3 .324 **Pzr 4✓** .430	P(H), P(K|H) and P(Recog)
Coslin and Walker	Wt'd # of Detections[8]* Wt'd # of Aircraft Kills[9] Wt'd # of Tank Kills[10]* # of Infantry Kills* Wt'd Rg of Detections[11]* Wt'd Kills/Fires[12] Wt'd Kills/Detections[13]	0.20	MAU	Flash .416 **Brutus✓** .459 T-bolt .440 B-force .424 M1A1 .226	P(H)

Table 4.1 Summary of Preliminary Design Results (Block II (enhanced))

We might conclude from these results that the preferred alternatives are the ones that employed all the enhancements (Creeping-Death and Panzer 4). We argue that the marginal contribution provided by the P(K|H) and P(Recog) enhancements is not great. We conclude the alternatives with only the P(H) enhancement are best (Lancer, Panzer 2, and Brutus).

---

[3]Total number of red systems killed by FMBT system

[4]Total number of red losses divided by the total number of FMBT losses

[5]Kills at three kilometers or more

[6]Number of FMBT shots fired divided by the total number of FMBT kills

[7]Precision of mean response of each design point was estimated at 16.7% from the true mean

[8]Where a detection of a more important system was weighted more

[9]Where a kill of a more important aerial system was weighted more

[10]Where a kill of a more important tank system was weighted more

[11]Where a detection at greater range was weighted more

[12]Where a kill of a more important system was weighted more

[13]Where a kill of a more important system was weighted more

4.2. Electric Tank

Cadet Group	MOEs * indicates used in decision model	Sig Level Used	Decision Model Used	System Utility Scores ✓ indicates recommendation		Main Gun Rounds Recom-mended
Torreano and Pratt	SER vs T80 FER Wt'd Kills* Wt'd Detections* Fires/Kills of T80*	0.30	MAU Rel Eff	Killer **Bruiser✓** Crusher **Killer✓** Bruiser Crusher	1.0 1.16 0.58 0.491 0.609 0.324	C, D, and E
Bodgan and Hodges	SER # of Tanks Killed[14] Avg Det Rg by FMBT % Contribution[15]	.05	Rel Eff	**BJ✓** Term'r Rouge	1.0 0.84 0.84	A only

Table 4.2 Summary of Preliminary Design Results (Electric Tank)

We conclude that the alternative utilitizing the A round (Killer and Blackjack) and the alternative utilizing the C, D, and E rounds (Bruiser) are best.

---

[14]Kills by FMBT only

[15]%Contribution of kills from tank killing systems only

5. Summary of Detailed Design Results

Appendix I contains a sample of work for this phase from cadets Torreano and Pratt. The charts below (figure 5.1) summarizes cadet work in this phase. The "Sig Level Used" refers to a level of a two-tailed test conducted on a null hypothesis. This hypothesis asserted that the means of the responses for a given MOE associated with each factor level are equal. The MOE in this analysis phase should be robust enough to detect the system's contribution to the overall force effectiveness.

Cadet Group	MOEs * indicates used in decision model	Sig Level Used	Decision Model Used	System Utility Scores ✓ indicates recommendation	
Bernetti and Oktay	Detection Ratio* FER* Kills/Fires (of enemy)* Vulnerability[16]* Avg Range to Kill*	0.14	Rel Worth	Mix **Lancer✓**	0.47 0.99
Tarantelli and White	Combat Effectiveness[17]* # of Detections* Killing Potential[18]* Detections as Max Rg[19]*	0.05	MAU	**Mix-N[20]✓** Pzr 2-N **Mix-D[21]✓** Pzr 2-D	0.797 0.724 0.791 0.671
Coslin and Walker	FER* LER* Wt'd # of Detections* Wt'd Kills to Det Ratio Wt'd # of Enemy Tank Kills Wt'd Range of Detections Wt'd Fires/Kills*	0.30	MAU	Brut-T[22] **Mix-T✓** Brut-F[23] Mix-F M1A1	0.374 0.551 0.403 0.430 0.433
			Rel Eff	Brut-T **Mix-T✓** Brut-F Mix-F M1A1	1.532 1.671 1.447 1.493 1.0

Table 5.1 Summary of Detailed Design Results

---

16 # of FMBT killed/# of red fires

17 Red losses/Blue tank losses

18 Kills at max ranges (greater than 3 kilometers)

19 Detections between 2-5 kilometers

20 Night Operations

21 Day operations

22 Thermal sensor used

23 2nd Generation FLIR sensor used

Cadet Group	MOEs * indicates used in decision model	Sig Level Used	Decision Model Used	System Utility Scores ✓ indicates recommendation	
Torreano and Pratt	FER* LER* Fires/Kills* # of Enemy Kills* Avg Range to Detection* # of Detections of Enemy*	0.40	MAU Rel Worth	Bruiser Mix✓ Bruiser Mix✓	0.496 0.600 0.821 1.0
Bodgan and Hodges	SER # Enemy Killed* Avg Kill Range for FMBT Cmbt Sys Utilization* LER FER Surviving % of FMBTs*	0.20	Rel Worth[24]	BJ Mix✓	0.672 1.373

Table 5.1 (cont) Summary of Detailed Design Results

We conclude that the mix of one company of Block II (enhanced) and one company of Electric Tanks is best over the wide spectrum of combat conditions simulated. The results, it seems, are highly dependent on the choice of sensor. The Block II (enhanced) systems sported a thermal sensor whereas the Electric Tanks utilized the 2nd Generation FLIR. The FLIR performed better in daylight whereas the thermal was preferred at night. This deserves a closer look in future simulations. Also, the Lancer system deserves a more meticulous look to determine why it outperformed other Block II (enhanced) systems.

[24] This model integrated all significant MOE using an average response surface.

6. References

Advanced Land Combat Vehicle Science and Technology Thrust Panel. *Science and Technology Base Investment for Advanced Land Combat Vehicles*. 1992.

Banks, Jerry and Carson, John S. "Discrete Event System Simulation" (Englewood Cliffs, NJ: Prentice Hall, Inc., 1984)

Blanchard, Benjamin S. *System Engineering Management*. New York: John Wiley & Son Inc., 1991.

Chamberlain, Gary. "Armor Takes a Lighter Turn." *Design News* 20 Aug. 1990: 25-26.

Combat Modeling (SE485). Class Notes. United States Military Academy, West Point, NY, Department of Systems Engineering.

Combat Modeling (SE485). *Combat Modeling Notes*. United States Military Academy, West Point, NY, Department of Systems Engineering.

Crawford, Major S.W. "The Main Battle Tank: Future Developments- A British perspective." *Armor* Jan.-Feb. 1993: 18-25.

DoD Science and Technology Thrusts, Panel 5. *Advanced Land Combat: Draft Report*. 25 August 1992.

Introduction to Systems Design (SE401). Lesson Handouts and Class Notes. United States Military Academy, West Point, NY, Department of Systems Engineering.

Law, Averill M., and W. David Kelton. *Simulation Modeling & Analysis*, 2nd Ed. New York: McGraw-Hill, 1991

McVey, Peter, MG, and Col John Caldwell. *Abrams Tank System: Abrams on the Move*. American Defense Preparedness Association, 19 SEP 1992.

Nobbe, Thomas A.. "Armor Goes Hi-Tech." *Materials Engineering* Jun. 1986: 30-33.

Sage, Andrew P. "Systems Engineering" (New York: John Wiley and Sons, Inc., 1992)

Systems Design I (SE402). Lesson Handouts and Class Notes. United States Military Academy, West Point, NY, Department of Systems Engineering.

Systems Design II, Systems Effectiveness (SE403A). Lesson Handouts and Class Notes. United States Military Academy, West Point, NY, Department of Systems Engineering.

Appendix A System Names and Weapon Configurations Used in the Cadet Designs

Block II (enhanced) Tank

Cadets Coslin and Walker

System Name	Wpn	Basic Load	Name of Weapon
Flash	IA1	27	Classified
	IB1	13	Classified
			No Enhancements
Brutus	IA2	27	Classified
	IB2	13	Classified
			With P(H) Enhancement
Thunderbolt	IA3	27	Classified
	IB3	13	Classified
			With P(K|H) Enhancement
Brute-Force	IA4	27	Classified
	IB4	13	Classified
			With Both P(H) and P(K|H) Enhancements

Cadets Bernetti and Oktay

System Name	Wpn	Basic Load	Name of Weapon
Knight	IA1	27	Classified
	IB1	13	Classified
			No Enhancements
Lancer	IA2	27	Classified
	IB2	13	Classified
			With P(H) Enhancement
Goliath	IA3	27	Classified
	IB3	13	Classified
			With P(K|H) Enhancement
Creeping-Death	IA4	27	Classified
	IB4	13	Classified
			With Both P(H) and P(K|H) Enhancements

Block II (enhanced) Tank (continued)

Cadets White and Tarantelli

System Name	Wpn	Basic Load	Name of Weapon
Panzer 1	IA1	27	Classified
	IB1	13	Classified
			No Enhancements
Panzer 2	IA2	27	Classified
	IB2	13	Classified
			With P(H) Enhancement
Panzer 3	IA3	27	Classified
	IB3	13	Classified
			With P(K|H) Enhancement
Panzer 4	IA4	27	Classified
	IB4	13	Classified
			With Both P(H) and P(K|H) Enhancements

Electric Tank Concept

Cadets Bogdan and Hodges

System Name	Wpn	Basic Load	Name of Weapon
Blackjack	IIA	38	Classified
Terminator	IIB	24	Classified
	IIC	10	Classified
	IID	6	Classified
Rouge	IIE	24	Classified
	IIC	10	Classified
	IID	6	Classified

Cadets White and Pratt

System Name	Wpn	Basic Load	Name of Weapon
Killer	IIA	38	Classified
Crusher	IIB	24	Classified
	IIC	10	Classified
	IID	6	Classified
Bruiser	IIE	24	Classified
	IIC	10	Classified
	IID	6	Classified

Appendix B Feasibility Study Report Format Phase I

A. Executive Summary (limited to one page)

1. Purpose of Conceptual Design (Feasibility Study)
2. Courses of Action (Feasible Set of Alternatives)
3. Recommendations for Future Design Effort

B. Needs Analysis

1. Purpose of Needs Analysis (incl background info)
2. Goals (may incl goal tree in annex--*a vertical approach*)
3. System Description (Functional Analysis or Input/Output Analysis *may be incl in annex--a horizontal approach*)
4. Statement of Operational (effective) Need

C. Problem Definition (Operational Requirements Document)

1. Parameters (inputs)
2. Variables
3. Objectives (desired outputs)
4. Constraints

D. Solution Synthesis

1. Creative Techniques Used to Develop Alternatives (brainwriting, etc)
2. System Alternatives (may incl discussion of emerging technologies in annex)

E. Summarization of Feasible Alternatives

1. Screening Criteria
2. Feasible Set of Alternatives (*includes discussion of goal and functional coverage of alternative*)

F. Testing and Evaluation Master Plan (Concept only)

1. *Categories of Tests and Models to Use*
2. *Description of Tests to Perform*

Appendix C

Sample Work (Feasibility Study) from Cadets Coslin, Walker, Bernetti, Oktay, Bogdan, Hodges, White and Tarantelli

certification of each alternative. We will also use tests to determine the maintainability demonstration and reliability qualification of each alternative.

Needs Analysis

Purpose of Needs Analysis: The purpose of the Needs Analysis "is to demonstrate whether the original need, which was presumed to be valid, does indeed have current existence, or strong evidence of latent existence." For this project, our purpose was to determine if there indeed existed a need for a new generation of Main Battle Tanks. And if there exists a need, what is the rationale behind the need and what can be developed to counter and solve this need. The following paragraph is the client's primitive need, upon which we began the process of our needs analysis.

Primitive Need:

> The costs of combat systems have escalated enormously. The US Army has long recognized the ***need for reliable and maintainable systems*** in a variety of combat environments. A ***need to reduce maintenance, training, and support requirements*** exists along with ***increasing mission availability***. It is also believed that ***relatively cheap and sophisticated weapons*** will be capable of destroying expensive combat systems. A ***need exists to reduce the vulnerability*** of combat systems. Further, as the US Army recoils to CONUS stations, ***the need to deploy and quickly project overwhelming force anywhere with little notice*** is foreseen. If possible, combat ***systems should be capable of multiple roles.***

Currently, the backbone of our heavy units is the M1 Abrams series of main battle tanks. These tanks were developed and produced to win the great clash between the US and the Soviet Union. These tanks were designed to fight battles, using forward deployed forces, on the plains of Europe. As a result of this mind frame, these tanks weight in the range of 60 to 68.5 tons (McVey & Caldwell, 4). However, the downfall of the Soviet Union has brought about a new look at the present armor force. We are no longer concerned with a confrontation with the Soviet military. Instead, the world as we know it is transitioning from a stable bipolar world to an unstable unipolar world. The crumbling of the Soviet Union has unleashed years of repressed racial and cultural struggles (Advanced Land Combat Vehicle Science & Technology Thrust Panel, 2-3). The Serbia-Bosnia conflict is an example of the kind of confrontation that we will have to react to in the future. Another role the military is currently involved in is the assisting of law enforcement agencies and humanitarian relief. Some current examples are Operation Restore Hope in Somalia, and drug enforcement operations in South America. However, with budgetary cut backs combined with an emphasis on domestic spending, military leaders can no longer rely on a forward deployed force to accept these missions. Our heavy forces will have to rely on a CONUS based structure with rapid strike capability in order to perform their missions (Advanced Land Combat Vehicle Science & Technology Thrust Panel, 5).

Although our present M1 series of tanks are more than capable of meeting these threats, the major downfall of these tanks is their size. As mentioned before, the M1 was designed to used by a forward deployed force, the tank was not designed to be rapidly transportable by air. Its size limits its number to one in a C5 Galaxy, the Air Force's largest transport. Additionally, it is only transportable on railheads due to its weight. The result of this tank's impressive size is a tank that is an excellent tank for its mission; however, the M1 must be in the theater of operations in order to demonstrate its capabilities.

The ability of smart munitions to destroy an armored vehicle has added a new dimension to the modern battlefield. Weapons ranging from the "fire and forget" hellfire to the tank sensing SAD munitions have caused a need for armor protection all over the vehicle (Advanced Land Combat Vehicle Science & Technology Thrust Panel, 5). These weapons have advantages that include inexpensive costs and deadly accuracy. These smart munitions raise the need for a tank to reduce its ability to be detected.

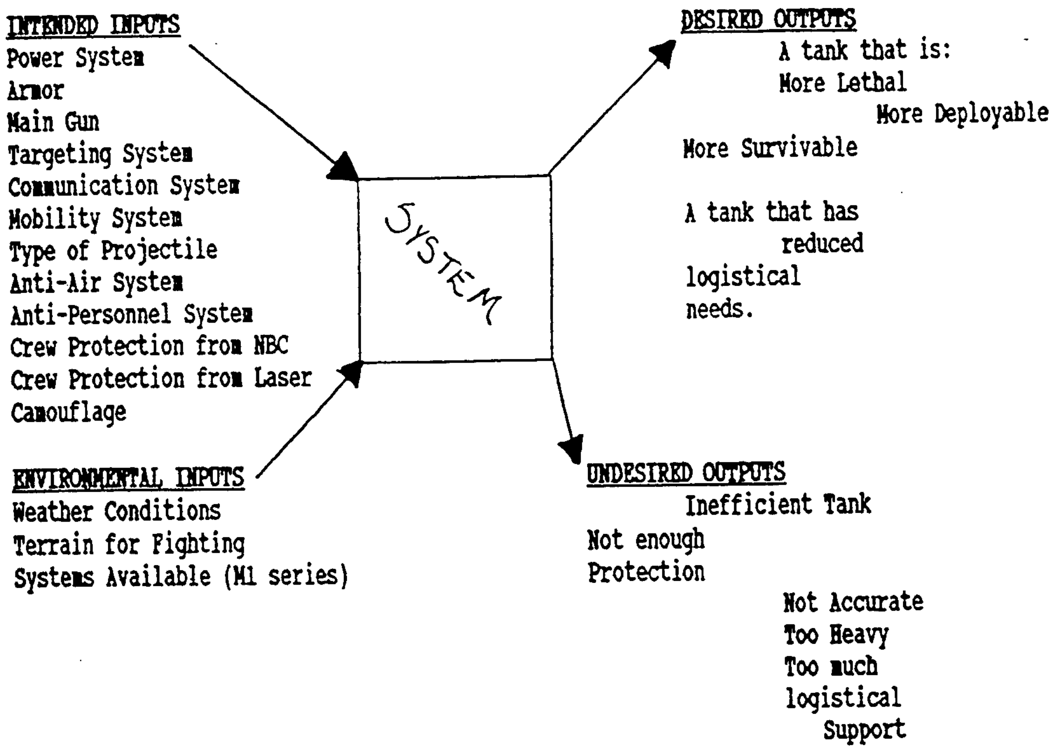
Goals:

The goals of a system help define what the system is expected to perform. These goals drive the design process: from the selection of alternatives to the objectives and criteria and weighting scheme used to evaluate the performance of the system. For our system, we determined our overall goal to be **DESIGN A TANK TO MEET THE DEMANDS OF THE FUTURE BATTLE FIELD.** The immediate sub-goals that will help us to achieve our overall goals are: **To be more Lethal, To be more Deployable, To be more Survivable, To reduce Logistical Needs.** (See Appendix A for a Series of Goals Trees)

System Description: The Future Main Battle Tank's mission and function will remain relatively the same. The tank must be able to **Shoot, Move,** and **Communicate.** These basic functions give way to several sub functions. We have functionally decomposed the functions of the FMBT the following was the result. The following table is intended to represent this process of functional decomposition.

Acquire Target	Start Engine	Initiate Calls
Estimate Range	Power transmission	Receive Calls
Fire	Move Tracks	Share Information
Kill Target	Move Vehicle	Receive Intelligence

After developing the functional decomposition of the system, we developed an input/output diagram to aid our analysis of what the future system should be composed of. The input/output diagram is below:



Statement of Operational Need:

The operational need of the system can be defined as the actual need that the design must address. Through a process of research and validation, one will derive the operational need. For the Future Main Battle Tank, the operational need seems to be the following:

Design a new Main Battle Tank that will allow our heavy forces to quickly react to threats all over the world. This tank needs to be smaller than our present system, but must be more lethal at the same time. There exists a need to reduce the logistical train that accompanies our heavy forces. Even though our present tanks are very survivable from frontal attacks, they lack the ability to protect vital parts from any other forms of attacks. Therefore, there exists a need to protect our tanks and crews even better than present systems, however the weight of these systems must be kept to a minimum.

Problem Definition

Purpose of the Problem Definition: The purpose of the problem definition is to bound the needs subjectively. The goals identified in the needs analysis will be converted into an engineering problem statement. The engineering problem statement will concisely state the objectives, constraints, criteria, parameters, and variables.

Parameters:

1.) Range for Angle of Elevation: to have a range from between -8 and 30 degrees.
2.) Fuel Capacity: 300 gallons
3.) Engine BHP: 1500 hp
4.) Weight:
   - Armor
   - Main Gun
   - Electronics
   - Hydraulics
   - Power plant
5.) Crew Size: 3 person
6.) Rate of fire in rounds per minute
7.) Weight measured in tons
8.) Armor protection, distance of penetration into armor by enemy sabot round at a distance of 2000 m.

Variables:

1.) Fuel Weight
2.) Ammunition Weight
3.) Ammunition Type
4.) Vehicle Speed
5.) Output of Power plant

Objectives:

1.) Maximize range of Main Gun: Supports goal "To make more lethal"
2.) Minimize the Radar Signature: Supports goal "To make less vulnerable"
3.) Minimize signature of Main Gun: Supports goal "To make less vulnerable"
4.) Maximize Kinetic Energy: Supports goal "To make more lethal"

5.) Minimize system weight: Supports goal **"To make more deployable"**

6.) Maximize armor protection: Supports goal **"To make more survivable"**

7.) Maximize use of composite armor protection: Supports goal **"To make more survivable"**

8.) Minimize fuel consumption: Supports goal **"To reduce logistical needs"**

9.) Maximize protection for crew from Artillery, NBC, fragments, and fire: Supports goal **"To make more survivable"**

10.) Maximize fuel and ammunition from fire, artillery, and direct hits: Supports goal **"To make more survivable"**

11.) Maximize protection for electronics from Electromagnetic Bursts: Supports goal **"To make more survivable"**

12.) Maximize rate of fire of Main Gun: Supports goal **"To make more lethal"**

13.) Minimize number of transportation assets required: Supports goal **"To reduce logistical needs"**

14.) Maximize the use of commercial shipping and loading assets: Supports goal **"To make more deployable"**

15.) Maximize visibility capabilities window: Supports goal **"To make more lethal"**

16.) Minimize vulnerability to air firepower: Supports goal **"To make more survivable"**

17.) Minimize vulnerability to infantry threat: Supports goal **"To make more survivable"**

18.) Minimize costs

19.) Maximize cross country mobility: Supports goal **"To make more lethal"**

20.) Maximize ability to defeat an enemy munitions: Supports goal **"To make more survivable"**

<u>Criteria:</u>

1.) Range of detection in meters through smoke and dirt obscuration

2.) Cross country mobility measured in gradient angle and diameter of obstacle

3.) Weighted Number of Detections

4.) Weighted Number of kills of Aircraft

5.) Weighted Number of kills of Tanks

6.) Number of kills of Infantry

7.) Weighted Average Range of Detections

8.) Weighted kills to Fire Ratio

9.) Weighted kills per Detection Ratio

<u>Constraints:</u>

1.) Minimum BHP produced by the power plant - 1500 hp

2.) Minimum firing distance - must fire at least 5 km

3.) Maximum Dimensions for air transport - less than 156 in ht, 144 in wide for C5; less than 142 in ht, 111 in wide for C17

4.) Maximum Dimensions for rail transport - less than 115 in ht, 128 in wide

5.) Maximum Dimensions for sea transport - N/A

7.) Maximum weight for rail transport - 65 - 73 tons

8.) Maximum weight for highway transport (including bridges) - 40 tons

9.) Maximum weight for sea transport - 70.6 tons

10.) Minimum detection range - greater than 5 km

11.) System must be at least 98% reliable

12.) Minimum distance on one load of fuel is 600 km

Engineering Problem Statement

Design a tank system that will begin to replace the current system by the year 2015. This system must perform all functions that our present series of tanks performs in addition to any new need that may arise. In order to meet these new demands, the new system must reduce the cost of maintenance, repair, and operation. Additionally this new system must reduce the time required to deploy to South West Asia. The new system must be more lethal and survivable than our present system. The new system must be financially feasible and all the technologies must be mature by 2015.

The system must be able to perform the following:

a. Elevate the gun between -8 and 30 degrees
b. Travel 600 km on 300 gallons of fuel
c. Weigh less than 50 tons fully combat equipped
d. Must have an engine capable of producing at least 1500 hp
e. Fall within the dimensions of a C17 aircraft: 142 in tall and 111 in wide
f. Must have a reliability of 98% utilizing several parallel systems
g. Must be capable of commercial shipping and loading, causing the weight to be less than 40 tons
h. Utilize stealth technology to reduce radar signal
i. Minimize the flash of the Main Gun
j. Maintain a rate of fire of 18 rounds per minute

Solution Synthesis

Creative Techniques Used:

Brainstorming - When we began to synthesize our alternatives, we decided to use the brainstorming technique in order to develop ideas for the different type of sub-systems that we wanted for the Future Main Battle Tank. Brainstorming is when the design group just sits down and thinks of different alternatives for the system.

Brain writing - In the next step of the design we began to write down on a sheet of paper some ideas of what some of the alternatives for each of the sub-systems might include.

Zwicky's Morphological Box - We also used Zwicky's morphological box in order to expand on the various alternatives that we may have for our system. To use this technique, we set up the sub-systems in a matrix and then multiplied the number of components in each of the sub-systems by each other in order to determine the total number of possible combinations for the system. We determined that we could have over 403 million different systems using each of the sub-systems.

FEASIBLE SET OF ALTERNATIVES:

For the design of the future main battle tank, we used various subsystems to compose our vehicle. We used thirteen subsystems to describe our new system. These subsystems are: Power plant, Armor, Main Gun, Targeting system, Communication system, Mobility system, Type of loader, Type of Projectile, Anti-air system, Anti-personnel system, Crew protection from NBC, Crew protection from laser, and Type of Camouflage.

These subsystems were basically named due to the available as well as the emerging technology used to produce them. Each of the sub-systems were made up of the following components:

Power pack- Turbine engine, Diesel engine, Nuclear powered engine, Jet propulsion system, Electric power system, Rocket propulsion, and a regular internal combustion engine.

Armor- Ceramic armor, Steel, Depleted Uranium, Kevlar, and a glass-fiber armor. Refer to Appendix B to view our brief report concerning the direction armor developments. The subject of the report is the use of composite armor and reactive and active armor.

Main Gun- 120mm, 135mm, and 140mm smooth bore cannon, the Electromagnetic rail gun, and possibly a laser gun.

Targeting System- Forward Looking Infrared, Thermal Tank Sight, Radar, Magnification Lens, and the Night-vision starlight sight.

Communication System- Singar FM radio, Satellite, Flags, Hand and arm signals, and Wire.

Mobility System- Tracks, Wheel, Skids, Rail, and Mechanical Legs.

Type of Projectile- Sabot, HEAT, Chemical Explosive, and High Explosive.

Anti-Air System- Laser guided munitions, Heat Seeking missile, Radar guided, .50 caliber machine gun, Main Gun - close proximity fused munitions, and the Electromagnetic gun.

Anti-Personnel System- Coax machine gun, .50 caliber machine gun, Main gun Flechet round, Ultrasonic boom, Laser gun, FASCAM, Flame-thrower, and Napalm round.

Crew Protection from NBC- Over-pressure system, Pop-out masks inside of tank (such as on airplanes), Man-carried, and Anti-NBC drugs.

Crew Protection from Laser- Reflective lenses, Glasses worn by crew, and Mirrors mounted on tank.

Camouflage- Camouflage paint, Anti-radar Covering net, Stealth paint, and Chameleon (color changing) paint.

SUMMARIZATION OF FEASIBLE ALTERNATIVES

With so many subsystems for our FMBT, there could be a total of more than 4 hundred million combinations. Therefore, we could not set up a Feasibility Matrix in order to screen our alternatives. Basically, we just went through each of the subsystems and decided if we had the technology to create them and funds available to purchase them. In many of the cases, we were able to reduce the subsystem to two or three components each. The components were broken down as follows:

Power pack- Turbine engine, Diesel engine, Nuclear powered engine, and Electric power system.

Armor- Ceramic armor, Steel, Depleted Uranium, and a glass-fiber armor.

Main Gun- 135mm, and 140mm smooth bore cannon, and the Electromagnetic rail gun.

Targeting System- Forward Looking Infrared, and Thermal Tank Sight.

Communication System- Sincgar FM radio and Flags.

Mobility System- Tracks

Type of Projectile- Sabot, HEAT, and EM rounds.

Anti-Air System- Heat Seeking missile, .50 caliber machine gun, Main Gun - close proximity fused munitions, and the Electromagnetic gun.

Anti-Personnel System- Coax machine gun and .50 caliber machine gun.

Crew Protection from NBC- Over-pressure system.

Crew Protection from Laser- Reflective lenses.

Camouflage- Camouflage paint and Anti-radar Covering net.

We also used the fact that we had to be able to develop a vehicle used for rapid deployment to screen the alternatives. Therefore, weight and size dimensions were the main criteria used for screening.

After narrowing down each of the components of the system, we developed four main alternatives using various combinations of the sub-components.

Feasible Alternatives

ALTERNATIVE ONE:

A main battle tank powered by a turbine engine. It will have ceramic armor and an EM gun. The targeting system will be the Forward Looking Infrared (FLIR). The tanks will communicate with Singar radios and the tank will move on tracks. The main gun will have an auto loader and will shoot sabot as well as HEAT rounds. The anti-air system will be heat guided missiles fired from pods on the outside of the tank. The main anti-personnel assets will include the coax machine gun as well as a commander's .50 cal. There will be an over pressure system to protect the crew from NBC threats as well as reflective lenses to protect their eyes from lasers. The camouflage will consist of camouflage paint.

This alternative will meet our goal being more lethal by having the FLIR which will enhance it capability of detecting targets. The EM rail gun will also enhance the tank's lethality. Since the EM gun fires a smaller projectile, the tank will be able to carry more ammunition and reduce the need to resupply frequently. This meets our goal of reducing the logistical needs. By developing this alternative with the ceramic armor, the tank will be much lighter and therefore satisfy our goal of being more deployable. In line with our goal of being more survivable, the over pressure system will protect the crew from an NBC threat and the reflective lenses will also improve the crew's ability to survive if a laser is shot at their eyes. The ceramic armor and camouflage paint will provide protection for the tank so that it is more survivable on the battlefield.

ALTERNATIVE TWO:

A main battle tank powered by a nuclear engine. It will have depleted uranium armor and a 135mm main gun. The targeting system will be the Tank Thermal sight. The tanks will communicate with Singar radios and the tank will move on tracks. The main gun will have an auto loader and will shoot sabot as well as HEAT rounds. The anti-air system will be heat guided missiles fired from pods on the outside of the tank. The main anti-personnel assets will include the coax machine gun, the commander's .50 cal, and a flechet round for the main gun. There will be an over pressure system to protect the crew from NBC threats as well as reflective lenses to protect their eyes from lasers. The camouflage will consist of an anti-radar net.

Alternative two will meet the goal of being mnore lethal by having a 135mm main gun. This main gun will fire both HEAT and SABOT rounds in order to increase its lethality. Due to the weight of the depleted uranium armor, this alternative failed to meet the goal of being more deployable. However, the depleted uranium armor will increase the survivability of the tank. The over pressure system and the reflective lenses also meets the goal of being more survivable by improving the survivability of the crew. The nuclear engine should be a more efficient engine, therefore reducing the amount of refueling and satisfying the goal of reducing the logistical needs.

ALTERNATIVE THREE:

A main battle tank that is "All electric." It will be powered by an electric engine. It will have a combination armor consisting of both steel and glass-fiber. The targeting system will be the Forward Looking Infrared (FLIR). The tanks will communicate with Singar radios and the tank will move on tracks. The main gun will be the EM gun, have an auto loader, and will shoot sabot as well as HEAT rounds. The anti-air system will be heat guided missiles fired from pods on the outside of the tank. The main anti-personnel assets will include the coax machine gun as well as a commander's .50 cal. There will be an over pressure system to protect the crew from NBC threats as well as reflective lenses to protect their eyes from lasers. The camouflage will consist of camouflage paint.

Alternative three will meet the goal of being more survivable with its steel and glass-fiber armor. The over pressure system and reflective lenses will protect the crew better as well. The FLIR and EM gun will improve the lethality of the tank. Since the tank will be all electric the logistcal needs will be reduced. The EM gun will also reduce the logistical needs since the rounds will be smaller and the tank will be able to carry more ammunition. The steel and glass-fiber weights less than the depleted uranium armor; therefore, the tank will be more deployable.

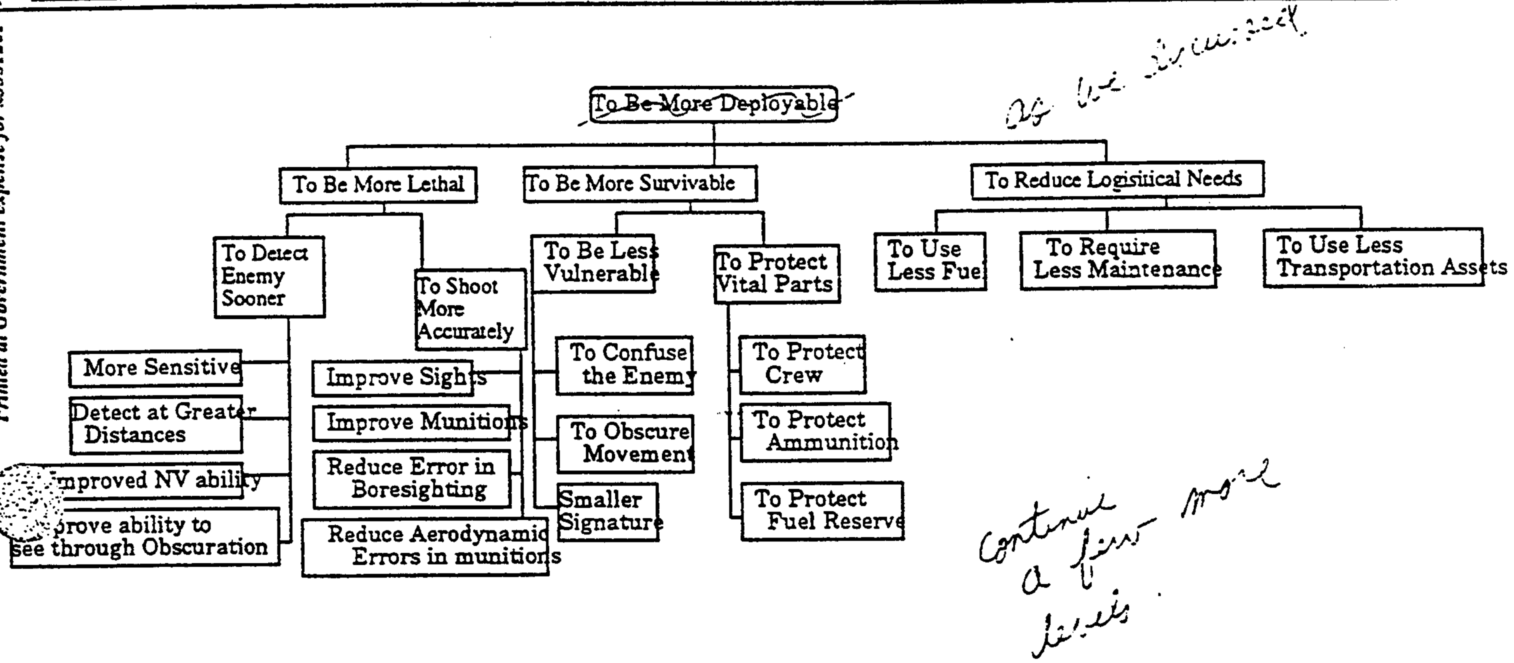
ALTERNATIVE FOUR:

A main battle tank powered by a diesel engine. It will have a composite armor of ceramic and steel. The targeting system will be the Tank Thermal Sight. The tanks will communicate with flags as well as Singar radios and the tank will move on tracks. The main gun will be a 140mm smooth bore and have an auto loader and will shoot sabot as well as HEAT rounds. The anti-air system will be heat guided missiles fired from pods on the outside of the tank and a proximity-fused HE round. The main anti-personnel assets will include the coax machine gun, the commander's .50 cal, and a flechet round for the main gun. There will be an over pressure system to protect the crew from NBC threats as well as reflective lenses to protect their eyes from lasers. The camouflage will consist of camouflage paint.

The ceramic and steel armor will allow alternative four to meet the goal of being more deployable as well as the goal of being more survivable. The 140mm main gun, which shoots both HEAT and SABOT rounds, will improve the lethality of the tank. This alternative also has an over pressure system and reflective lenses to improve the survivability of the crew. Due to the size of the ammunition and the diesel engine, alternative four failed to meet the goal of reducing the logistical needs.

Enclosure 1

Goals Tree For the Future Main Battle Tank



Printed at Government expense for x3531 2el 930204-18:00

C. Problem Definition

1. Parameters

a. Makeup of units- Standard US Army doctrine for numbers of vehicles in each unit

b. Mission of units- close and destroy enemy through fires and shock effect.

c. Given state of technology and those reachable by 2010 timeframe.

d. Current modes of global transport- C17 aircraft, rail, fast sealift ships.

2. Variables

a. Weapons System mounted (Main armament/Secondary).

b. Propulsion System (Engine/Fuel).

c. Size of whole system (Hth/Wth/Lth).

d. Crew size.

e. Protective System (Armor/Sensors/NBC).

f. Mobility System (Tracks/Wheels).

g. Communications System.

3. Objectives

a. Must be able to sight engage, and kill enemy before being engaged itself.

b. Must withstand attack from kinetic, chemical, NBC, and mine attacks.

c. Must be able to deploy to any region of the world quickly.

d. Must traverse wide variety of terrain and obstacles.

Printed at Government expense for x35939e1 930212 06:10

e. Must be able to continue on operations over a large area for an extended period of time.

f. Must be low on training, supply, and support requirements.

4. Constraints

a. Must fit into C17 cargo airplane.

b. Must weigh less than 59 tons.

c. Must be able to be loaded on sealift vessels.

d. Must be able to be loaded on all international rail gages.

e. Must be at least as good as the current MBT system.

D. SOLUTION SYNTHESIS

1. Creative Techniques Used to Develop Alternatives- To come up our different alternatives, we used a combination Zwicky's Morphological Box/Brainstorming method. First, we split up the characteristics of the system by specific subsystem which would make up any MBT. Then we used brainstorming and research to find options for each subsystem. Finally, we applied Zwicky's method to enumerate each combination, leaving us with 1,259,712 alternatives.

2. See ANNEX C for a breakdown of the subsystems and the choices therein. As you can see, we wanted to incorporate both existing technologies and future concepts into our design. This led to some research into what new technologies were even on the drawing board, and some that

Printed at Government expense for x3593Yel 930112 06:10

were not. These created many far out ideas for a future MBT, but that is what we wanted. So do I!

E. SUMMARIZATION OF FEASIBLE ALTERNATIVES

1. Screening Criteria- With all those alternatives, we had to cut down this lot, in order to be able to test a reasonable amount of alternatives. So we introduced our screening criteria, which should whittle down this large number to our set of feasible alternatives. These criteria had some to do with the constraints delineated before, but also came from other frames of mind. Some are economical, some are technological, and some are just common sense. method? These are the ones we came up with it.

1. The tank must be technologically feasible for the type of system- This eliminated the "hair-brain" ideas that really! we had in propulsion: Jet engine, solar engine, steam engine.

2. The tank must be physically realizable- This leads to a lot of cuts, where we will only take options that will honestly be fielded: Ultrasonic detection, two man and five man crews, straight rubber or steel tracks.

3. The tank must be economically feasible- This will cut out specific combination of technologies that cost too much together: EM armor and EM gun. good

After making these cuts, we wanted to ensure that the new system was at least an improvement over the current

Printed at Government expense for x35939e1 930212 06:10

system, so this cut out some options: Solid and spaced armor, diesel engine.

Finally, we had been able to get our choices down to a more manageable scale. These are the choices left:

ARMOR	Composite, Reactive, Active
GUN	Smoothbore, EM gun
GUN SIZE	120mm, 125mm, 140mm
ENGINE	Multi-fuel, Gas Turbine
TRACKS	Rubber/Steel
DETECTION SYSTEM	Infared/Thermal, Ultrasonic
ACCURACY	Autotracker, Guided/Smart
TARGET ACQUISITION	2nd generation FLIR, Laser Warning, CPS
LOADING	Manual, Auto, Auto w/ Backup
CREW	3, 4
TURRET	Fixed, None

Very good! I follow.

2. Feasible Set of Alternatives- After the screening criteria were taken into effect, we still had 2592. alternatives. We will now forward four alternatives, with specifications for each.

SPECIFICATIONS/STARTING BASE FOR ALL FOUR ALTERNATIVES. (ALL FOUR WILL HAVE THESE CHARACTERISTICS, WITH ITEMS SPECIFIC TO EACH GIVEN AFTERWARDS)

Max road speed	75 kph
Max range	550 km
Fuel Cap	1500 L
Fording	1.2 m

Printed at Government expense for x15939el 930212 06:10

Vertical Obstacle	1.2 m
Trench	3.0 m
Gradient	60
Sideslope	40
Crew	3
Height (turret top)	2.2 m
Height (no turret)	2.0 m
Length	7.0 m
Width	3.4 m
Ground Clearance	0.4 m
Weight	45000 kg
Power/Weight ratio	25
Ground Pressure	.85

good

Printed at Government expense for x35939e1 930212 06:10

ALTERNATIVE 1: ELECTRIC KNIGHT

This tank is the base tank, with focus of technology in its 120mm EM gun with Autotracker sights and, 2nd generation FLIR, with an automatic loader with backup. The funds put into this weapon give it standard layout for the rest of the subsystems: Composite layered Chobham armor, Gas Turbine, IR/Thermal sights, Oscillating turret.

good

ALTERNATIVE 2: ARMORED FOX

What this tank lacks with no EM gun, it makes up in sensors and still packs a punch with its 125mm smoothbore cannon. It will be able to perform an ARMORED LRRP with its Multi-fuel engine which gives it an addition 300 km range. It will track using an extensive detection/tracking suite,

good

Printed at Government expense for x3593el 930212 06:10

adding an ultrasonic detection system to the IR/Thermal sights, 2nd generation FLIR, MMW radar, Laser Warning Receiver. In addition, it will have standard autoloader, Oscillating turret, Rubber/Steel tracks, Composite Layered Chobham armor.

ALTERNATIVE 3: GOLIATH

This tank will incorporate extensive armor protection to protect it against all attacks, including Active Armor, Reactive Armor, and Chobham. Its main weapon is the mammoth ATACS (Advanced Technology Armored Cannon System) 140mm smoothbore cannon with Guided/Smart munitions. Its other features include Gas Turbine engine, autoloader with backup, Oscillating turret, Rubber/Steel tracks, 2nd Generation FLIR, IR/Thermal sights and Combat Protection System.

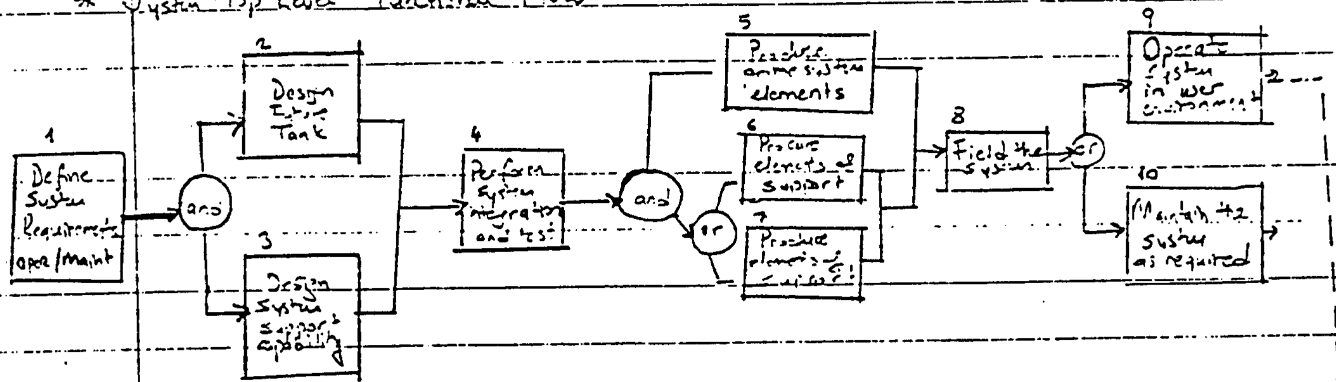
ALTERNATIVE 4: CREEPING DEATH

This tank will sport a sleek no-turret design, with only the 125mm EM gun above the hull, which houses the two man crew. It will also have reactive armor protection in addition to its Composite Armor. Its other features will be a Diesel engine, Rubber/Steel tracks, Autoloader with Backup, 2nd generation FLIR, Laser Warning Receiver, Ultrasonic-IR/Thermal detection.

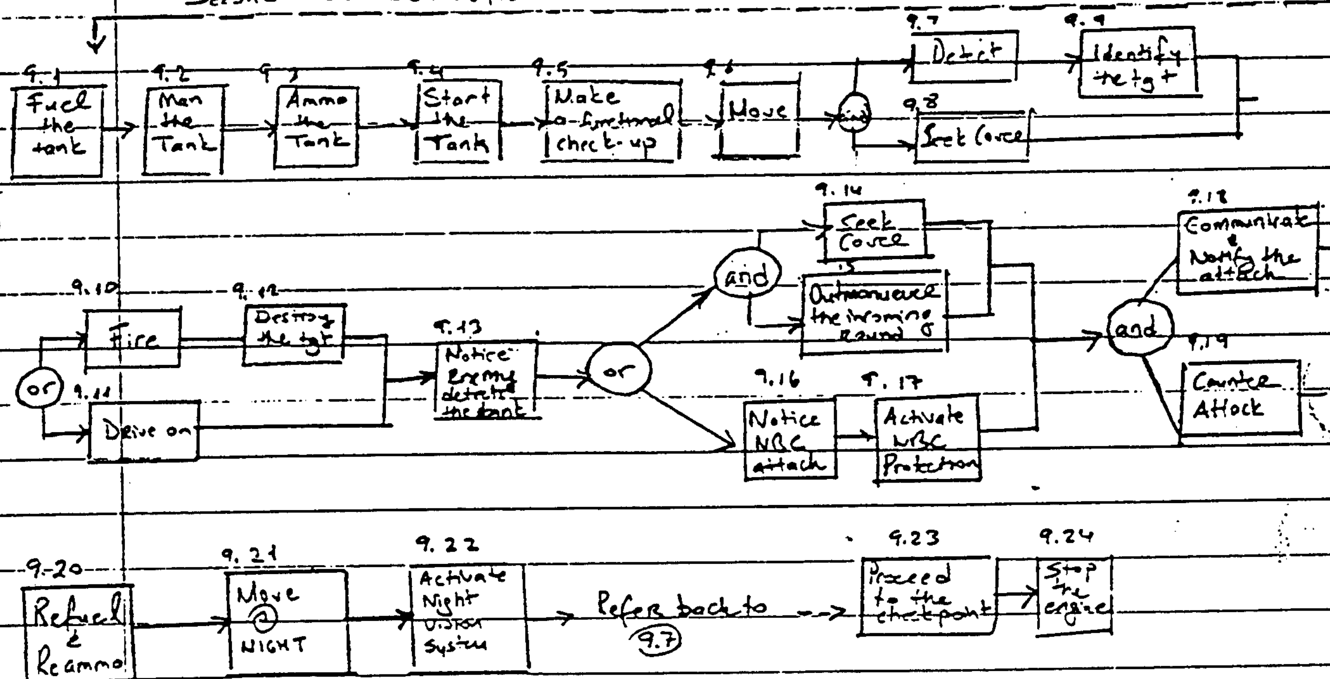
The specifications not covered by the subsystems were obtained from research into current tank design. We looked at the makeup of the current tank system and made sure that our new tank would be at least as good as the world's best

ANNEX B

* System Top Level Functional Flow



Second level Functional flow



*System Top-Level Functional Flow is obtained from the Systems Engineering Management Text by Benjamin S. Blanchard.

Annex C: Objectives, Criteria, Parameters, and Variables

Objectives	Criteria	Parameters	Variables
To min deployment time	days	dimensions combat weight	geographic location weather
To min dimensions	Cubic ft.	length, width, height	
To min life cycle costs	NPV$	logistical support	
To max cross country range	km	engine power supply combat weight	weight fuel level
To min maintenance time	MTBM	configuration	operational status
To max durability	MTBF	configuration	operational status
To max reliability	R(system)	configuration	operational status
to max % slope	gradient	engine power supply drive type	terrain weather mission
To max fording capability	ft. of water	configuration weight	terrain weather
To max cross country cruising speed	km/h over cruise range	engine power supply	fuel level weight
To min weight	tons	combat weight	weight
To max engine power	horsepower / ton	engine type	
To min 180 degree turn time	seconds		
To max top speed	km/h	engine type combat weight	terrain
To max ROF	rounds per minute	armament type	ammunition
To max lethality	SSKP	armament type fire control	threat force terrain weather
To min CEP	meters	armament type ammunition load	weather
To max armor penetration	inches of steel	armament type ammunition load	threat force
To max average detection range	meters	sensors crew	threat force weather terrain vegetation
To max queue size	number of enemy	fire control type crew	operational status
To max # of weapons	integer	armament type fire control type	
To min target ID time	seconds	fire control type sensors crew	threat force weather terrain vegetation
To min target lock time	seconds	fire control type crew	threat force weather terrain vegetation
To max fire arcs	degrees	armament type configuration	direction of threat attack

Printed at Government expense for x3560841 02/12/93 14:36.

Annex D: Zwicky's Morphological Box

Well done!

Printed at Government expense for x3560841 02/12/93 14:36

Main Gun	Support Weapons	Passive Defense	Active Defense	Fire Control
EMG	.50 cal	IFF emitter	Smart/scatter mines	Human
140mm	7.62mm MG	Low visibility	Adv. Smoke	Computer-enhanced
ECG	TOWs	Reactive armor	Stinger (ADA)	Total automation
Laser	Vulcan/Flak	Adv. composite	Smoke	
Existing	Laser/Energy	NBC	ECMs	
	Missiles (Indirect)	Low shilouette	Vulcan	
	Mortar (Indirect)	Laser absorber		
	Grenade Launcher	Laser detector		
Maneuver	**Configuration**	**Crew**	**Command & Control**	
wheeled	Turret	4(TC,D,G,L)	Broken into 3 sub	
tracked	WWI style	3(TC,D,G)	categories (see	
hovercraft		2(TC,D)	below)	
		1(TC)		
		None - Robot		
Commo	**Navigation**	**Sensors**		
Radio (encode/decode)	GPS	visual		
SAT-link	Computer-tracked	ground radar		
Pulse	dead reckoning	FLIR (2nd gen)		
		UAV		

Examples:

Annex E: Emerging Technology Study

I. Explosive Reactive Armor

The future emerging technology we will address in this study is explosive reactive armor (ERA). This armor is bolted in boxes on tank hulls and turrets, and consists of explosives sandwiched between armor plates (Crawford 22). The purpose of the explosives is to defeat high-explosive, antitank ammunition (or HEAT), which Western forces use in most infantry-fired antitank weapons (Flint 84). Such rockets and missiles create a needle-thin stream of plasmatic material that works its way through steel as a finger pushed through soft butter (see Enclosure 1).

The reactive armor thwarts the antitank ammunition by literally exploding against it. Before the incoming rocket strikes the tank's armor, it hits the reactive armor panel, which detonates, deflecting the force of the warhead and its direction, preventing it from penetrating the tank's shell (Flint 84). Although ERA itself has little effect on KE (kinetic energy) attacks, such as Sabot ammunition, its combination with Chobham-type armor has made CE (chemical energy) warheads, as used by most anti-tank weapon systems obsolete (Crawford 22).

This type of armor was first used by the Israelis when they invaded Lebanon's Bekaa valley in 1982, called at that time "Blazer". In service for the Israelis, Blazer armor has enabled their tanks to take multiple direct hits and keep on fighting, where unprotected tanks would have been seriously damaged or destroyed (Brown 62). Since then, the Soviets have retrofitted their newest tanks (T-80s) with reactive armor. Right now, the U.S. is considering using it on the Bradley Fighting Vehicle, the fast troop carrier and tank fighter which has come under criticism in the past for being too vulnerable on the modern day battlefield (Flint 86).

The reactive armor does have its shortcomings though. The material adds about a ton to the weight of a tank, thereby slowing it down and increasing fuel consumption. The armor also offers less protection from aerial attack or antitank mines (Flint 86).

Printed at Government expense for x35G0Rd1 02/12/93 14:36.

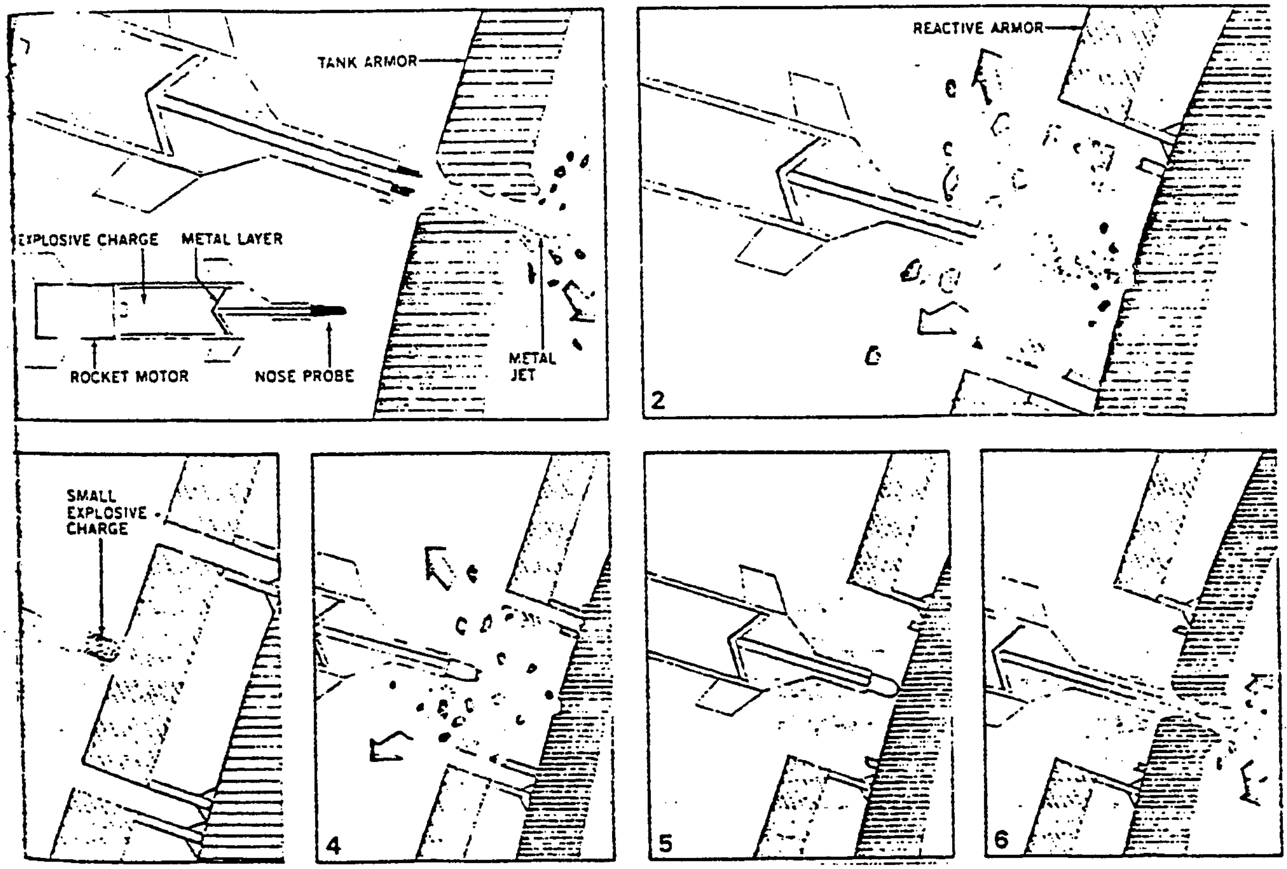
Printed at Government expense for x15608d1 02/12/93 14:36

Other benefits become apparent when one looks at the physics behind the EM gun. The equation mv^2/d^2, where **m** is mass, **v** is velocity, and **d** is round diameter, describes the penetration performance of the KE rail gun rounds (Crawford 20). The velocity of the round has a much greater impact than its mass due to the fact that it is squared. Therefore, the weight of the round is almost negligible due to the rate of speed it will attain. Also, the diameter of the round comes into play because its square is in the denominator. Therefore, one would want to decrease the diameter in order to increase the penetrating ability of the round. This possible decrease in the size of the projectile will in effect increase the amount of ammunition a tank can carry or allow the future tanks to be much smaller and will, in either case, ease the strain on logistical support train of the tank (Crawford 20).

Two other benefits arise from the EM gun. First, the ammunition does not need propellant, thus eliminating ammunition vulnerabilities in stowage. Second, the electrical technology needed to make such a weapon feasible invites its use for other in-tank systems such as electrical transmissions. (Crawford 20) The EM Rail gun is feasible, as demonstrated by bulky prototypes systems. However, miniaturizing it to the size for a main battle tank will not be likely until around 2010.

Printed at Government expense for x35608d1 02/12/93 14:36

Enclosure 1, Annex E: Emerging Technology Diagrams



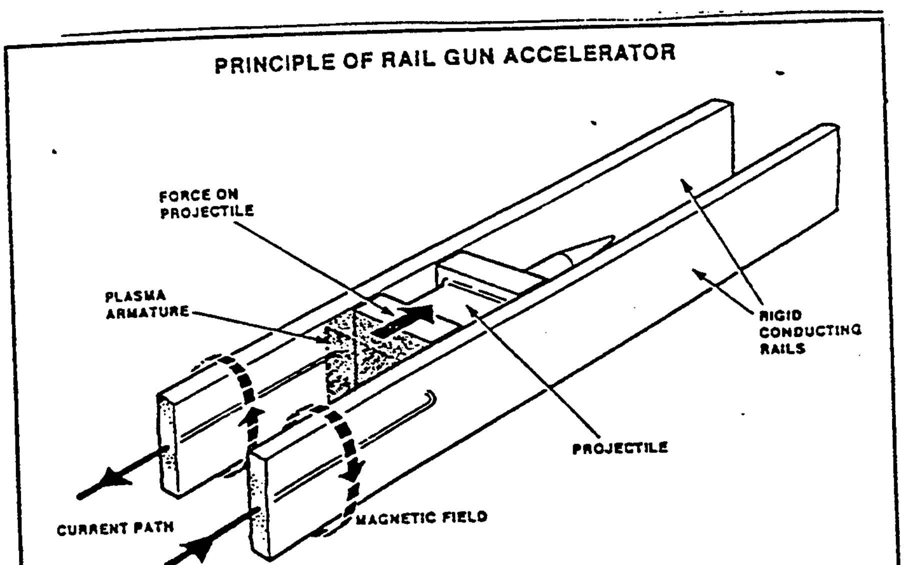


Figure 1

Appendix D Instructions to Cadets on the Conduct of the Trade-Off Determination for Future Main Battle Tanks on Janus (A)

1. Your concepts were well received. Now, as part of a larger engineering effort, you have been directed to select two or your alternatives (less main gun armament) for future design and testing. One alternative should be a Block IIish type configuration. The other should be an alternative employing the electric tank concept.

2. ARDEC has directed that a Trade-off Determination (TOD) be performed against the Block II design and the Electric Tank. Specifically, they wish to address the idea of enhancing the Block II main gun's P(H) and P(K), as well as the Sensor's P(Recognition). They also wish to explore alternative main guns on the Electric Tank.

3. In order to support the client need, I have partitioned the TOD requirements.

For the Block II type tank (Design Alternative I):

ABS Wpn #	Weapon Name	Enhancement
105	IA1	None
106	IA2	P(H) Only
107	IA3	P(K|H) Only
108	IA4	Both P(H) and P(K|H)
109	IB1	None
110	IB2	P(H) Only
111	IB3	P(K|H) Only
112	IB4	Both P(H) and P(K|H)

Weapon A is capable of defeating only tanks out to 3 km. Basic load is 27 rds.

Weapon B is capable of defeating all targets except tanks out to 3 km. Basic load is 13 rds.

Furthermore, I envision the following types of systems each with the below indicated levels of enhancements to each system's suite of weapons (A and B). The two levels of P(H) and P(K) reflect the exclusion (-) or inclusion (+) of enhancements to each weapon's P(H) and/or P(K). ARDEC has also directed a trade-off on the Block II type sensor: either with (+) or without (- enhanced probability of target recognition. Each system will include two sensors. Both sensors will have the same level of enhancement to the P(R). The low level will be the 1st Generation FLIR (sensor #5). The high level be the 1st Generation FLIR with an enhanced P(R) (sensor #8).

	System Name (Wpns Mounted)	P(H)	P(K)	Sensor
	W (105, 109)	−	−	−
	X (106, 110)	+	−	−
	Y (107, 111)	−	+	−
	Z (108, 112)	+	+	−
	W (105, 109)	−	−	+
	X (106, 110)	+	−	+
	Y (107, 111)	−	+	+
	Z (108, 112)	+	+	+

As a result, the below named groups will each prepare and conduct a Trade-off analysis on the four (4) system configurations from their Block II type alternative. Use the Combat System Generator developed by the CSL to document required database parameters for each system configuration. The only difference between each system will be the selection of weapons that define the appropriate factor levels. The sensor type may be altered during the conduct of the experiment to reflect the different P(R) used. The table below assigns the graphics symbol number as well as system numbers to each system configuration.

Graphics Symbol #	Group Name	W	X	Y	Z
126	Tarantelli, White	192	193	194	195
127	Coslin, Walker	196	197	198	199
128	Berneti, Oktay	200	202	203	204

For the Electric Tank (Design Alternative II):

SYSTEM X		SYSTEM Y		SYSTEM Z	
ABS WPN #	WPN NAME	ABS WPN #	WPN NAME	ABS WPN #	WPN NAME
119	IIA	120	IIB	123	IIE
	None	121	IIC	121	IIC
	None	122	IID	122	IID

Weapon A is capable of defeating all known targets out to 4 km. Basic load is 38 rds.
Weapon B is capable of defeating only tanks out to 4 km. Basic load is 24 rds.
Weapon C is capable of defeating all targets except tanks out to 4 km. Basic load is 10 rds.
Weapon D is capable of defeating tanks from 2.5-4 km and is the preferred weapon over B in this range.
Basic load is 6 rds.
Weapon E is a possible replacement for B and is capable of defeating only tanks out to 4 km. Basic load is 24 rds.

Here, I envision a comparison of alternatives methodology, where system X is the basecase for comparison. As a result, the below named groups will each prepare and conduct a Trade-Off Analysis on the three system configurations from their Electric Tank alternative. Use the Combat System Generator developed by the CSL to document required database parameters for each system configuration. The only difference between each system will be the selection of weapons. Each system will also employ a 2nd Generation FLIR (sensor #9). The table below assigns the graphics symbol number as well as system numbers to each system configuration.

Graphics Symbol #	Group Name	X	Y	Z
129	Hodges, Bogdan	205	206	207
130	Pratt, Torreano	208	209	210

MARK E. TILLMAN
CPT, FA
Assistant Professor, SE403A

Appendix E Format for the Preliminary Design

A. Executive Summary (limited to one page)
   1. Purpose of Preliminary Design
   2. Recommended Course of Action

B. The Aquisition Issue
   1. Refined Problem Definition and Need
   2. Threat and Environment
   3. Constraints and Justification
   4. Operational Concept (include a battle narrative)

C. Alternatives
   1. Functional Objectives
   2. Discription of Alternatives

D. Analysis of Alternatives
   1. Models Used in Trade-Off Determination
      a. Discussion
      b. Design of Experiment
   2. Measures of Effectiveness

E. Results and Conclusions

F. Recommendations

G. Annexes/Appendices
   1. Corrected "Type A" System Specification
   2. Reliability Analysis
   3. Maintainability Analysis
   4. Operational Tests
   5. Results of Janus Runs (applicable JEDA Reports)
   6. Statistical Analysis of Alternatives in Trade-Off
   7. Decision Analysis
      a. Relative Effectiveness
      b. MAU

8. Sensitivity Analysis on Decision Analysis

Appendix F

Sample Work (Preliminary Design of Block II (enhanced)) from Cadets Coslin and Walker

SE 403A
Section 1/B
CPT Tillman
7 April 1993

Preliminary Design Report
Future Main Battle Tank Alternatives

Flash
Brutus
Thunder Bolt
Brute Force

Name	Yr	CO
Dave Coslin	93	E1
Robb Walker	93	H1

Table of Contents

Executive Summary

The purpose of the Preliminary Design Phase is to identify the best alternative from the set of feasible alternatives forwarded from the Feasibility Study. This system will best meet the needs addressed by the Feasibility Study. The choice of the best system will be based upon its performance in comparison to the other systems. Performance, for this report, is the system's performance will be defined as its performance, measured by MOE, in the stochastic model Janus (A).

Our study addressed four different tank alternatives: Flash, Brutus, Thunder Bolt, and Brute Force. These alternatives were analyzed using a fractional factorial design, pair wise comparison, relative effectiveness, and MAU. Our results show that Brutus, a block II variant, with an enhanced P(H) should be the choice forwarded to the detail design phase for further refinement. The alternative yielded the highest utility of any of the FMBT alternatives. Overall, it out performed all other FMBT alternatives as well as the baseline M1A1.

Acquisition Issue

Problem Definition and Need:

The US Army has long recognized the need for reliable and maintainable systems in a variety of combat environments. A need to reduce maintenance, training, and support requirements exists along with increasing mission availability. There exists a need to reduce the vulnerability of our combat systems. Additionally, due to budgetary constraints, our forces must rely on CONUS based forces causing the need to deploy and quickly project overwhelming force anywhere with little notice.

These needs have prompted the design team of Coslin and Walker to develop and test the next generation of Main Battle Tanks for the US Army. We began by defining our problem statement, the following was the result:

Design a tank system that will begin to replace the current system by the year 2015. This system must perform all functions that our present series of tanks performs, as well as, serve as a quick reaction element capable of being moved to any part of the world at a moment's notice. Furthermore, this system must reduce maintenance, training, and support requirements. It must be less vulnerable and more reliable than its predecessors. Included in these needs is a need for the new system to reduce the cost of maintenance, repairs, and operation. Additionally this new system must reduce the time required to deploy to the target area, South West Asia. The new system must be more lethal and survivable than our present M1 series. The new system must be financially feasible and all the technologies must be mature by 2015. The system must meet the following constraints:

a. Capable of elevating the main gun between -8 and 30 degrees
b. Travel 600 km on 300 gallons of fuel
c. Weigh less than 55 tons fully combat equipped
d. Must have an engine capable of producing at least 1500 hp
e. Fall within the dimensions of a C17 aircraft: 142 in tall and 111 in wide
f. Must have a reliability of 98% utilizing several parallel systems

g. Must be capable of commercial shipping and loading, causing the shipping weight to be less than 40 tons
h. Minimize the flash and signature of the Main Gun
i. Maintain a rate of fire of 18 rounds per minute
j. Increase survivability through reduced delectability and improved armor protection
k. Reduce vulnerability to enemy tanks, aircraft, and infantry
l. Capable of performing multiple roles such as peace keeping, assisting in law enforcement, and humanitarian assistance

Threat

The threat that was put against our brigade was designed to emulate the perceived threat against our armored forces in the future. Focus was given to the likelihood of another Desert Storm scenario against armor-heavy formations on the offense against our units. Accordingly, the brigade was to conduct an area defense to counter these forces. The specific threat facing TF 1-1 Mech, which is where the FMBT's were deployed, was composed of second-echelon regiments of the lead division, specifically a Reinforced Motor Rifle Battalion with the most forward elements being reinforced tank companies equipped with the T - 80 and BMP - 2. These elements would use former Eastern Bloc tactics in order to secure EA Dean. The enemy is capable and has in the past employ chemical weapons in order to stun the defending force while they move on the objective. The T - 80 and HIND employ very lethal kinetic and chemical weapons capable of defeating the armor of the M1A1 and FMBT.

The FMBT with its enhancements and baseline weapons and sensors should be capable of meeting any threat in this scenario. It has the capabilities to detect and destroy both ground and aerial targets. In addition to vehicles, the FMBT has the capability of finding and killing an infantry threat.

Environment:

Given that in our problem definition we were concerned with the ability to deploy rapidly to South West Asia, we chose the arid, mountainous terrain of the National Training Center (NTC) for our tests. The weather was clear and gave us the best possible situation for the analysis. We were able to establish very good LOS for each of the FMBT's employed, thus allowing us to gather data under ideal conditions.

Constraints and Justification:

The BLUE force in our scenario is assumed to be an US Army combined arms mechanized task force containing armor, mechanized infantry, and anti-armor assets. The armor assets are a mix of the current M1A1 and the FMBT alternatives. In support of the mission are the artillery and MLRS units firing improved munitions to include DPICM, precision guided, FASCAM munitions. In addition to these support elements, air defense and engineer support in the form of minefields, tank ditches, smoke pots, road craters, as well as preparing positions were present.

The FMBT's were employed in mass as a tank company, C Company, and also placed with an M1 company. The rationale was to mass the FMBT fire in an area that would allow for it to get maximum firing ability as well as act as the main effort in the area defense. The FMBT were employed using the current Air-Land Battle Doctrine. We assumed that our purpose was to determine the effectiveness of our FMBT, not to create a future battle concept. In other words, we assumed that our improved state of technology and lethality will not have any impact on our current battle doctrine. We also assume that the RED systems employed are their current state of the art systems that will be the main threat for at least ten years. We do not anticipate any future threat that cannot be modeled by looking at the current threat systems.

Operational Concept:

Task Force 1-1 Mech will be employed in an area defense orienting all weapons into EA Dean. The primary mission is to destroy the second regiments of the lead division and to defeat the second-echelon division. The highly motivated scout elements of the Brigade will be deployed forward of PL TRAVELLER to conduct zone reconnaissance. They will upon contact and proper identification of the lead elements, conduct a passage of lines at PP1 and create a screen for the Task Force's Northern Flank. The FMBT company, C Company, will be the main effort in the defense. The anti-armor company, E Company, will assist in canalizing the enemy into EA Dean. The M1 company, A Company will provide support for C Company. The Brigade's aviation scouts, the OH - 58D, will provide aerial reconnaissance of enemy activity, however, their flight path will be limited to the flight corridor that runs from the FARP to PL TRAVELLER.

The FMBT's activities will be limited to a stationary defensive position. Due to the short time allotted for the computer simulation, the TF will not transition to the counter offensive to deliver the decisive blow that would be necessary to completely destroy the enemy forces. The road craters and smoke pots will be detonated within the first 10 minutes of battle. The M106A1 mortars will be responsible for firing several volleys of WP smoke rounds into EA Dean to help mark target as well as help conceal the TF's positions. Due to the limitations of the FMBT's sensor, no pop-up capabilities, they will be occupy unprepared positions. The AFAS will have several preplanned missions to deliver their DPICM rounds, as well as firing many volleys of priority missions. They will also be required to lay three FASCAM minefield at the forward edge of EA Dean to slow the progress of the enemy forces. The AFAS and MLRS units will coordinate in order to deliver as much destructive ordinance to the battle as possible. This coordination is especially important in the FASCAM minefield in order to cause as much destruction to the immobile units as possible.

Alternatives

Functional Objective:

The FMBT must be capable of performing the mission of armor in all weather and terrain conditions. The FMBT must be able to close with and destroy the enemy using firepower, maneuver, and shock effect. We understand that our new system must be able to perform at least as good as our baseline alternative, the M1A1. Looking at the M1's capabilities gives us a reference point from which to build. Functionally speaking, the FMBT must be able to locate, acquire, identify, aim, fire, and destroy the target. In order to perform these functions, the FMBT must be able to detect the enemy units as far away as possible. The two possible sensor alternative are the 1st Generation FLIR with or without enhancements. Additionally, the FMBT uses both an optical and thermal sensor capable of detecting a target out to 5 km under day, night, and obscured conditions. As far as lethality, the FMBT can utilize a host of different weapon systems.

Each FMBT's main gun can fire Weapon A with the capability of defeating any tank out to the range of 3 km. Each tank carries a combat load of 27 of these rounds. Another weapon for the main gun is Weapon B with the capability of defeating all targets except tanks out to ranges of 3 km. Each tank carries a combat load of 13 of these rounds. Each FMBT will have laser range finders and sensors for wind, movement, terrain, and elevation that will feed information into the on board fire control system. The FMBT will also be equipped with the .50 caliber machine gun with a 3000 round capacity and a 7.62 mm coax machine gun with a 3000 round capacity. These weapon's primary purpose is for use against infantry and soft targets at close range.

We expect our FMBT to perform the mission of engaging and destroying the mechanized, armor, aerial, and infantry elements of the Reinforced Motorized Rifle

Battalion presented to it. We hope that by increasing the system's lethality and detection ability we will improve our ability to destroy the enemy. Our goal is to utilize the advanced technologies in our FMBT to create a more survivable and lethal mechanized force.

Description of Alternatives:

Given that the purpose of this study is not to determine the advantages and disadvantages of varying the automotive design of the FMBT, but to conduct a Trade-Off Analysis of the different weapon and sensor enhancements, each of our systems was based upon the same basic platform. We did, however, wish to meet the deployability consideration of the FMBT. The result was a very light weight, durable, less detectable, more transportable tank that is capable of delivering incredible amounts of firepower to the battlefield at a moment's notice.

The FMBT's inner shell will be made of light weight titanium or aluminum alloy capable of withstanding a direct shot from a 25 mm weapon from 500 m. The chassis will be smaller than the present M1 series to aid in the crossing of obstacles such as streams and minefields. The maximum width of the FMBT is 2.51 m (8.25 ft), resulting in a track width of .8 m (2.62 ft). The maximum height of the FMBT, from the bottom of the track to the top of the Tank Commanders Independent Viewer, will be 2 m (6.56 ft). The distance from the ground to the tip of the front slope is .76 m (2.5 ft). The overall length of the FMBT is 6.71 m (22 ft).

As far as armored protection, the FMBT will be equipped with modular armor arranged in two basic packages. Each package will be utilized based upon the expected threat. Package I will be used for a light infantry threat capable of using only light anti-tank weapons and small arms. This package consists of a fiberglass and ceramic armor that will be fastened into place for the track skirts, front slope, crew compartment, and the turret. This armor must be capable of withstanding up to a blast from a 100 mm recoilless rifle at 100 m. Package II will be used primarily for heavily armored threats with the capability of employing heavy anti-tank weapons such as the main round from a main battle tank, T - 80, or an anti-tank missile, like the Sagger. This package consists of a clamp-on front slope, crew compartment cover, and track skirts made of layer ceramic wrapped in Kevlar. The turret will have a fiberglass and ceramic shell with reactive block to add extra protection. This armor package must have the capability of withstanding a direct frontal hit from a 125 mm main gun HEAT round from 1000 m.

The FMBT will be powered by a gas turbine engine producing 1500 hp. The FMBT, with its reduced weight will be capable of achieving road speeds near 100 km/h. The efficiency of the engine must be capable of allowing the FMBT to have 600 km range with its 300 gallon fuel capacity.

1. Flash

Flash is a Block II design utilizing the IA1 and IB1 rounds for the main gun. The A round is capable of defeating only tanks out to 3 km. The B round is capable of destroying all targets other than tanks out to 3 km. These weapon systems are the baseline with no enhancements. Additionally each tank is equipped with a .50 caliber machine gun and a 7.62 mm coax machine gun, each with 3000 rounds. The ranges of these weapons is 1200 and 900 m respectively. The 1st Generation FLIR with enhancements is being used and evaluated on this system. This enhancement will allow for each scan made to be wider, hopefully increasing the likelihood of detecting a target. Each tanks has optical and thermal sight capabilities allowing them to see during both night and day time operations.

2. Brutus

Brutus is a Block II design utilizing the IA2 and IB2 rounds for the main gun. The A round is capable of defeating only tanks out to 3 km. The B round is capable of destroying all targets other than tanks out to 3 km. These weapon systems are the baseline with enhancements for P(H). Additionally each tank is equipped with a .50 caliber machine gun and a 7.62 mm coax machine gun, each with 3000 rounds. The ranges of these weapons is 1200 and 900 m respectively. The 1st Generation FLIR without enhancements is being used and evaluated on this system. The baseline 1st Generation FLIR has a narrower view than the one with enhancements. Each tanks has optical and thermal sight capabilities allowing them to see during both night and day time operations.

3. <u>Thunder Bolt</u>

Thunder Bolt is a Block II design utilizing the IA3 and IB3 rounds for the main gun. The A round is capable of defeating only tanks out to 3 km. The B round is capable of destroying all targets other than tanks out to 3 km. These weapon systems are the baseline with enhancements in P(K). Additionally each tank is equipped with a .50 caliber machine gun and a 7.62 mm coax machine gun, each with 3000 rounds. The ranges of these weapons is 1200 and 900 m respectively. The 1st Generation FLIR without enhancements is being used and evaluated on this system. Each tanks has optical and thermal sight capabilities allowing them to see during both night and day time operations.

4. <u>Brute Force</u>

Brute Force is a Block II design utilizing the IA4 and IB4 rounds for the main gun. The A round is capable of defeating only tanks out to 3 km. The B round is capable of destroying all targets other than tanks out to 3 km. These weapon systems are the baseline with enhancements in the P(H) and P(K). Additionally each tank is equipped with a .50 caliber machine gun and a 7.62 mm coax machine gun, each with 3000 rounds. The ranges of these weapons is 1200 and 900 m respectively. The 1st Generation FLIR with enhancements is being used and evaluated on this system. Each tanks has optical and thermal sight capabilities allowing them to see during both night and day time operations.

Analysis of Alternatives

Discussion of Models:

Given that we are concerned with determining how well each our alternatives perform, our models must be able to capture the performance data quantifiably and allow us to analyze the output. We chose to use Janus (A), a stochastic, combat simulation model that allows us to employ and monitor our FMBT under a "realistic" combat scenario to generate the data. We relied upon the Fractional Factorial Design, Relative Effectiveness, Pair wise comparison, and Multi-Attribute utility theory to aid us in our decision making process. Janus (A) puts our FMBT against a aggressive, lethal enemy, requiring that it find, aim, and engage the enemy. This model allows quantifiable Measures of Effectiveness to be gathered for further analysis.

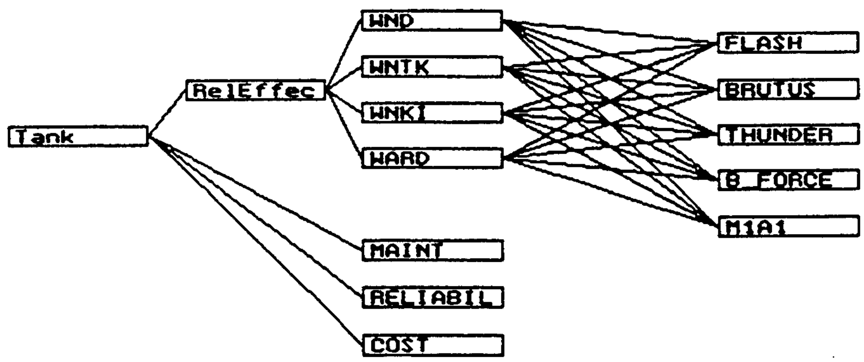
We "validated" our measures of effectiveness by using the Fractional Factorial design. We, in essence, were attempting, using statistical analysis, to determine if we affected our system's performance by utilizing the enhancements. We established a design matrix [Cite Appendix ***] that compared the different high and low factors, such that we could establish a confidence interval to determine whether or not the MOE is significant at a specified significance level. We chose a significance level of 75%, corresponding to a t value of 1.478, when interpolated linearly from a values table. Due to our limited resources and inability to make a large numbers of runs, we concluded that if more than 3 of our 7 possible factors for each MOE was significant, then the MOE must be significant and could be used to further evaluate the alternatives. The underlying and driving aspect of the Factorial Design is to determine if for some MOE, there exists data such that Factor 1, P(H), and Factor 2, P(K), are both significant. If we find that the data produced from the simulations causes a difference between the two factors, then we can conclude the two factors do cause a difference and the MOE is a significant measure.

Using the significant MOE found in the factorial design, we conducted both a pair wise comparison and relative effectiveness evaluation of our alternatives based upon the performance of our base model, the M1A1. The pair wise comparison was conducted using MOEs #1, 3, 4, and 5. In essence this technique took the average of the difference between the performance score of the new alternative and base model and established a confidence interval to determine significance. We established an 80% confidence interval for our testing purposes. Similarly, we used Relative Effectiveness to determine how well our alternative compared to the baseline. In this model, we used the average of each of the four runs for each MOE. These averages were then normalized by dividing through by the baseline performance score. This measure helps give us a feel of how well our present system performs in contrast with the M1A1. Additionally, this measure can be incorporated with cost information to determine the relative worth of the system. This relative worth gives us an idea of how much more effectiveness we will be gaining by investing in the various alternatives relative to the additional cost incurred.

Multi-Attribute Utility theory gives us a way to model the decision makers preferences and concerns about the design. This model allows the decision maker to weight certain attributes, or MOE, to his preferences. In our case the Weighted Number of Tank Kills had the highest weight of all the MOE. This method involves the establishment of a hierarchical tree analysis, which results in a weighted utility score for each alternative. As stated before, we were concerned only with the performance of our system, therefore our analysis focused solely on the relative effectiveness of the system. This score can then be used by the decision maker to determine his course of action. The following tree is a graphical representation of our decision making hierarchy.

Figure 1: MAU Diagram

MAU Hierchial Diagram



WND = Weighted Number of Detections

WMTK = Weighted Number of Tank Kills

WNKI = Weighted Number of Kills of Infantry

WARD = Weighted Average Range of Detections

<u>Measures of Effectiveness:</u>

Measures of Effectiveness (MOE) are the measures by which we used to determine how well we meet our goals and objectives established in the feasibility study.

MOE and Associated goals and objectives

MOE	GOAL or OBJECTIVE
Weighted Number of Detections	To Maximize ability to detect the enemy
Weighted Number of kills of Aircraft	To reduce vulnerability to enemy aircraft & To maximize lethality
Weighted Number of Tank Kills	To Maximize lethality and reduce vulnerability to enemy tanks
Number of Kills of Infantry	Minimize vulnerability to infantry threat
Weighted Average Range of Detections	To detect the enemy sooner
Weighted Fires to Kill Ratio	To Maximize lethality
Weighted Kills to Detection Ratio	To Maximize lethality

1. Weighted Number of Detections

1. *Definition of the Measure*: Weighted Number of Detections (WND) is a very simple measure of effectiveness for the FMBT. The measure can be defined as the total number of detections of selected lethal killing system multiplied by some weighting function.

WND = ΣNumber of Detections of a System * *f(x)*

This measure will give a representation of the number of detections of deadly RED systems our FMBT alternatives are capable of making. The deadly RED systems that will be used are the T - 72, T - 80, HIND, HIP, BMP - 1, and BMP - 2.

The weighting function was derived by using the following rank ordering and preferences. The BMP -1 is the most non-lethal of the systems, getting a weight of 1. The following table will outline the rank ordering and relative importance of each system

Rank order of Deadly RED systems for Weighted Number of Detections

RED SYSTEM	Importance relative to the BMP - 1
T - 80	24 times
HIND	12 times
T - 72	6 times
HIP	6 times
BMP - 2	2 times
BMP - 1	1 times

2. *Dimension of the Measure*: WND will be measured in number of detections

3. *Limits on the Range of the Measure*: The lower limit of the measure is zero, or never having detected another system at all. The upper limit on the measure is the unlimited.

4. *Rationale for the Measure*: As indicated in Table 1, we have as a goal of our system to maximize the ability to detect the enemy. In order to demonstrate that we are taking full advantage of the enhancement of the new sensing system we will use the weighted number of detections.

5. *Decisional Relevance of the Measure*: The number of detections based upon the importance of certain systems will give us a feel as to whether or not our system out performs the current series of main battle tanks. By determining if the new system out performs the current M1, we can draw conclusions regarding modifications and direction of the project. Additionally, we will be able to draw certain conclusion concerning the necessity of the enhancement in the sensor and recommend which sensor is the best.

6. *Associated Measures*: Average Range of Detections, Kills to Fire Ratio

2. Weighted Number of Kills of Enemy Aircraft

1. *Definition of the Measure*: The weighted number of kills of aircraft (WNKA) is defined as the total number of kills of each aircraft system multiplied by some weighting functions.

$$\textbf{WNKA} = \Sigma \textbf{ Number of Kills of Aircraft} * f(x)$$

This measure will give a representation of the number of kills of lethal RED aircraft our FMBT alternatives are capable of making. The deadly RED tanks that will be used are the HIND and HIP. The importance of these two tanks was determined by assuming the HIND was twice as dangerous as the HIP, therefore the weighting was 2:1.

2. *Dimension of the Measure*: The dimension for the measure is number of kills of enemy aircraft.

3. *Limits on the Range of the Measure*: The number of kills can range from zero to as many kills as possible.

4. *Rationale for the Measure*: Two of our goals were to design a system that increased lethality and reduced vulnerability to aircraft. This measure is a way for us to determine if we meet these goals. In other words, if we can significantly increase the number of kills of enemy aircraft, we can conclude that we have reduce the vulnerability of our system.

5. *Decisional Relevance of the Measure*: If we compare the ability to kill aircraft of our FMBT against the M1, and it is statistically significant, we can conclude that our design is worth while. Additionally, there exists the possibility of concluding whether or not the enhancements in the weapon used or the sensor is worthwhile.

6. *Associated Measures*: Fires per Kill

3. Weighted Number of Kills of Enemy Tanks

1. *Definition of the Measure*: The weighted number of kills of tanks (WNKT) is defined as the total number of kills of each tank system multiplied by some weighting functions.

$$\text{WNKA} = \Sigma\ \text{Number of Kills of Tanks} * f(x)$$

This measure will give a representation of the number of kills of lethal RED tanks our FMBT alternatives are capable of making. The deadly RED tanks that will be used are the T - 80 and T - 72. The importance of these two tanks was determined by assuming the T - 80 was twice as dangerous as the T - 72, therefore the weighting was 2:1.

2. *Dimension of the Measure*: The dimension for the measure is number of kills of enemy tanks.

3. *Limits on the Range of the Measure*: The number of kills can range from zero to as many kills as possible.

4. *Rationale for the Measure*: Two of our goals were to design a system that increased lethality and reduced vulnerability to enemy tanks. This measure is a way for us to determine if we meet these goals. In other words, if we can significantly increase the number of kills of enemy tanks, we can conclude that we have reduce the vulnerability of our system.

5. *Decisional Relevance of the Measure*: If we compare the ability to kill enemy tanks of our FMBT against the M1, and it is statistically significant, we can conclude that our design is worth while. Additionally, there exists the possibility of concluding whether or not the enhancements in the weapon used or the sensor is worthwhile.

6. *Associated Measures*: Fires per Kill

4. Number of Kills of Infantry

1. *Definition of the Measure*: Number of kills of Infantry (KOI) is simply defines as the sum of the kills of infantry.

$$\mathbf{KOI = \Sigma\ \underline{Kills\ of\ Infantry}}$$

This measure will give a representation of the lethality that our system can be expected initiate against an enemy infantry threat. The infantry systems that we will look at are the LT, LT MG, and RIFLEMEN systems.

2. *Dimension of the Measure*: The measure will be in terms of number of kills of infantry.

3. *Limits on the Range of the Measure*: The number of kills can range from zero to as many kills as possible.

4. *Rationale for the Measure*: Since two of our goals were to make our system less vulnerable to an infantry threat and to increase lethality this measure will give us an idea of how well we accomplish these goals.

5. *Decisional Relevance of the Measure*: If we compare the ability to kill infantry of our FMBT against the M1, and it is statistically significant, we can conclude that our design is worth while. Additionally, there exists the possibility of concluding whether or not the enhancements in the weapon used or the sensor is worthwhile.

6. *Associated Measures*: Fires per Kill, Kills to Detections Ratio

5. Weighted Average Range of Detections

1. *Definition of the Measure*: Weighted average range of detections (WRD) is a very simple measure of effectiveness for the FMBT. The measure can be defined as the average range of detections of selected lethal killing system multiplied by some weighting function.

WRD = Σ Average Range of Detections of a System * *f(x)*

This measure will give a representation of the average range of detections of deadly RED systems our FMBT alternatives are capable of making. The deadly RED systems that will be used are the T - 72, T - 80, HIND, HIP, BMP - 1, BMP - 2, BRDM - A, BRDM - M, and BTR - 70.

The weighting function was derived by using the following rank ordering and preferences. The BRDM - M is the most non-lethal of the systems, getting a weight of 1. The importance was based upon the systems ability to cause damage at long range. Using this rational, any system that could employ a AT missile was given a higher priority. The following table will outline the rank ordering and relative importance of each system.

Rank order of Deadly RED systems for Weighted Average Range of Detections

RED SYSTEM	Importance relative to the BRDM - M
T - 80	24 times
HIND	12 times
T - 72	6 times
HIP	6 times
BMP - 2	3 times
BRDM - A	3 times
BTR - 70	2 times
BMP - 1	2 times
BRDM - M	1 times

2. *Dimension of the Measure*: WRD will be measured in meters.

3. *Limits on the Range of the Measure*: The lower limit of the measure is zero, or blank point range. The upper limit on the measure is the maximum range of the sensor, 4 km.

4. *Rationale for the Measure*: We have as a goal of our system to maximize the ability to detect the enemy. In order to demonstrate that we are taking full advantage of the enhancement of the new sensing system and detecting the enemy as far away as possible, we will use the weighted average range of detections.

5. *Decisional Relevance of the Measure*: The range of detections based upon the importance of RED systems will give us a feel as to whether or not our system out performs the current series of main battle tanks. By determining if the new system out performs the current M1, we can draw conclusions regarding modifications and direction of the project. Additionally, we will be able to draw certain conclusion concerning the necessity of the enhancement in the sensor and recommend which sensor is the best.

6. *Associated Measures*: Number of Detections, Kills per Detection Ratio

6. Weighted Fires per Kill Ratio

1. *Definition of the Measure*: Weighted fire per kill ratio (WFKR) will be the ratio of fire taken against a system and the number of kills of that system multiplied by a weighting function.

$$\text{WFKR} = \frac{\Sigma \text{ Number of Fires taken at a system}}{\Sigma \text{ Kills of a system}} * f(x)$$

This measure will give a representation of how accurate and lethal our FMBT alternative are against certain deadly RED systems. The deadly RED systems that will be considered are the T - 72, T - 80, HIND, and HIP.

The weighting function was derived by using the following rank ordering and preferences. The HIP is the least important getting a weight of 1. The following table will outline the rank ordering and relative importance of each system

Rank order of Deadly RED systems for Weighted Fire to Kills Ratio

RED SYSTEM	Importance relative to the HIP
T - 80	4 times
HIND	3 times
T - 72	2 times
HIP	1 times

2. *Dimension of the Measure*: WFKR will be measured in kills per fire

3. *Limits on the Range of the Measure*: The lower limit of the measure is zero, or never having engaged another system at all. The upper limit on the measure is the unlimited.

4. *Rationale for the Measure*: We have as a goal of our system to maximize the lethality of our system. In order to demonstrate that we are taking full advantage of the enhancements of the new weapon system we will use the weighted fires per kill ratio.

5. *Decisional Relevance of the Measure*: The kills to fire ratio based upon the importance of certain systems will give us a feel as to whether or not our system out performs the current series of main battle tanks. By determining if the new system out

performs the current M1, we can draw conclusions regarding modifications and direction of the project. Additionally, we will be able to draw certain conclusion concerning the necessity of enhancing the weapon system and recommend the best one.

6. *Associated Measures*: Kills per Detection Ratio

7. Weighted Kills per Detection Ratio

1. *Definition of the Measure*: Weighted kills per detection ratio (WKDR) will be the ratio of kills of a system and the number of detections of that system multiplied by a weighting function.

$$\textbf{WKDR} = \frac{\underline{\Sigma \text{ Number of Kills of a system}}}{\Sigma \text{ Detections of the system}} * f(x)$$

This measure will give a representation of how lethal our FMBT alternative are against certain deadly RED systems. The deadly RED systems that will be considered are the T - 72, T - 80, HIND, HIP, BMP - 2, and BRDM - A.

The weighting function was derived by using the following rank ordering and preferences. The BRDM - A is the least important getting a weight of 1. The following table will outline the rank ordering and relative importance of each system

Rank order of Deadly RED systems for Weighted Kills to Detection Ratio

RED SYSTEM	Importance relative to the HIP
T - 80	12 times
HIND	12 times
T - 72	4 times
HIP	4 times
BMP - 2	2 times
BRDM - A	1 times

2. *Dimension of the Measure*: WKDR will be measured in kills per detection

3. *Limits on the Range of the Measure*: The lower limit of the measure is zero, or never having engaged another system at all. The upper limit on the measure is the unlimited.

4. *Rationale for the Measure*: We have as a goal of our system to maximize the lethality of our system. In order to demonstrate that we are taking full advantage of the enhancements of the new weapon system we will use the weighted fires per kill ratio.

5. *Decisional Relevance of the Measure*: The kills to detection ratio based upon the importance of certain systems will give us a feel as to whether or not our system out performs the current series of main battle tanks. By determining if the new system out performs the current M1, we can draw conclusions regarding modifications and direction of the project. Additionally, we will be able to draw certain conclusion concerning the necessity of enhancing the weapon system and recommend the best one.

6. *Associated Measures*: Kills to Fire ratio

Results and Conclusions

We conducted the above mentioned tests and analysis for all of our runs. For our Fractional Factorial Design, we used various significance levels to try to determine a reasonable number of significant MOE. Our result was four significant MOE at a significance level of .25. We did, however, have mixed results concerning the significance of our primary factors, P(H), P(K), and Sensor type. The following table outlines the primary factors and the result of their test for significance for each of the MOE.

Results of Factorial Design for Significance of Primary Factors

	P(H)	P(K)	Sensor Type
Weighted Number of Detections	NO	YES	NO
Weighted Number of Kills of Aircraft	NO	NO	NO
Weighed Number of Tank Kills	NO	YES	YES
Number of Kills of Infantry	YES	YES	YES
Wt Average Range of Detections	YES	NO	YES
Wt Kills to Fire Ratio	NO	NO	NO
Wt Kills to Detection Ratio	NO	NO	NO

As one can tell not all of the MOE were significant, however, we used Weighted Number of Detections as a significant MOE because of the interaction effects that resulted, Weighted Number of Tank Kills, Number of Kills of Infantry, and Weighted Average Range of Detections [Cite Appendix E for complete and comprehensive calculations concerning the results of the factorial design calculations.]

The determination of the significant MOE lead us into the next step, the pair wise comparison with the baseline M1A1. We established a significance level of .2, for two reasons. First, this level is higher than the significance level used for the factorial design, thus we could find out how sensitive our confidence intervals were to change in the significance level. Secondly, we consider 80% our lower bound as far as our analysis of the alternative is concerned. The conduct of the comparison gave us information about which system or systems our performed the M1A1 for each of the MOE. The following table lists the systems that out performed the M1A1 by MOE.

Results of a the Pair wise Comparison between the M1A1 and FMBT

MOE	1st Choice	2nd Choice	3rd Choice	4th Choice
WND	Brutus	Thunder Bolt	Brute Force	-
WNTK	Flash	Brutus	Thunder Bolt	Brute Force
NKI	None			
WARD	Brutus			

It is obvious from the above chart that the alternative Brutus is clearly better than the M1A1 in three out of four measures. It is also apparent that most of the FMBTs are better detectors and killers of enemy tanks than the M1A1.

Our Multi-Attribute Utility theory analysis was conducted based upon several assumptions. In order to determine the utility functions, we had to assume the utility curve of the decision maker. First, we assumed that the decision maker was a risk seeker in all measures except Weighted Number of Tank Kills. Our rationale for these assumptions is that in all of these measures, the higher the number the better, therefore, more utility must be associated with the values at the high end of the scale. On the other hand, the number of tank kills must have a high utility associated with it even at the low end of the scale because of the high lethality of the enemy tank. Our weighting scheme was based upon the relative importance the measure had in relation to the FMBT survival. In order, our ranking of importance went like this, WNTK, WARD, WND, NKI. The results of our MAU, supported the conclusion we reached in the Pair wise comparison-Brutus was our best alternative. The following diagram and accompanying measures support this conclusion.

Figure 2: Graphical MAU Results for alternatives

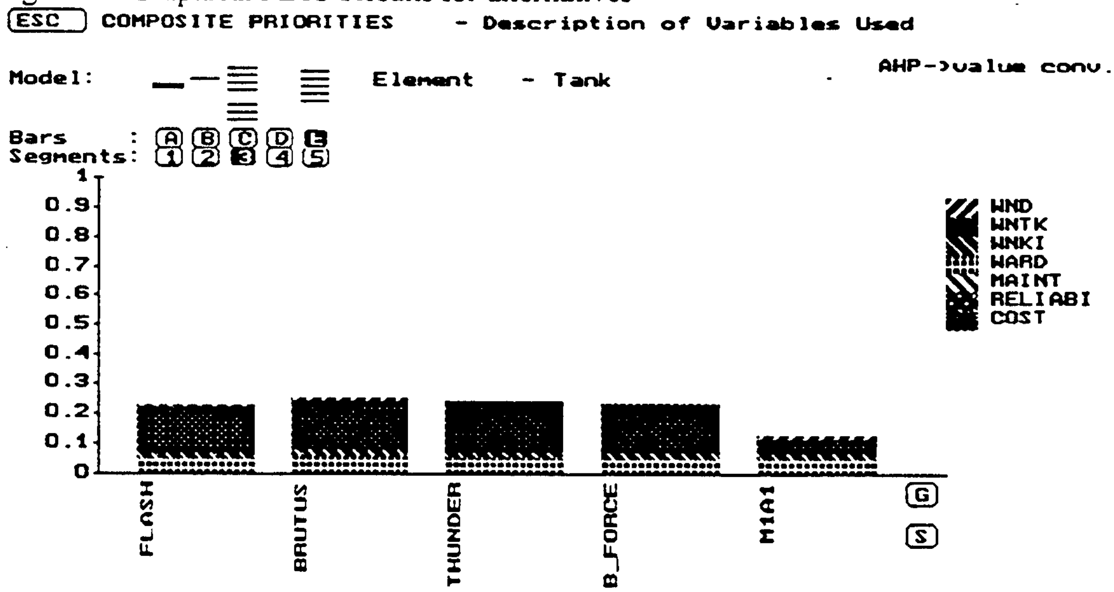


Figure 3: Total Utility for each alternative

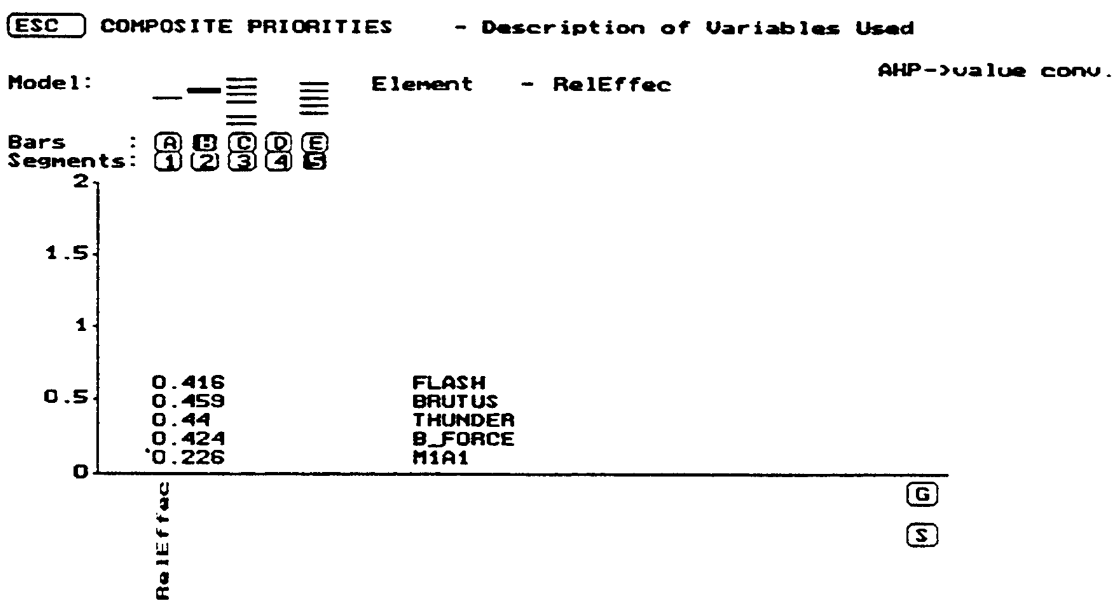
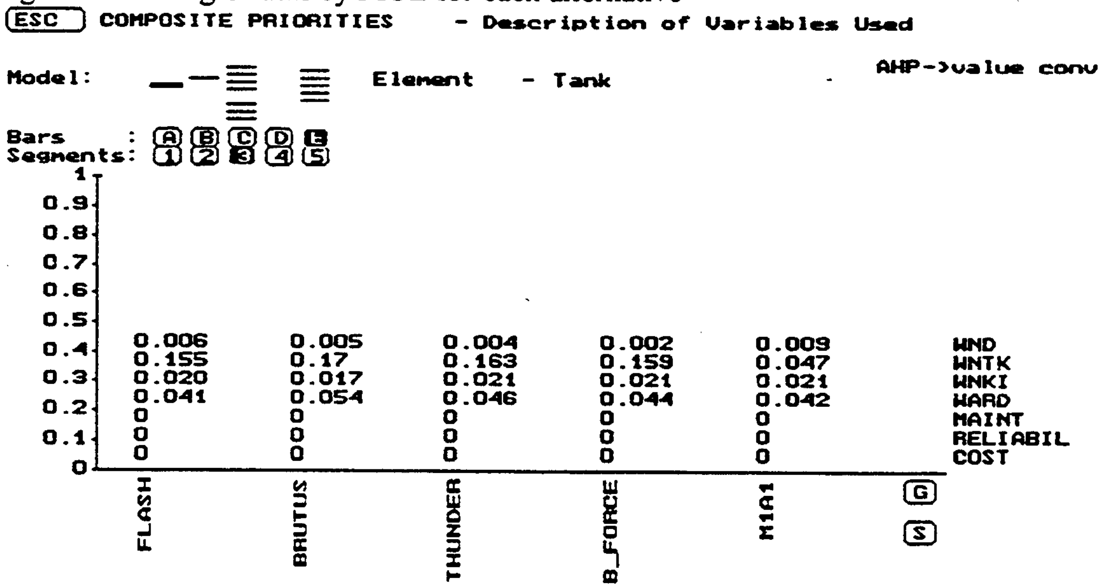


Figure 3: Listing of utils by MOE for each alternative



As one can Brutus out performs Brute Force by a .035 utils. Therefore we conclude that Brutus is our best alternative.

Our final step in the analysis was to determine how much our decision was subject to changes in our weighting scheme, or sensitivity analysis. The following graphs represent the sensitivity of our decision to the weights applied.

Figure 5: Weighted Number of Detections

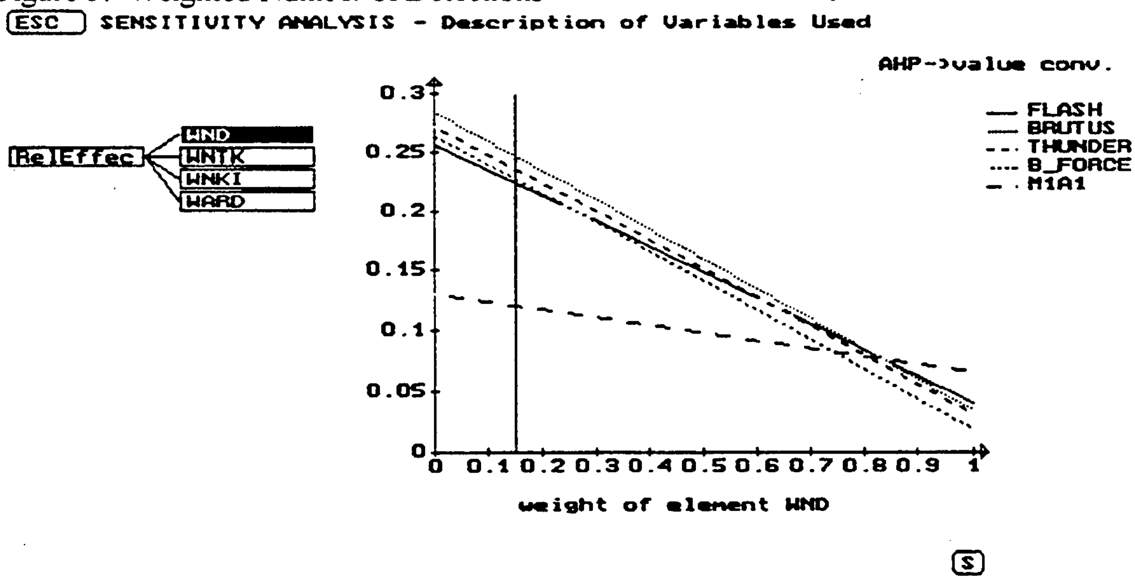


Figure 6: Weighted Number of Tank Kills

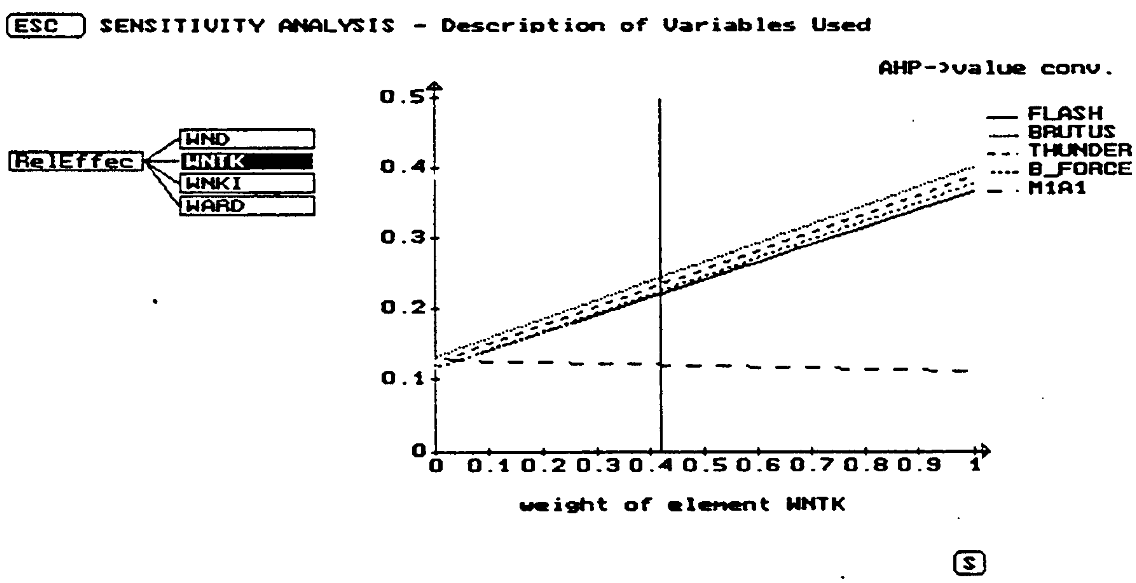


Figure 7: Number of Kills of Infantry

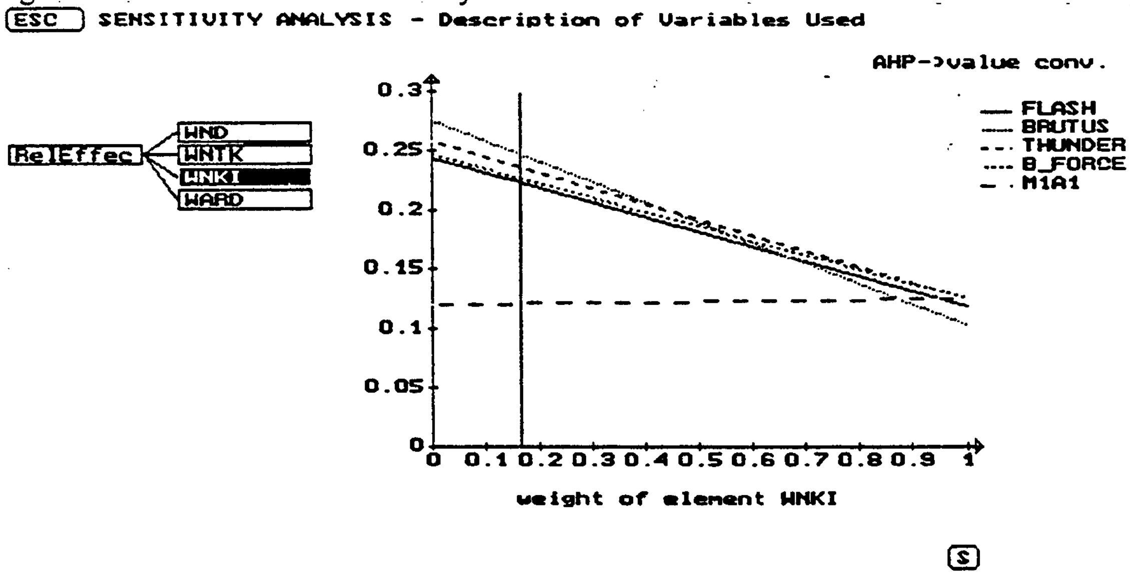
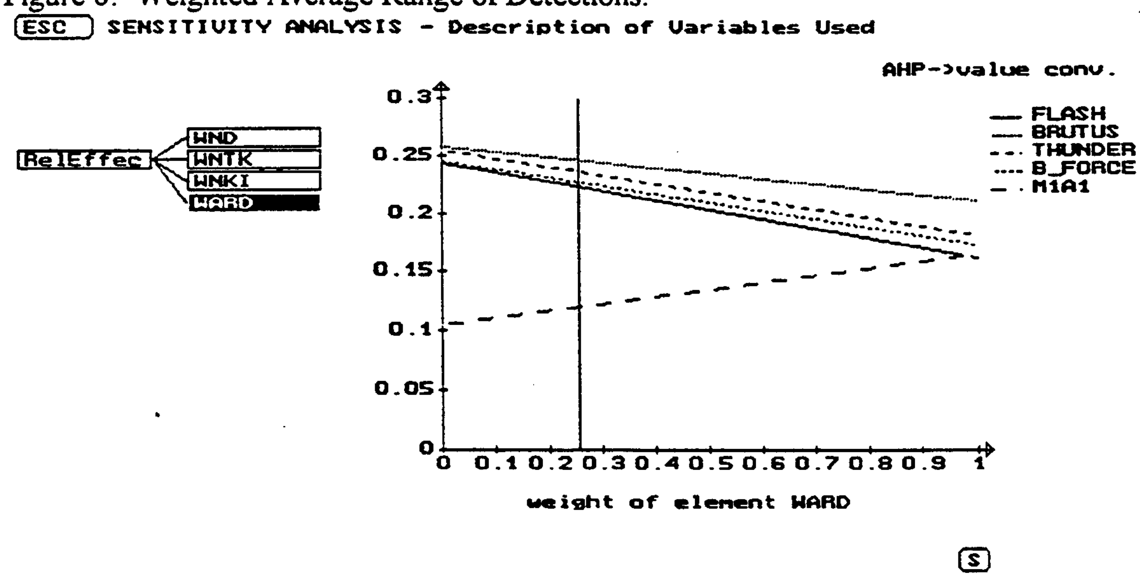


Figure 8: Weighted Average Range of Detections:



As one can tell, our weighting scheme is very insensitive to the weight of the MOE. In fact, Brutus dominates in most of the MOE.

Recommendations

Based upon our analysis of the Janus (A) output and MAU decision making model, our recommendation for the FMBT is Brutus. Brutus is describes as:

> Brutus is a Block II design utilizing the IA2 and IB2 rounds for the main gun. The A round is capable of defeating only tanks out to 3 km. The B round is capable of destroying all targets other than tanks out to 3 km. These weapon systems are the baseline with enhancements for P(H). Additionally each tank is equipped with a .50 caliber machine gun and a 7.62 mm coax machine gun, each with 3000 rounds. The ranges of these weapons is 1200 and 900 m respectively. The 1st Generation FLIR without enhancements is being used and evaluated on this system. The baseline 1st Generation FLIR has a narrower view than the one with enhancements. Each tank has optical and thermal sight capabilities allowing it to see during both night and day time operations.

Brutus showed that it provided greater utility based upon our weighting scheme above. It out performed the others and was far better than the baseline M1A1.

Works Cited

Advanced Land Combat Vehicle Science and Technology Thrust-Panel. Science and Technology Base Investment for Advanced Land Combat Vehicles. 1992.

Blanchard, Benjamin S. System Engineering Management. New York: John Wiley & Son Inc., 1991.

Chamberlain, Gary. "Armor Takes a Lighter Turn." Design News 20 Aug. 1990: 25-26.

Crawford, Major S.W.. "The Main Battle Tank: Future Developments- A British perspective." Armor Jan.-Feb. 1993: 18-25.

DoD Science and Technology Thrusts, Panel 5. Advanced Land Combat: Draft Report. 25 August 1992.

Law, Averill M., and W. David Kelton. Simulation Modeling & Design, 2nd Ed. New York: McGraw-Hill, 1991

McVey, Peter, MG, and Col John Caldwell. Abrams Tank System: Abrams on the Move. American Defense Preparedness Association, 19 SEP 1992.

Nobbe, Thomas A.. "Armor Goes Hi-Tech." Materials Engineering Jun. 1986: 30-33.

Type A Specifications

Part One

1.0 Scope:

The scope of our design effort will move the Future Main Battle Tank through the Preliminary Design Phase. Additionally, we will integrate the system into our current force using Janus (A). Once integrated we will determine if the addition of our Future Main Battle Tank increases our current force's operational effectiveness. The end result of our effort will be detailed specifications for a Main Battle Tank that will meet the expected requirements and increases our capabilities upon the future battlefield.

2.0 Applicable Documents:

The applicable documents for the Future Main Battle Tank are listed in our Works Cited section (page 21). In addition to these sources, our Feasibility Study has a significant amount of information concerning the development of the system specifications.

3.0 Requirements:

3.1 System Definition

3.1.1 General Description

The Future Main Battle Tank (FMBT) will need to be at least as effective as the current M1 series of Main Battle Tanks on the battlefield of tomorrow. As a result, the FMBT must be able to withstand a frontal attack from both a Kinetic Energy and HEAT round. However, unlike the M1, the FMBT will require greater deployability, reduced weight, and greater lethality due to its more powerful weapon system. The protection requirement for the crew will be greater due the increased threats from aerial vehicles, improved anti-armor weapons, and smart munitions. The system will utilize sensors and detection equipment that will greatly increase the probability of detecting any type of enemy, whether on the ground or in the air.

3.1.2 Operational Requirements

Need:

Design a new Main Battle Tank that will allow our heavy forces to quickly react to threats all over the world. This tank needs to be smaller than our present system, but must be more lethal at the same time. There exists a need to reduce the logistical train that accompanies our heavy forces. Even though our present tanks are very survivable from frontal attacks, they lack the ability to protect vital parts from other forms of attack. Therefore, there exists a need to protect our tanks and crews even better than present systems, however the weight of these systems must be kept to a minimum.

Mission:

The primary mission of the Future Main Battle Tank remains the same as the present system: ***To close with and destroy the enemy using firepower, maneuver, and shock effect***.

Utilization Profile:

The utilization of the FMBT will be dependent upon the political environment: whether there is peace or a state of war. Table 1 lists a few measurements of the utilization of the FMBT.

Table 1: FMBT Utilization in Peacetime and War Time

Criterion	Peacetime Utilization	Wartime Utilization
Hours of Daily Operation	5 - 10	Up to 24
Duty Cycle	Continuous	Continuous
On-Off Cycles per Month	Avg. 1.5 weeks per month in training	Continuously on movements

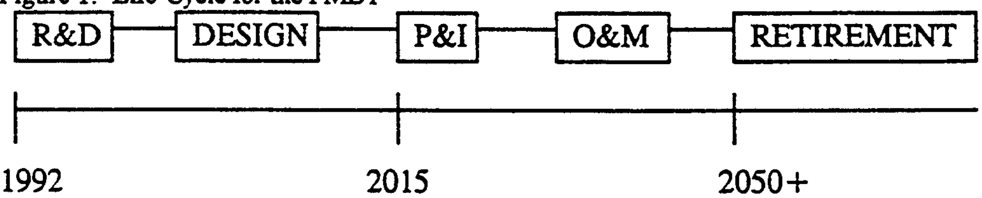
Distribution:

The distribution of the FMBT is still under consideration. However, it is a logical assumption that the primary distribution will be CONUS. Given the primitive need from the client to look at a tank to be more deployable, one can draw the conclusion that the new force will be CONUS based and rely on force projection. The current number of active Army divisions is twelve, however this number is forecast to be reduced to nine, with at least 3 of these being light units. The FMBT can probably be expected to be located at Fort Hood, Fort Stewart, and Fort Riley.

Life Cycle:

The life cycle of the FMBT describes the life of the system from the beginning of the Research and Development phase to the Retirement of the system. In the case of the FMBT, research was begun in 1992. For our purposes, the Design Phase began in 1993. However, the guidance from the client was to have a working, production model by the year 2015. Using the fact that the M1 series has been in the inventory since the early 80's and is expected to be in the inventory until at least 2015, our system would have to last at least that long, through 2050. The following diagram, Figure 1, gives a visual representation of the life cycle of the system.

Figure 1: Life-Cycle for the FMBT



3.1.3 Maintenance Concept

1. Levels of maintenance

a. Organizational Maintenance: This maintenance will be performed by the individual tank companies. This form of maintenance will include "periodic checks of equipment performance, visual inspections, cleaning of equipment, some servicing, external adjustments, and the removal and replacement of some components." In other words, the units can check and change the lubrication in the engine and transmission, can grease the suspension and moving parts, replace some of the easily replaceable parts, and clean the interior and exterior of the tank.

b. Intermediate Maintenance: This maintenance will be conducted by the battalion level maintenance company. This form of maintenance includes "the repair by removal and replacement of major modules, assemblies, or piece parts." These "shops" are either mobile or fixed in position. The kind of maintenance one can expect from these units is the periodic servicing of the main gun system, power pack, sighting and computer system, and communication system. This level of maintenance incorporates a higher level of training and often uses specialists for the repairs.

c. Depot or Supplier Maintenance: This maintenance will be conducted at the division or corps level. The units are stationary and capable of a very high volume of productivity and repair part inventory. Some of the maintenance that can be expected at this level include "complete overhauling, rebuilding, and calibration of equipment, and the performance of highly complex maintenance actions."

2. Repair Policies: The repair policy for the FMBT will be established by the Division Commander. Most of the unit repair policy will be dependent upon the requirement for the unit readiness. Since some units will require a higher state of readiness, these policies about what is a high priority repair mission will be made by the Commander.

3. Organizational Responsibilities: This aspect is closely related to the mind frame concerning the repair policies. If the unit has a responsibility to maintain high readiness rating, it will take actions to ensure that its readiness is high.

4. Logistic Support Elements: The support aspect of the FMBT is an important part of the design criteria. One of our goals is to reduce the dependence and length of the logistical train that accompanies a heavy division when it deploys. The need is for support elements that can maintain a great supply of repair parts, facilities to conduct high level repairs, transportation and handling personnel and facilities. However these elements need to be small and mobile. They need to be able to hit the ground shortly after the ground units and begin to support the units immediately.

3.1.5 Interface Criteria

This aspect deals with the compatibility of our components. In other words, how well will our system's sub-systems work together. We will attack this aspect by looking at trade-offs between our various components. For instance, we may have a gun that can fire 10 km, but our optical sighting system may only be able to detect targets out to 5 km. Another example might be maximum cross country speed. We can use a very powerful engine and improve our speed greatly, however, there is a certain trade-off that must be made between speed and the ability of the suspension to react to terrain. These are all criteria that must be addressed in order to determine the compatibility of our sub-systems.

Another notion that we can consider is the size of the FMBT. As the size increases, the weight and complications of transportation increase. The result is a search to reduce the size, but at the same time we must maintain or increase the survivability, fightability, and lethality of the FMBT.

3.1.6 Environmental Conditions

The FMBT must be designed to conduct various roles under any weather and terrain conditions. Some possible roles that the FMBT may be asked to perform could be the armored spearhead of an attack, reconnaissance, and infantry support and suppression. These missions must be able to be performed in jungle, desert, and open fields under both day and night conditions.

3.2 System Characteristics

3.2.1 Performance Characteristics

These characteristics are essentially our objectives, goals, and constraints. The following is a short list of the FMBT characteristics:

Objectives

- Maximize the range of the Main Gun
- Minimize the Radar Signature
- Minimize signature of the Main Gun
- Maximize Kinetic Energy
- Minimize system weight
- Maximize armor protection
- Maximize use of composite armor protection
- Minimize fuel consumption
- Maximize protection for crew from Artillery, NBC, fragments, and fire
- Maximize fuel and ammunition protection from fire, artillery, and direct hits
- Maximize protection for electronics from electromagnetic pulses
- Maximize rate of fire of main gun
- Maximize the use of commercial shipping and loading assets
- Maximize visual capabilities window
- Minimize vulnerability to air firepower
- Minimize vulnerability to infantry threat
- Minimize costs
- Maximize cross country mobility
- Maximize ability to defeat an enemy munitions

Goals

- Overall goal: Design a tank to meet the demands of the Future Battlefield
- Supporting goals: To be more Lethal, To be more Deployable, To be more Survivable, To reduce Logistical Needs

Constraints

- Minimum BHP produced by the power plant - 1500 HP
- Minimum firing distance - must fire at least 5 km
- Maximum dimensions for air transport - less than 156 in tall, 144 in wide for C5; less than 142 in tall, 111 in wide for C17
- Maximum dimensions for rail transport - less than 115 in tall, 128 in wide
- Maximum weight for rail transport - 65 to 73 tons
- Maximum weight for highway transport (including bridges) - 40 tons
- Maximum weight for sea transport - 70.6 tons
- Minimum detection range - 5 km
- System must be at least 70 % reliable
- Minimum distance on one load of fuel is 600 km

3.2.2 Physical Characteristics

- Range for angle of elevation for main gun is between -8 and 30 degrees
- Fuel Capacity: 300 gallons
- Weight: 36 Tons
  - Main Gun
  - Electronics
  - Hydraulics
  - Power Plant
  - Attachable Armor: 15 - 20 tons
- Crew Size: 3 persons
- Utilize an autoloader
- Main Gun: 140 mm
- Rate of Fire is 18 rounds per minute

3.2.3 Effectiveness Requirements

- Average distance the FMBT can detect an enemy threat
- Rate of speed the FMBT can move and still engage a target accurately
- Probability of killing a target if target is hit
- Distance system can travel without refueling
- Probability of the FMBT being killed given it is hit by an enemy round
- Probability of the FMBT being detected by an enemy sensor
- Average range of the FMBT to deliver a catastrophic kill
- Mean time between main gun fires
- Mean time between failure

3.2.4 Reliability

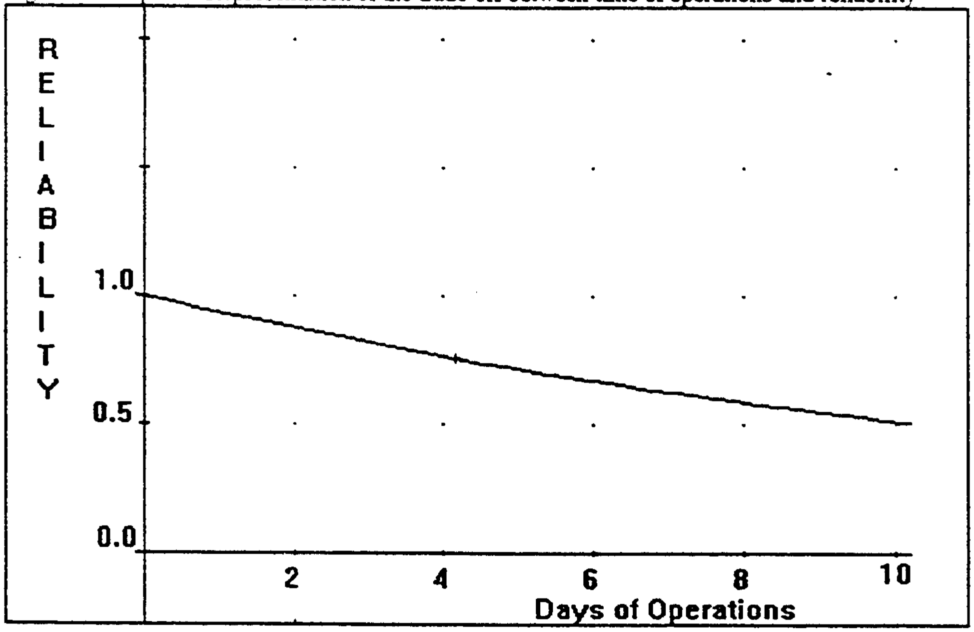
The reliability of our system will be dependent upon several aspects. First, how much money is the client willing to spend upon development of the system. Obviously, the more reliable the system, the more expensive it will be to produce.

Secondly, each component will have its individual reliability. And finally, we must determine the overall reliability of the systems and backup systems. We have done some calculations using the relationship between reliability and time of operation.

$$\mathbf{R} = e^{-t/M}$$ (Blanchard 77)

Using this equation and the assumption that the appropriate time between failures (M) is 15 days, we plotted the values of reliability against the number of days in operation and the following was the result.

Figure 2: Graphical Representation of the trade-off between time of operations and reliability



As one can tell, as the time of operation increases the reliability decreases. The following table, Table 2, lists the mean time between failures, the reliability, and number of days of continuous operations the system can be expected to be able to perform without malfunctions.

Table 2: Reliability, Time of operations, and mean time between failure

Mean Time between Failures	Reliability	Number of days of continuous operation
·15	70%	5.28 days
15	75.8%	4.17 days (100 hrs)
15	82%	3.08 days

Looking at Desert Storm, which had a ground war that lasted 100 hours, our system, with a mean time between failure of 15 days, would have had a reliability of 75.8%.

3.2.5 Maintainability

The aspect of maintainability is a very complex and detailed area, incorporating factors such as active maintenance time, preventive maintenance time, failure rate, logistical delays, and administrative delays. The only aspect that will be looked at with sample calculations for the purpose of this report is the aspect of active maintenance time. This value can be derived using the following expression:

$$M = \frac{(l)(Mct) + (fpt)(Mpt)}{l + fpt} \quad \text{(Blanchard 89)}$$

If we make some assumptions concerning the reliability, mean active maintenance times, and time between failure of the system we can calculate the time that the unit will spend actively performing maintenance on a defective piece of equipment. The following table lists the active maintenance times associated with a MTBF of 15 days, a Mpt of 48 hrs, a fpt 4 times per month, and a Mct of 72 hrs.

l	*fpt*	Mct	Mpt	M
2 fail/mnth	4 times/mnth	.1 month	.06667 month	.07778

What can be gained for this calculations is that only about 7.8 percent of the time a tank is down will there be active maintenance going on.

3.2.6 Human Factors

Human factors play an important part in design anytime there is a human-machine interface. In this case great consideration must be taken when determining placement of instruments, seats, sights, and switches. Additionally, the size of the turret, hatches, and other pieces of hardware that will be used by the operator. Some aspects we must consider when designing the human-machine interface areas are the following:

- Placement of controls and read outs on the tank commander, driver, and gunner control station
- Size of control handle for the main gun
- Size and shape of the steering device for the driver
- Placement of the manual controls for the main gun
- Average strength of the operator given certain positions
- The affects that a thermal sight will have on the night vision capability of the gunner and tank commander

This list is not exhaustive, however, it demonstrates that the human-machine interface must be a serious consideration when making our specifications. We must keep in mind that this interface must assist the operator rather than hinder him.

3.2.7 Supportability

This aspect relates to the ability of the logistical trains to support the tank elements. The kind of support they will need is fuel and ammunition as well as repair parts and servicing. As mentioned earlier, in the Logistical Support Elements section, we are attempting to design a system that can greatly reduce the need for the slow moving logistical train and can deploy and fight with out the great dependence on the support elements. For this reason we have designed a tank that is more survivable and fightable. It is an attempt to reduce the need for repair parts and servicing. We have attempted to reduce the need for fuel by using a more fuel efficient design for an engine.

3.2.8 Transportability/Mobility

This aspect must be addressed by looking at the ability to transport as many of the FMBTs to the theater of operations as quickly as possible. The best and fastest way to do this is to make the tank air-transportable. We are currently looking at the C5 and C17 as the strategic air lift assets that will be available to us. Given that the C17 is the smaller of the two aircraft, the tank must be design with this aircraft in mind. The dimensions of our FMBT will determine not only how many tanks can be loaded at one time, but what type of additional cargo may accompany the tank. To maximize the ability to move the as many FMBTs to the area of combat, we have chosen to reduce the size of our tank enough to allow the C17 and C5 to carry as many as two FMBT at a time. Additionally, as mentioned in the parameters of the system a considerable amount of additional armor plating will accompany the FMBT to the theater to allow it to function fully as a Main Battle Tank. Essentially, the

FMBT will consists of a aluminum and composite shell capable of withstanding a 20 mm round, however, additional armor plating (reactive and depleted uranium) will be added after the air lift to the theater. The end result should be a fully functional combat force, rapidly deployed, and ready for combat in a matter of hours. The following table, Table 3, identifies the dimensions and transportation weight that the FMBT will be according to the type of aircraft being used.

Table 3: Dimensions and Weights for the FMBT by aircraft

AirCraft type	Height	Width	Weight
C5	142 in	99 in	32 tons
C17	142 in	99 in	32.5 tons

4.0 Test and Evaluation

This section will be covered in Part Three of this report.

Part Two

Combat System Generator:

In part two of this Interim Progress Report, we had to define the parameters describing our system, which will be used later to input our system into Janus. We used the Combat Systems Generator in order to define our system. Since our system, Killer, was modeled after the Block II tank, we looked at the data for the M1A1 tank in the Janus Database in order to see how it was defined. This information will be used later in our TOA. Our system that we defined only consists of the following data points of the Combat Systems Generator: **Characteristics** (General - System Parameters, Functional Data, Weights & Volumes, Detection Data, Vulnerability to Mines, and POL Data), **Hit & Kill Probabilities** (Crew Member PKs and Kill Distribution), **Weapons & Ordnance** (WPN/Ordnance for System and MOPP Effects), and **Aircraft Data & Arty** (Vulnerability Codes).

The output from the Combat Systems Generator follows:

Janus Commands:
SY CC GG

Systems General Characteristics

System Number	System Name	Max R Speed Km/Hr	Max Visbi Km	Wpn Rng Km	Sensor Hght (m)	Crew Size	Elem Spac (m)	Chem Xmit Fctr	Gra Sym	Host Cap
196	Killer	100.0	10.0	7.5	2.5	3	100.0	0.0	127	*

Janus Commands:
SY CC FF

SYSTEM FUNCTIONAL CHARACTERISTICS

System Number	System Name	Laser Desig	Mine Disp	Engr Type	Fire Cat	Fly Type	Logis Type	Move Type	Rdr Type	Smk Disp	Chem Det	Swi Cap
196	Killer	0	3	3	3	0	2	2	2	3	0	1

Janus Commands:
SY CC VV

Systems Weights & Volumes

System Number	System Name	Normal (fuel&ammo) Weight (lbs)	Volume (CuFt)	Additional Capacity Weight (lbs)	Volume (CuFt)
196	Killer	102000.0	5000.0	100000.0	100000.0

Janus Commands:
SY CC DD

DETECTION DATA

System Number	System Name	Minimum Dimension [meters]	Detection Contrast [Exposed]	Class [Defilade]	Thermal Sensors Primary	Secondary
196	Killer	2.00	6.0	10.0	5	3

Janus Commands:
SY CC MM

System Vulnerability to Mines

System Number	System Name	Track Width (m)	Belly Width (m)	Total Magnetic Width (m)
196	Killer	0.5000	1.1800	20.0000

Janus Commands:
SY CC PP

Systems POL Data

System Number	System Name	Fuel Type	Tank Size (gal)	Consumption Rate (gal/hr) Stationary	Moving	Fuel Carrying Capacity
196	Killer	2	300	10.0	40.0	

Janus Commands:
SY KK CC

Systems - Crew Member Kill Probability

Note: Enter probability (in percent) for each system damage category.

System Number	System Name	Mobility Only	Firepower Only	Mobil & Firepower	Catastophic Kill
196	Killer	0.00	0.30	0.30	0.40

Janus Commands:
SY KK SY

Systems - Kill Category Distributions

Note: Enter percent of kills which fall into each damage category.
(Entries must sum to 100 percent for each system)

System Number	System Name	Mobility Only	Firepower Only	Mobil. & Firepower	Catastrophic Kill
196	Killer	0.10	0.20	0.30	0.40

Janus Commands SY WW

Weapons / Ordnance for blue system number 196

--- Wpn/Ord Number---				Upload	Rel Wpn/Ord to use
Relative (1-15)	Absolute (1-250)	Wpn/Ord Name	Basic Load	Time (Minutes)	if Ammo Expended (1-15)
1	105	IA1	27	15	2
2	109	IB1	13	15	1
3	54	7.62MG	3000	5	4
4	53	.50cal	150	5	3

Weapons / Ordnance for blue system number 197

--- Wpn/Ord Number---				Upload	Rel Wpn/Ord to use
Relative (1-15)	Absolute (1-250)	Wpn/Ord Name	Basic Load	Time (Minutes)	if Ammo Expended (1-15)
1	105	IA1	27	15	2
2	109	IB1	13	15	1
3	54	7.62MG	3000	5	4
4	53	.50cal	150	5	3

Weapons / Ordnance for blue system number 198

--- Wpn/Ord Number---				Upload	Rel Wpn/Ord to use
Relative (1-15)	Absolute (1-250)	Wpn/Ord Name	Basic Load	Time (Minutes)	if Ammo Expended (1-15)
1	105	IA1	27	15	2
2	109	IB1	13	15	1
3	54	7.62MG	3000	5	4
4	53	.50cal	150	5	3

Weapons / Ordnance for blue system number 199

--- Wpn/Ord Number---				Upload	Rel Wpn/Ord to use
Relative (1-15)	Absolute (1-250)	Wpn/Ord Name	Basic Load	Time (Minutes)	if Ammo Expended (1-15)
1	105	IA1	27	15	2
2	109	IB1	13	15	1
3	54	7.62MG	3000	5	4
4	53	.50cal	150	5	3

Janus Commands:
SY WP MM

MOPP Effects on Weapon Performance

Weapon Number	Weapon Name	MOPP Time Factor	P(Hit) Factor
105	IA1	1.20	0.60
106	IA2	1.20	0.60
107	IA3	1.20	0.60
108	IA3	1.20	0.60

Janus Commands:
SY VV

Systems Vulnerability to Artillery

System Number	System Name	Vulnerability Category (1 thru 28) Exposed	Protected
196	Killer	6	5

Results of Operational Testing

The operational tests that we conducted can be broken down into three catagories: Lethality, Mobility, and Survivability. In other words, can the FMBT fulfill its mission of *closing with and destroying the enemy*? To determine the FMBT's operational effectiveness, we conducted a scenerio in Janus (A) that would afford the tank the opportunity to detect, engage, and possibly destroy all of the systems that it can identify as a legitimate target. Additionally we wanted to determine if the tank could move across a stream, a minefield, climb a hill, as well as its susceptibility to a chemical attack.

We conducted the mobility test by extending the travel line of each FMBT so that it would cross a stream, a bridge, a hill, a minefield, as well as travel down a road. In addition to these tests, we subjected the system to a chemical artillery attack to determine how well the over pressure system worked on the system. The results were mixed, but very favorable-Table 1 outlines the results of the mobility test for each tank alternative.

Table 1: Results of Mobility and Survivability Test

Test Type	Result	Correction
Stream crossing	Could not cross	Change Swim Capability to 1
Bridge Crossing	Could not cross	Change Swim Capability to 1
Hill Crossing	Could Cross	N/A
Road Traveling	Could Perform	N/A
Minefield	Could Cross	N/A - Due to narrow track width
Chemical Attack	System inoperable	Change Surveillance type to 0
Enemy Attack	All systems destroyed	Change detection demension to 2 m from 2.5 m - make a smaller silhouette

The lethality test was conducted to determine how well the system detected and engaged its legitimate targets at various ranges. The targets were situated so that the FMBT could see them at maximum range-the LOS of the tanks were also altered to ensure they could see the targets. The FMBT was required to detect and shoot while moving and stationary, however the targets remained stationary. We were very pleased to see the performance of our system in this area. It was able to detect and destroy targets at more than 3 km. Table 2 gives a list of Red systems that were destroyed by the FMBT [See Enclosure One for a listing of legitimate targets]. However we were not able to see if the FMBT could destroy all of the systems due to its premature death caused by the unexpected returned enemy fire. It did, however, destroy about 15 targets out of 27 before all of the tanks were killed.

Table 2: Summary of Lethality Tests

122mm Self-Propelled Howitzer	BTR - 15
BMP - 2	Hokem
LAW	Hind
BRDM - AT	T - 72

As one can tell, the results of our operational test demonstrate that our design of the FMBT is both operating correctly as well as performing very well against this set of enemy in the given situation. With this information and validation completed, we are now able to continue with our trade-off analysis and factorial design.

Enclosure One

Listing of legitimate targets for the FMBT

1. 82 mm Self-Propelled Mortar
2. 120 mm Self-Propelled Mortar
3. 240 mm Self-Propelled Mortar
4. 122 mm Self-Propelled Howitzer
5. 152 mm Self-Propelled Howitzer
6. T - 55
7. T - 62
8. T - 64
9. T - 72
10. T - 80
11. BTR - 60
12. BTR - 70
13. BMD
14. BMP - 1
15. BMP - 2
16. BTR - 152
17. BRDM - MG
18. BRDM - AT
19. 100mm ATG
20. Commander
21. Sapper
22. SVD
23. Rifleman
24. Lt MG
25. LAW
26. MAW Team
27. HAW Team
28. HIND
29. HIP
30. Hokem
31. Utility Truck
32. POL Truck
33. CP Vehicle

Coslin, Walker							
SE 403 A							
Factorial Design Matirx							
	Low Level	High Level					
Factor 1: P(H)	No Enhancement	Enhancement					
Factor 2: P(K)	No Enhancement	Enhancement					
Factor 3: Sensor	1st Gen FLIR	1st Gen FLIR w/Enhancement					
Design Point	P(H)	P(K)	Sensor	RanNum Run 1	RanNum Run 2	RanNum Run 3	RanNum Run 4
1	-	-	+				
2	+	-	-				
3	-	+	-				
4	+	+	+				

Coslin, Walker
SE 403A - Average Range of Kills

MOE # 1 - Weighted Number of Detections

Constants	
k=	3
p=	1
RanNum 1 =	93953
RanNum 2 =	12823
RanNum 3 =	89525
RanNum 4=	29983
t=	1.478
n=	4

DP	P(H)	P(K)	Sensor	RandNum1 93953 Run 1	RandNum2 12823 Run 2	RandNum3 89525 Run 3	RandNum4 29983 Run 4
1	-	-	+	23.43137255	15.07843137	15.45098039	6.980392157
2	+	-	-	8.470588235	13.25490196	10.90196078	8.803921569
3	-	+	-	25.76470588	13.78431373	14.62745098	9.352941176
4	+	+	+	8.980392157	14.78431373	12.19607843	7.666666667
		Total Effects:	P(H)	-15.87254902	-0.411764706	-3.490196078	0.068627451
			P(K)	1.421568627	0.117647059	0.235294118	0.617647059
			Sensor	-0.911764706	1.411764706	1.058823529	-1.754901961
			P(H)&P(K)	-0.911764706	1.411764706	1.058823529	-1.754901961
			P(H)&Sensor	1.421568627	0.117647059	0.235294118	0.617647059
			P(K)&Sensor	-15.87254902	-0.411764706	-3.490196078	0.068627451
			P(H)&P(K) & Sensor	-24.34313725	-13.66666667	-14.39215686	-8.735294118

Factor 1: P(H)		Factor 2: P(K)		Factor 3: Sensor	
Mean Effect:	-4.926470588	Mean Effect:	0.598039216	Mean Effect:	-0.049019608
Variance:	55.73769704	Variance:	0.34698193	Variance:	2.338523645
Half Length:	5.51720281	Half Length:	0.435309222	Half Length:	1.130095957
Upper Bound:	0.590732222	Upper Bound:	1.033348438	Upper Bound:	1.081076349
Lower Bound:	-10.4436734	Lower Bound:	0.162729994	Lower Bound:	-1.179115565
Significant	NO	Significant	YES	Significant	NO

P(H)&P(K)		P(H)&Sensor		P(K)&Sensor	
Mean Effect:	-0.049019608	Mean Effect:	0.598039216	Mean Effect:	-4.926470588
Variance:	2.338523645	Variance:	0.34698193	Variance:	55.73769704
Half Length:	1.130095957	Half Length:	0.435309222	Half Length:	5.51720281
Upper Bound:	1.081076349	Upper Bound:	1.033348438	Upper Bound:	0.590732222
Lower Bound:	-1.179115565	Lower Bound:	0.162729994	Lower Bound:	-10.4436734
Significant	NO	Significant	YES	Significant	NO

P(H)&P(K)&Sensor	
Mean Effect:	-15.28431373
Variance:	42.78822248
Half Length:	4.833999053
Upper Bound:	-10.45031467
Lower Bound:	-20.11831278
Significant	YES

Coslin, Walker
SE 403A - Average Range of Detections

MOE # 2 - Weighted Number of kills of Aircraft

Constants	
k =	3
p =	1
RanNum 1 =	93953
RanNum 2 =	12823
RanNum 3 =	89525
RanNum 4=	29983
t =	1.478
n =	4

				RandNum1	RandNum2	RandNum3	RandNum4
				93953	12823	89525	29983
DP	P(H)	P(K)	Sensor	Run 1	Run 2	Run 3	Run 4
1	-	-	+	2	4.666666667	4.666666667	4.333333333
2	+	-	-	3.333333333	2	3.666666667	3.333333333
3	-	+	-	2	2.333333333	3.333333333	3
4	+	+	+	3.333333333	5.333333333	3	2
		Total Effects:	P(H)	1.333333333	0.166666667	-0.666666667	-1
			P(K)	0	0.5	-1	-1.333333333
			Sensor	0	2.833333333	0.333333333	0
			P(H)&P(K)	0	2.833333333	0.333333333	0
			P(H)&Sensor	0	0.5	-1	-1.333333333
			P(K)&Sensor	1.333333333	0.166666667	-0.666666667	-1
			P(H)&P(K) & Sensor	-2	-1.833333333	-4.333333333	-4.333333333

Factor 1: P(H)		Factor 2: P(K)		Factor 3: Sensor	
Mean Effect:	-0.042	Mean Effect:	-0.458333333	Mean Effect:	0.791666667
Variance:	1.081	Variance:	0.729166667	Variance:	1.877314815
Half Length:	0.7684	Half Length:	0.631041385	Half Length:	1.012541873
Upper Bound:	0.7267	Upper Bound:	0.172708051	Upper Bound:	1.804208539
Lower Bound:	-0.81	Lower Bound:	-1.089374718	Lower Bound:	-0.220875206
Significant	NO	Significant	NO	Significant	NO

P(H)&P(K)		P(H)&Sensor		P(K)&Sensor	
Mean Effect:	0.7917	Mean Effect:	-0.458333333	Mean Effect:	-0.041666667
Variance:	1.8773	Variance:	0.729166667	Variance:	1.081018519
Half Length:	1.0125	Half Length:	0.631041385	Half Length:	0.768353379
Upper Bound:	1.8042	Upper Bound:	0.172708051	Upper Bound:	0.726686712
Lower Bound:	-0.221	Lower Bound:	-1.089374718	Lower Bound:	-0.810020045
Significant	NO	Significant	NO	Significant	NO

P(H)&P(K)&Sensor	
Mean Effect:	-3.125
Variance:	1.9514
Half Length:	1.0323
Upper Bound:	-2.093
Lower Bound:	-4.157
Significant	YES

Coslin, Walker
SE 403A - Average Range of Initial Engagement

MOE #3 - Weighted Number of Kills of Tanks

Constants	
k =	3
p =	1
RanNum 1 =	93953
RanNum 2 =	12823
RanNum 3 =	89525
RanNum 4=	29983
t =	1.478
n =	4

DP	P(H)	P(K)	Sensor	RandNum1 93953 Run 1	RandNum2 12823 Run 2	RandNum3 89525 Run 3	RandNum4 29983 Run 4
1	-	-	+	6.4	8.2	8.8	8.2
2	+	-	-	4.8	11.4	8.2	11.4
3	-	+	-	13.6	12.6	11.8	9
4	+	+	+	11.2	9.6	10.4	8.8
		Total Effec	P(H)	-2	0.1	-1	1.5
			P(K)	6.8	1.3	2.6	-0.9
			Sensor	-0.4	-3.1	-0.4	-1.7
			P(H)&P(K)	-0.4	-3.1	-0.4	-1.7
			P(H)&Sensor	6.8	1.3	2.6	-0.9
			P(K)&Sensor	-2	0.1	-1	1.5
			P(H)&P(K) & Sensor	-6.8	-11.3	-9.2	-9.9

Factor 1: P(H)		Factor 2: P(K)		Factor 3: Sensor	
Mean Effect:	-0.35	Mean Effect:	2.45	Mean Effect:	-1.4
Variance:	2.257	Variance:	10.49667	Variance:	1.66
Half Length:	1.11	Half Length:	2.394254	Half Length:	0.9521349
Upper Bound:	0.76	Upper Bound:	4.844254	Upper Bounc	-0.4478651
Lower Bound:	-1.46	Lower Bound:	0.055746	Lower Bounc	-2.3521349
Significant	NO	Significant	YES	Significant	YES

P(H)&P(K)		P(H)&Sensor		P(K)&Sensor	
Mean Effect:	-1.4	Mean Effect:	2.45	Mean Effect:	-0.35
Variance:	1.66	Variance:	10.49667	Variance:	2.25666667
Half Length:	0.952	Half Length:	2.394254	Half Length:	1.11014101
Upper Bound:	-0.45	Upper Bound:	4.844254	Upper Bounc	0.76014101
Lower Bound:	-2.35	Lower Bound:	0.055746	Lower Bounc	-1.46014101
Significant	YES	Significant	YES	Significant	NO

P(H)&P(K)&Sensor	
Mean Effect:	-9.3
Variance:	3.54
Half Length:	1.39
Upper Bound:	-7.91
Lower Bound:	-10.7
Significant	YES

Coslin, Walker
SE 403A - Kills at Max Range

MOE #4 - Number of Kills of Infantry

Constants	
k =	3
p =	1
RanNum 1 =	93953
RanNum 2 =	12823
RanNum 3 =	89525
RanNum 4=	29983
t =	1.478
n =	4

DP	P(H)	P(K)	Sensor	RandNum1 93953 Run 1	RandNum2 12823 Run 2	RandNum3 89525 Run 3	RandNum4 29983 Run 4
1	-	-	+	24	16	17	6
2	+	-	-	1	0	3	7
3	-	+	-	0	0	3	11
4	+	+	+	0	6	3	2
		Total	P(H)	-11.5	-5	-7	-4
			P(K)	-12.5	-5	-7	0
			Sensor	11.5	11	7	-5
			P(H)&P(K)	11.5	11	7	-5
			P(H)&Sensor	-12.5	-5	-7	0
			P(K)&Sensor	-11.5	-5	-7	-4
			P(H)&P(K) & Sensor	-12.5	-5	-10	-11

Factor 1: P(H)		Factor 2: P(K)		Factor 3: Sensor	
Mean Effect:	-6.88	Mean Effect:	-6.125	Mean Effect:	6.125
Variance:	11.06	Variance:	26.72917	Variance:	59.0625
Half Length:	2.458	Half Length:	3.820649	Half Length:	5.679372
Upper Bound:	-4.42	Upper Bound:	-2.30435	Upper Bound:	11.80437
Lower Bound:	-9.33	Lower Bound:	-9.94565	Lower Bound:	0.445628
Significant	YES	Significant	YES	Significant	YES

P(H)&P(K)		P(H)&Sensor		P(K)&Sensor	
Mean Effect:	6.125	Mean Effect:	-6.125	Mean Effect:	-6.875
Variance:	59.06	Variance:	26.72917	Variance:	11.0625
Half Length:	5.679	Half Length:	3.820649	Half Length:	2.457939
Upper Bound:	11.8	Upper Bound:	-2.30435	Upper Bound:	-4.41706
Lower Bound:	0.446	Lower Bound:	-9.94565	Lower Bound:	-9.33294
Significant	YES	Significant	YES	Significant	YES

P(H)&P(K)&Sensor	
Mean Effect:	-9.63
Variance:	10.56
Half Length:	2.402
Upper Bound:	-7.22
Lower Bound:	-12
Significant	YES

Coslin, Walker
SE 403A - Number of Detections made by Air craft

MOE #5 - Weighted Average Range of Detections

Constants	
k =	3
p =	1
RanNum 1 =	93953
RanNum 2 =	12823
RanNum 3 =	89525
RanNum 4=	29983
t =	1.478
n =	4

DP	P(H)	P(K)	Sensor	RandNum1 93953 Run 1	RandNum2 12823 Run 2	RandNum3 89525 Run 3	RandNum4 29983 Run 4
1	-	-	+	3.336016949	3.751118644	3.654694915	3.48420339
2	+	-	-	3.193067797	3.525508475	3.581745763	3.413779661
3	-	+	-	3.553474576	3.812016949	3.557423729	3.621
4	+	+	+	3.246440678	3.673728814	3.178847458	3.168576271
		Total	P(H)	-0.224991525	-0.181949153	-0.225762712	-0.261423729
			P(K)	0.135415254	0.104559322	-0.250084746	-0.05420339
			Sensor	-0.082042373	0.043661017	-0.152813559	-0.191
			P(H)&P(K)	-0.082042373	0.043661017	-0.152813559	-0.191
			P(H)&Sensor	0.135415254	0.104559322	-0.250084746	-0.05420339
			P(K)&Sensor	-0.224991525	-0.181949153	-0.225762712	-0.261423729
			P(H)&P(K) & Sensor	-3.418059322	-3.707457627	-3.807508475	-3.67520339

Factor 1: P(H)		Factor 2: P(K)		Factor 3: Sensor	
Mean Effect:	-0.22	Mean Effect:	-0.01607839	Mean Effect:	-0.095548729
Variance:	0.001	Variance:	0.031238757	Variance:	0.01065066
Half Length:	0.024	Half Length:	0.130614476	Half Length:	0.076266305
Upper Bound:	-0.2	Upper Bound:	0.114536086	Upper Bound:	-0.019282424
Lower Bound:	-0.25	Lower Bound:	-0.146692866	Lower Bound:	-0.171815034
Significant	YES	Significant	NO	Significant	YES

P(H)&P(K)		P(H)&Sensor		P(K)&Sensor	
Mean Effect:	-0.1	Mean Effect:	-0.01607839	Mean Effect:	-0.22353178
Variance:	0.011	Variance:	0.031238757	Variance:	0.001057341
Half Length:	0.076	Half Length:	0.130614476	Half Length:	0.024029899
Upper Bound:	-0.02	Upper Bound:	0.114536086	Upper Bound:	-0.199501881
Lower Bound:	-0.17	Lower Bound:	-0.146692866	Lower Bound:	-0.247561679
Significant	YES	Significant	NO	Significant	YES

P(H)&P(K)&Sensor	
Mean Effect:	-3.65
Variance:	0.028
Half Length:	0.123
Upper Bound:	-3.53
Lower Bound:	-3.77
Significant	YES

Coslin, Walker
SE 403A - Number of Kills of Enemy Tanks

MOE #6 - Weighted Kills to Fire Ratio

Constants	
k =	3
p =	1
RanNum 1 =	93953
RanNum 2 =	12823
RanNum 3 =	89525
RanNum 4=	29983
t =	1.478
n =	4

DP	P(H)	P(K)	Sensor	RandNum1 93953 Run 1	RandNum2 12823 Run 2	RandNum3 89525 Run 3	RandNum4 29983 Run 4
1	-	-	+	0.10683908	0.265711575	0.297975709	0.503846154
2	+	-	-	0.161100688	0.331142857	0.302744425	0.397619048
3	-	+	-	0.225925926	0.411607143	0.2675	0.36875
4	+	+	+	0.160296061	0.272268908	0.398239437	0.363333333
		Total Effec	P(H)	-0.005684129	-0.036953477	0.067754077	-0.055821886
			P(K)	0.059141109	0.043510809	0.032509651	-0.084690934
			Sensor	-0.059945736	-0.102384759	0.06298536	0.05040522
			P(H)&P(K)	-0.059945736	-0.102384759	0.06298536	0.05040522
			P(H)&Sensor	0.059141109	0.043510809	0.032509651	-0.084690934
			P(K)&Sensor	-0.005684129	-0.036953477	0.067754077	-0.055821886
			P(H)&P(K) & Sensor	-0.166784816	-0.368096334	-0.234990349	-0.453440934

Factor 1: P(H)		Factor 2: P(K)		Factor 3. Sensor	
Mean Effect:	-0.01	Mean Effect:	0.012617659	Mean Effect:	-0.012234979
Variance:	0.003	Variance:	0.004327824	Variance:	0.006661731
Half Length:	0.04	Half Length:	0.048616001	Half Length:	0.060316757
Upper Bound:	0.033	Upper Bound:	0.06123366	Upper Bound:	0.048081778
Lower Bound:	-0.05	Lower Bound:	-0.035998342	Lower Bound:	-0.072551736
Significant	NO	Significant	NO	Significant	NO

P(H)&P(K)		P(H)&Sensor		P(K)&Sensor	
Mean Effect:	-0.01	Mean Effect:	0.012617659	Mean Effect:	-0.007676354
Variance:	0.007	Variance:	0.004327824	Variance:	0.002956287
Half Length:	0.06	Half Length:	0.048616001	Half Length:	0.040180722
Upper Bound:	0.048	Upper Bound:	0.06123366	Upper Bound:	0.032504368
Lower Bound:	-0.07	Lower Bound:	-0.035998342	Lower Bound:	-0.047857076
Significant	NO	Significant	NO	Significant	NO

P(H)&P(K)&Sensor	
Mean Effect:	-0.31
Variance:	0.017
Half Length:	0.095
Upper Bound:	-0.21
Lower Bound:	-0.4
Significant	YES

MOE #7 - Weighted Kills per Detection Ratio

Constants	
k =	3
p =	1
RanNum 1 =	93953
RanNum 2 =	12823
RanNum 3 =	89525
RanNum 4=	29983
t =	1.478
n =	4

DP	P(H)	P(K)	Sensor	RandNum1 93953 Run 1	RandNum2 12823 Run 2	RandNum3 89525 Run 3	RandNum4 29983 Run 4
1	-	-	+	0.147830045	0.41100112	0.445989305	1.227601088
2	+	-	-	0.247343159	0.283500326	0.58961039	0.633682277
3	-	+	-	0.212769545	0.342186578	0.384675952	0.767597965
4	+	+	+	0.340031898	0.40148857	0.321428571	0.388429752
		Total Effec	P(H)	0.113387733	-0.034099401	0.040186852	-0.486543512
			P(K)	0.07881412	0.024586851	-0.164747585	-0.352627824
			Sensor	0.013874619	0.093401393	-0.103434233	0.107375299
			P(H)&P(K)	0.013874619	0.093401393	-0.103434233	0.107375299
			P(H)&Sensor	0.07881412	0.024586851	-0.164747585	-0.352627824
			P(K)&Sensor	0.113387733	-0.034099401	0.040186852	-0.486543512
			P(H)&P(K) & Sensor	-0.133955425	-0.317599727	-0.549423538	-1.12022579

Factor 1: P(H)		Factor 2: P(K)		Factor 3: Sensor	
Mean Effect:	-0.09	Mean Effect:	-0.10349361	Mean Effect:	0.02780427
Variance:	0.073	Variance:	0.038486873	Variance:	0.009350704
Half Length:	0.2	Half Length:	0.144977548	Half Length:	0.071460588
Upper Bound:	0.108	Upper Bound:	0.041483939	Upper Bound:	0.099264858
Lower Bound:	-0.29	Lower Bound:	-0.248471158	Lower Bound:	-0.043656318
Significant	NO	Significant	NO	Significant	NO

P(H)&P(K)		P(H)&Sensor		P(K)&Sensor	
Mean Effect:	0.028	Mean Effect:	-0.10349361	Mean Effect:	-0.091767082
Variance:	0.009	Variance:	0.038486873	Variance:	0.072891443
Half Length:	0.071	Half Length:	0.144977548	Half Length:	0.19951829
Upper Bound:	0.099	Upper Bound:	0.041483939	Upper Bound:	0.107751208
Lower Bound:	-0.04	Lower Bound:	-0.248471158	Lower Bound:	-0.291285372
Significant	NO	Significant	NO	Significant	NO

P(H)&P(K)&Sensor	
Mean Effect:	-0.53
Variance:	0.184
Half Length:	0.317
Upper Bound:	-0.21
Lower Bound:	-0.85
Significant	YES

Weighted Number of Detections

	T - 80	HIND	T - 72	HIP	BMP - 2	BMP - 1	Weighted # of Detections
RUN 11	43	2	0	12	32	3	23.43137255
RUN 12	31	7	0	6	26	8	8.470588235
RUN 13	102	6	38	6	54	6	25.76470588
RUN 14	38	7	0	5	26	3	8.980392157
RUN 21	65	11	4	2	35	10	15.07843137
RUN 22	62	8	3	4	32	10	13.25490196
RUN 23	61	7	6	5	47	10	13.78431373
RUN 24	45	12	8	8	38	7	14.78431373
RUN 31	68	8	10	4	34	5	15.45098039
RUN 32	50	7	1	2	50	7	10.90196078
RUN 33	69	7	6	6	40	8	14.62745098
RUN 34	52	9	0	4	56	7	12.19607843
RUN 41	38	2	1	4	34	5	6.980392157
RUN 42	44	5	1	3	25	5	8.803921569
RUN 43	47	2	6	4	45	3	9.352941176
RUN 44	44	3	0	3	33	2	7.666666667
RUN 51	73	21	6	19	60	10	23.68627451
RUN 52	56	31	9	35	65	6	28.92156863
RUN 53	82	17	8	29	69	7	24.56862745
RUN 54	85	14	8	29	54	18	23.64705882

b 0.019608

d Kills to Fires Ratio					Weighted
	T - 80	HIND	T - 72	HIP	lls/Fire Ratio
RUN 11	0.137931	0.083333	0	0.266667	0.106839
RUN 12	0.146341	0.230769	0	0.333333	0.161101
RUN 13	0.253968	0.142857	0.074074	0.666667	0.225926
RUN 14	0.14433	0.230769	0	0.333333	0.160296
RUN 21	0.294118	0.193548	0.25	0.4	0.265712
RUN 22	0.56	0.166667	0.142857	0.285714	0.331143
RUN 23	0.234375	0.666667	0.214286	0.75	0.411607
RUN 24	0.323529	0.285714	0.142857	0.285714	0.272269
RUN 31	0.192308	0.5	0.105263	0.5	0.297976
RUN 32	0.188679	0.5	0.25	0.272727	0.302744
RUN 33	0.2	0.375	0.125	0.5	0.2675
RUN 34	0.183099	0.75	0	1	0.398239
RUN 41	0.384615	0.357143	1	0.428571	0.503846
RUN 42	0.285714	0.5	0.333333	0.666667	0.397619
RUN 43	0.171875	0.333333	0.5	1	0.36875
RUN 44	0.366667	0.5	0	0.666667	0.363333
RUN 51	0.090909	0.25	0	0	0.111364
RUN 52	0.285714	0.142857	0	0.2	0.177143
RUN 53	0.375	0.2	0	0	0.21
RUN 54	0.666667	0.6	0	0	0.446667

fkr 0.1

Weighted Number of Kills			Weighted
	HIND	*HIP*	*r of Kills of Aircraft*
RUN 11	1	4	2
RUN 12	3	4	3.333333
RUN 13	1	4	2
RUN 14	3	4	3.333333
RUN 21	6	2	4.666667
RUN 22	2	2	2
RUN 23	2	3	2.333333
RUN 24	6	4	5.333333
RUN 31	6	2	4.666667
RUN 32	4	3	3.666667
RUN 33	3	4	3.333333
RUN 34	3	3	3
RUN 41	5	3	4.333333
RUN 42	3	4	3.333333
RUN 43	3	3	3
RUN 44	1	4	2
RUN 51	4	0	2.666667
RUN 52	4	2	3.333333
RUN 53	3	0	2
RUN 54	3	0	2

nak 0.333333

Weighted Average Range of Detections

	T - 80	HIND	T - 72	HIP	BMP - 2	BRDM - A	BMP - 1	BTR - 70	BRDM - M	Weighted Avg Range of Detections
RUN 11	3.973	3.295	0	3.307	3.713	4.614	4.209	4.346	0	3.336016949
RUN 12	3.833	3.7	0	3.499	3.863	3.92	3.828	0	0	3.193067797
RUN 13	3.694	3.751	3.72	2.997	3.588	3.601	3.561	3.498	0	3.553474576
RUN 14	3.829	3.966	0	3.044	3.792	3.533	3.931	0	3.951	3.246440678
RUN 21	4.009	3.364	3.853	3.309	4.141	4.347	4.454	3.694	0	3.751118644
RUN 22	3.852	4.093	3.657	1.864	4.02	4.229	4.284	0	0	3.525508475
RUN 23	3.81	4.525	3.982	1.836	3.959	3.614	4.553	4.446	3.544	3.812016949
RUN 24	4.023	3.104	3.615	2.794	4.033	3.999	4.038	4.246	3.832	3.673728814
RUN 31	3.848	3.506	3.67	4.586	3.838	3.963	4.132	0	0	3.654694915
RUN 32	3.795	4.097	3.096	3.779	3.862	3.617	3.696	0	0	3.581745763
RUN 33	3.754	4.103	3.973	2.83	3.738	3.47	4.057	0	0	3.557423729
RUN 34	3.995	4.092	0	1.912	3.799	3.817	4.124	0	0	3.178847458
RUN 41	3.927	3.39	3.836	2.658	3.784	4.086	4.033	0	0	3.48420339
RUN 42	3.782	3.546	3.087	2.963	3.794	4.109	4.042	0	0	3.413779661
RUN 43	3.878	3.438	4.148	3.274	3.687	3.336	3.082	3.773	0	3.621
RUN 44	3.824	3.771	0	3.48	3.556	3.63	3.74	0	0	3.168576271
RUN 51	3.96	2.834	3.266	3.049	4.058	4.485	4.357	0	0	3.411542373
RUN 52	3.84	2.81	3.974	2.908	3.824	3.944	4.493	0	0	3.380711864
RUN 53	3.931	2.739	3.435	2.383	3.77	3.719	4.42	0	0	3.278423729
RUN 54	3.718	3.173	3.945	2.766	4.056	4.27	4.048	0	0	3.400813559

bc 0.016949

Weighted Kills to Detection Ratio

	T - 80	HIND	T - 72	HIP	BMP - 2	BRDM - A	Kill/Detection Ratio
RUN 11	0.186047	0.083333	0	0.333333	0.15625	0	0.147830045
RUN 12	0.193548	0.230769	0	0.666667	0.076923	0.25	0.247343159
RUN 13	0.156863	0.142857	0.10526316	0.666667	0.018519	0.3	0.212769545
RUN 14	0.368421	0.230769	0	0.8	0.115385	0.6	0.340031898
RUN 21	0.153846	0.545455	0.25	1	0.085714	0	0.41100112
RUN 22	0.225806	0.25	0.33333333	0.5	0.15625	0	0.283500326
RUN 23	0.245902	0.285714	0.5	0.6	0.106383	0.3	0.342186578
RUN 24	0.244444	0.5	0.5	0.5	0.157895	0	0.40148857
RUN 31	0.147059	0.75	0.4	0.5	0.176471	0	0.445989305
RUN 32	0.2	0.571429	1	1.5	0.1	0	0.58961039
RUN 33	0.202899	0.428571	0.5	0.666667	0.1	0.25	0.384675952
RUN 34	0.25	0.333333	0	0.75	0.089286	0.428571	0.321428571
RUN 41	0.263158	2.5	1	0.75	0.176471	0	1.227601088
RUN 42	0.318182	0.6	1	1.333333	0.28	0	0.633682277
RUN 43	0.234043	1.5	0.16666667	0.75	0.177778	0.5	0.767597965
RUN 44	0.25	0.333333	0	1.333333	0.242424	0	0.388429752
RUN 51	0.013699	0.190476	0	0	0	0	0.074245389
RUN 52	0.035714	0.129032	0	0.057143	0.092308	0	0.072428647
RUN 53	0.036585	0.176471	0	0	0.043478	0	0.080109939
RUN 54	0.047059	0.214286	0	0	0.018519	0	0.096156712

kdr 0.030303

Weighted Number of Kills			Weighted
	T - 80	*T - 72*	*Number of Kills of Tanks*
RUN 11	8	0	6.4
RUN 12	6	0	4.8
RUN 13	16	4	13.6
RUN 14	14	0	11.2
RUN 21	10	1	8.2
RUN 22	14	1	11.4
RUN 23	15	3	12.6
RUN 24	11	4	9.6
RUN 31	10	4	8.8
RUN 32	10	1	8.2
RUN 33	14	3	11.8
RUN 34	13	0	10.4
RUN 41	10	1	8.2
RUN 42	14	1	11.4
RUN 43	11	1	9
RUN 44	11	0	8.8
RUN 51	1	0	0.8
RUN 52	2	0	1.6
RUN 53	3	0	2.4
RUN 54	4	0	3.2

ntk 0.2

Coslin, Walker
SE 403A - Preliminary Design

Pair Wise Comparision of Baseline M1A1 with the FMBT

Constants:

Confidence	80.00%	
t value	2.353	[1-(.2/2)]/2
n =	4	

MOE #1 - Weighted Number of Detections

RUN #	M1A1	FLASH	BRUTUS	THUNDER BOLT	BRUTE FORCE	Z1	Z2	Z3	Z4
1	23.6863	23.431373	15.07843137	15.45098039	6.980392157	-0.254901961	-8.60784	-8.23529	-16.70588235
2	28.9216	8.4705882	13.25490196	10.90196078	8.803921569	-20.45098039	-15.6667	-18.0196	-20.11764706
3	24.5686	25.764706	13.78431373	14.62745098	9.352941176	1.196078431	-10.7843	-9.94118	-15.21568627
4	23.6471	8.9803922	14.78431373	12.19607843	7.666666667	-14.66666667	-8.86275	-11.451	-15.98039216
					Totals	-34.17647059	-43.9216	-47.6471	-68.01960784

FLASH		BRUTUS		THUNDER BOLT		BRUTE FORCE	
Mean Effect	-8.5441	Mean Effect	-10.98039216	Mean Effect	-11.9118	Mean Effect	-17.0049
Variance	114.281	Variance	10.70434448	Variance	18.30591	Variance	4.676503
Half Length	12.577	Half Length	3.849213231	Half Length	5.033703	Half Length	2.544207
Upper bound	4.03291	Upper bound	-7.131178925	Upper bound	-6.87806	Upper bound	-14.46069
Lower bound	-21.121	Lower bound	-14.82960539	Lower bound	-16.9455	Lower bound	-19.54911
Significant?	NO	Significant?	YES	Significant?	YES	Significant?	YES

MOE #3 - Weighted Number of Tank Kills

RUN #	M1A1	FLASH	BRUTUS	THUNDER BOLT	BRUTE FORCE	Z1	Z2	Z3	Z4
1	0.8	6.4	8.2	8.8	8.2	5.6	7.4	8	7.4
2	1.6	4.8	11.4	8.2	11.4	3.2	9.8	6.6	9.8
3	2.4	13.6	12.6	11.8	9	11.2	10.2	9.4	6.6
4	3.2	11.2	9.6	10.4	8.8	8	6.4	7.2	5.6
					Totals	28	33.8	31.2	29.4

FLASH		BRUTUS		THUNDER BOLT		BRUTE FORCE	
Mean Effect	7	Mean Effect	8.45	Mean Effect	7.8	Mean Effect	7.35
Variance	11.68	Variance	3.396666667	Variance	1.466667	Variance	3.21
Half Length	4.02081	Half Length	2.168295139	Half Length	1.424812	Half Length	2.107873
Upper bound	11.0208	Upper bound	10.61829514	Upper bound	9.224812	Upper bound	9.457873
Lower bound	2.97919	Lower bound	6.281704861	Lower bound	6.375188	Lower bound	5.242127
Significant?	YES	Significant?	YES	Significant?	YES	Significant?	YES

MOE #4 - Number of Infantry Kills

RUN #	M1A1	FLASH	BRUTUS	THUNDER BOLT	BRUTE FORCE	Z1	Z2	Z3	Z4
1	0	24	16	17	6	24	16	17	6
2	17	1	0	3	7	-16	-17	-14	-10
3	3	0	0	3	11	-3	-3	0	8
4	6	0	6	3	2	-6	0	-3	-4
					Totals	-1	-4	0	0

FLASH		BRUTUS		THUNDER BOLT		BRUTE FORCE	
Mean Effect	-0.25	Mean Effect	-1	Mean Effect	0	Mean Effect	0
Variance	292.25	Variance	183.3333333	Variance	164.6667	Variance	72
Half Length	20.1126	Half Length	15.92988531	Half Length	15.09714	Half Length	9.982934
Upper bound	19.8626	Upper bound	14.92988531	Upper bound	15.09714	Upper bound	9.982934
Lower bound	-20.363	Lower bound	-16.92988531	Lower bound	-15.0971	Lower bound	-9.982934
Significant?	NO	Significant?	NO	Significant?	NO	Significant?	NO

MOE #5 - Weighted Average Range of Detections

RUN #	M1A1	FLASH	BRUTUS	THUNDER BOLT	BRUTE FORCE	Z1	Z2	Z3	Z4
1	3.41154	3.3360169	3.751118644	3.654694915	3.48420339	-0.075525424	0.339576	0.243153	0.072661017
2	3.38071	3.1930678	3.525508475	3.581745763	3.413779661	-0.187644068	0.144797	0.201034	0.033067797
3	3.27842	3.5534746	3.812016949	3.557423729	3.621	0.275050847	0.533593	0.279	0.342576271
4	3.40081	3.2464407	3.673728814	3.178847458	3.168576271	-0.154372881	0.272915	-0.22197	-0.232237288
					Totals	-0.142491525	1.290881	0.50122	0.216067797

FLASH		BRUTUS		THUNDER BOLT		BRUTE FORCE	
Mean Effect	-0.0356	Mean Effect	0.322720339	Mean Effect	0.125305	Mean Effect	0.054017
Variance	0.04511	Variance	0.026296298	Variance	0.054614	Variance	0.055331
Half Length	0.24987	Half Length	0.190782809	Half Length	0.274944	Half Length	0.276744
Upper bound	0.21425	Upper bound	0.513503148	Upper bound	0.400249	Upper bound	0.330761
Lower bound	-0.2855	Lower bound	0.13193753	Lower bound	-0.14964	Lower bound	-0.222727
Significant?	NO	Significant?	YES	Significant?	NO	Significant?	NO

Relative Effectiveness Calculations

	Actual Effectiveness by System				
	FLASH	*BRUTUS*	*THUNDER BOLT*	*BRUTE FORCE*	*M1A1*
MOE#1	16.66176471	14.2254902	13.29411765	8.200980392	25.206
MOE#3	9	10.45	9.8	9.35	2
MOE#4	6.25	5.5	6.5	6.5	6.5
MOE#5	3.33225	3.69059322	3.493177966	3.421889831	3.3679

	Relative Effectiveness, M1A1-Baseline				
	FLASH	*BRUTUS*	*THUNDER BOLT*	*BRUTE FORCE*	*M1A1*
MOE#1	0.661026838	0.56437184	0.527421237	0.325359782	1
MOE#3	4.5	5.225	4.9	4.675	1
MOE#4	0.961538462	0.846153846	1	1	1
MOE#5	0.989422736	1.095823195	1.037206002	1.016038892	1

Appendix G

Sample Work (Preliminary Design of Electric Tank) from Cadets Torreano and Pratt

Course No. SE403A
Section No. 01-C
Instructor CPT Tillman
Date 07 April 1993

PRELIMINARY DESIGN REPORT: ELECTRIC TANK

Name	Yr	Co
Michael Pratt	93	G2
Mickey Torreano	93	G1

[illegible]

PURPOSE OF PRELIMINARY DESIGN

To date, we have been concerned with the first phase of the 3-phase Engineering Design Process, called the Conceptual Design or Feasibility Study. Our objectives in the Feasibility Study were to validate the client's needs, to identify the design goals, and to develop a set of feasible alternative solutions to satisfy the validated needs. (SE401 Handout, Lsn 16)

Now, we begin our study of the second phase of the Engineering Design: the Preliminary Design. The purpose of this step is to identify the "best" candidate system from the set of candidates already defined (see Annex A). This system will best meet the needs that have been identified during the Feasibility Study. The choice of the "best" candidate system implies the identification of one whose performance is better than that of the other remaining candidate systems. (SE402 Handout, Lsn 15)

RECOMMENDED COURSE OF ACTION

With our current information, we recomend that the Killer system be forwarded to the Detailed Design phase. We first recomend, however, that the problems in the firing tables need to be corrected and data re-analyzed before a final decision is made. We also recomend that the decision maker analyze Reliability, Maintainability, and Costs of our systems to consider in the final decision. We believe that the Crusher configuration can be eliminated at this time, but Killer and Bruiser should undergo the continued analysis.

PROBLEM DEFINITION AND NEED

NEED:

Department of Defense recently gave us a primitive need which is our basis for analysis into the Future Main Battle Tank (FMBT). This need can be summarized as follows:

1. A need for reliable and maintainable systems in a variety of combat environments.
2. A need to reduce maintenance, training, and support requirements.
3. A need to reduce the vulnerability of combat systems.
4. A need to deploy and quickly employ force anywhere with little notice.

Many events since the end of the Cold War provide justification for our need to develop a FMBT. These justifications include:

1. A less predictable and less stable multi-polar world.
2. Regional and territorial disputes arising in the post-Cold War states.

3. Economic Interdependence. Insurgencies that affect U.S. interest must often be dealt with quickly and effectively.

4. The military's new roles - counter narcotics and counter-terrorist roles, for example.

5. Technology proliferation resulting in a more lethal battlefield (ex. smart mines and munitions).

6. Domestic, economic, and political environments calling for a reduced military with less forward deployed units.

The Army has this need for a more deployable heavy force because of current problems with Intra-CONUS, Intertheater, and Intratheater deployment phases. Problems exist with rail, highway, air, and sea movements of heavy class systems. (Desert Shield and Desert Storm confirmed many of these problems.) One of the problems dealt with the size and weight of the heavy class systems (ie. the M1A2 main battle tank). The transports had difficulty loading, transporting, and unloading the systems. Their bulkiness was a main factor in not being able to carry many systems at once.

There appears to be great justification for a FMBT, and we have validated many of the needs observed by the Department of the Army. Not taken into account in the primitive statement of needs was the need for a more lethal tank system. As mentioned, technology proliferation will make the battlefield more lethal. If we do not develop a FMBT that is more capable of killing enemy systems, we will not keep pace with increases in threat lethality. The need for a more lethal system also advocates the need for a less vulnerable system. If we are able to kill an enemy system, that system no longer possesses the capability to destroy our FMBT. In other words, sometimes the best defense is a good offense.

We can now refine the primitive need into a validated effective need. We believe that by the year 2010 we must be able to replace the M1A2 system with a new, more capable, and financially feasible main battle tank. The FMBT must be a reliable and maintainable system, more capable of destroying enemy systems while being less vulnerable to existing and emerging threat technology. This system must be easily deployable and less dependent on maintenance, training, and support requirements. By saying that the system must be less dependent, we mean that the system must be more self-sufficient. For example, to be less dependent on support requirements, the system could carry more rounds and hold more fuel. This would decrease its dependence on the logistical chain to support it.

The Department of the Army also wanted us to examine the capabilities of various weapon system configurations on the Electric Battle Tank. Therefore, we established an addition to our effective need which consists of performing a Trade-Off Analysis on the different weapon systems for the FMBT. This need was communicated to us during the course of the design process.

PROBLEM DEFINITION:

Objectives

The main goal of our design is to provide the Army with a Future Main Battle Tank that possesses increased abilities to kill, to survive, and to deploy. The objectives, along with their respective criteria to measure their effectiveness shown in parenthesis, that have to be met in order to accomplish our goal include:

1. To deploy more quickly and efficiently we must: minimize logistical requirements (amount of ammo, fuel, food, water, and spare parts required), minimize weight of FMBT, minimize size of tank (surface area in m^2), maximize use of removeable and lightweight components (tons for weight of FMBT).

2. To survive on the battlefield we must: minimize signature (decibels of sound, degrees of heat, area of exposed region), maximize detection capabilities (seconds for time to detection or kilometers to detection), maximize maneuver capabilities (degree slope traversed, speed in km/hr, turning radius in meters), maximize protection of system and crew (damage sustained per hit and number of casualties per hit).

3. To kill enemy weapon systems we must: maximize lethality (CEP, ROF in rounds/min, rearm time in secs, and # of rounds carried, P(Kill/Hit)), increase accuracy (P(Hit)), maximize detection capabilities (TLE, km to detection, total

# of detections), maximize skill levels of crew (# of operational errors per mission, MQS test scores.

4. To be more cost effective we must: minimize logistical dependency (km/gal for fuel efficiency, # of rounds carried), maximize accuracy of munitions (P(Hit)), maximize reliability and maintainability (MTBF, MTTR, P(Breakdown)), maximize automation (# of crew required).

5. To be more reliable and maintainable we must: maximize quality of components (P(Breakdown), # of breakdowns), maximize redundancy (# of parallel systems, maximize training quality (MQS test scores, average # of mistakes/mission), minimize complex complicated subsystems (human factors test scores), maximize interchangeable components (# of parts).

Parameters

The parameters of the system are:

1. Type of fuel.
2. The number and type of detection systems.
3. The type of main gun and supporting weapon systems.
4. The types of munitions.
5. Weapons configurations.
6. The number of personnel required to operate the system.

Variables

The variables of the system are:

1. The number and type of enemy weapon systems.

2. Number and types of friendly units employed.

3. Weather.

4. Terrain.

5. Length of time FMBT will be engaged in combat.

Constraints

1. System must be completed by the year 2010.

2. Cost to develop and deploy FMBT must not exceed what Congress is willing to procur.

3. FMBT must weigh less than 59 tons.

4. FMBT must be an improvement to the M1 series tanks.

5. FMBT must be socially and legally acceptable.

THREAT AND ENVIRONMENT

Since the mission of the FMBT is to be deployable to many parts of the world, the range of the environmental conditions is wide. Some of the variables that may be included are:

1. The number and type of enemy weapon systems.

The FMBT will need to perform its mission against many types of enemy weapon systems. We will need to know if we will be facing direct or indirect fire, enemy mines or other obstacles, enemy airpower, or any other anti-tank weaponry. The tank should not be affected by small arms fire. For enemy armor or anti-tank weaponry (such as TOWs) the sides of the sides of the tank, including the tracks, are the most vulnerable. If the enemy will use helicopters against the FMBT, the top of the tank will be most vulnerable. Mines will disable the tracks or the belly of the tank. The FMBT will be able to detect and fire at the enemy armor faster and at further distances. The FMBT will be capable of detecting enemy minefields and its smaller design will make it less vulnerable to a hit. No area of the tank has been neglected with regards to its armor protection. Increased Offensive capabilities and better defensive systems will give the FMBT an advantage over any enemy weapon system it will face.

2. Number and types of friendly units employed.

We will need to know what the FMBT will be working with before we can determine its actual capabilities. Infantry support, air superiority, and artillery support will all affect how well the FMBT performs its mission.

3. Weather--ranging from an arctic to a tropical climate.

The FMBT should be able to perform its mission in all types of weather. Conditions which will affect its performance are excessive rain, snow, hail, sandstorms, freezing temperatures, and humidity. Conditions like snow could simply cause the tank to get stuck. High humidity could decrease reliability of certain components. We will control the environment inside the tank (temp and humidity control) so that crew errors are not caused by the outside weather.

4. Terrain--ranging from mountainous to flat terrain.

The FMBT will be able to traverse slopes of 45% (dependent on soil conditions). Moisture in the soil will affect trafficability, causing a lack of traction or the FMBT to sink into the mud. The lighter FMBT will be able to traverse more types of soils (clay, sand, and silt) under various saturation levels. Thickness of vegetation will also affect trafficability. Vegetation will hinder movement, generally, if tree diameter is greater than 6 inches and tree spacing is less than 15 feet. The FMBT's smaller design will allow it to travel in thicker vegetation. On the positive side, thick vegetation offers concealment, with an canopy providing overhead concealment. Man-made features and bodies of water (rivers, lakes, and streams) are also terrain factors which affect the performance of the FMBT. With these areas the design of the FMBT eases restrictions on movement, making it more possible to utilize boats, bridges, and to avoid obstacles altogether.(EV203 notes)

5. Length of time FMBT will be engaged in combat.

Length of time the FMBT is engaged in combat affects refueling (or recharging), resupply of food and ammo, and maintenance requirements on the tank itself. Crew weariness after prolonged engagement will also be increased. The FMBT is designed to be more self sufficient and require less maintenance. Ergonomics and automation will also allow the crew to function longer without more operator error.

The threat that the FMBT could encounter also has a wide range of possibilities. The threat could range from such third world countries as Somalia to more advanced countries such as Germany. In our Janus simulation, the threat forces were composed of Soviet systems characteristic of those used in Cold War scenarios:

1. Soviet Mechanized Infantry (BMP 1 and 2; BRDM A and M; BTR-70)

2. Soviet Armor (T-72 and T-80)

3. Soviet Aviation (HIND and HIP)

4. Soviet Artillery (120mmS, 122mmM, 152mmH, and AGS-17)

5. Soviet Air Defense Artillery (AD TM and ZSU-23)

The enemy will attack first with second-echelon regiments of the lead division and then with the second-echelon division. We also chose the National Training Center (NTC), Fort Irwin, CA. This environment constists of desert region that is arid and mountainous. All simulations are conducted during the day.

CONSTRAINTS AND JUSTIFICATION

1. System must be completed by the year 2010. The M1A2 has a projected effective life. When its useful life has come to an end the FMBT must be ready for deployment. We have projected that the FMBT must be ready for

deployment by the year 2010. This is the current time constraint, although it may change if battlefield technology decreases the effective life of the M1A2.

2. Cost to develop and deploy FMBT must not exceed what Congress is willing to procur. Because of the large federal debt, Congress will be willing to appropriate only so much money towards fielding the FMBT. We must avoid cost over-runs. We have not yet determined the amount Congress will appropriate, but the total of all life-cycle costs (R & D, Production & Deployment, Maintenance, and Retirement & Disposal) must be under this spending limit.

3. FMBT must weigh less than 59 tons. This constraint applies to the deployability of the system. More systems are capable of being transported at once as the weight of the system decreases (assuming that the design dimensions remain the same or decrease).

4. FMBT must be able to engage and destroy enemy heavy weapon systems. The purpose of the main battle tank is to provide shock effect on the battlefield and to counter enemy heavy forces. These systems include tanks, HIND helicopters, and armored troop carriers.

5. FMBT must be socially and legally acceptable. During peacetime, society tends to want to decrease the size of the Army and cut spending on defense. Therefore, we must ensure that the FMBT appeals to the public in order to obtain support from them which ultimately influences the politicians that control the budget.

In addition to the general system constraints previously listed, there are also constraints that we encountered while working with Janus.

1. Each simulation that we conducted in Janus only lasted 25 minutes. However, this shortened battle did not affect our analysis, because by this time, most of the systems that we were focusing the tests on had stopped firing.

2. We placed the FMBTs in a defensive posture, and they did not move from their initial positions. Therefore, when they were fired upon, they did not have the option to move to a better location since we did not program them to do so.

OPERATIONAL CONCEPT

The Future Main Battle Tank can be used in several roles due to its deployability and lethality. Since the FMBT is light-weight and is designed to sustain itself on the battlefield, the FMBT can be used in a scout role. Its high rate of speed (75 km/hr) also helps it to conduct this role with rapid deployment. Its high-quality sensors allow it to gather information at greater distances which enable to provide forward observation and reconaissance. However, the main operational concept of the FMBT is to provide shock effect to the battlefield with its lethal weapon systems. It can be used in either the defense or offense to combat enemy heavy forces.

In our Janus simulations, we placed our electric tank systems in the C Company area in a defensive posture. They did not move from their initial locations. We also oriented their fires on the NE sector of EA Dean. The enemy avenue of approach was a frontal assault on EA Dean from the east to the north. We deployed two OH-58 helicopters forward of our units to provide observation and reconaissance, while our 155-mm Battery and mortar platoon provided fire support for the mission. Our field artillery missions were not pre planned and were concentrated throughout the simulation on PL Traveler and the tank ditches to the east of our task force. We used AutoJan to replicate the simulations. Basically, the scenarios that we ran were heavy friendly forces against heavy enemy forces.

FUNCTIONAL OBJECTIVES

A major goal of our Future Main Battle Tank (FMBT) is to destroy enemy weapon systems. A sub-goal associated with this goal is to increase the firepower of our Main Battle Tank. The functional objectives which our system should meet in order to attain this goal are:

1. To maximize the rate of fire (ROF) of the main gun. This objective will allow the system to put more steel on target in a shorter amount of time. Thus, the enemy will have less time to react to the overwhelming volume of fire.

2. To maximize the lethality of our main gun rounds. This will increase our efficiency both technically and economically. If our system can kill an enemy target

with less rounds, then operating the system will cost less money. Also, it will increase the survivability of the system, because, blow for blow, our system will withstand the battle longer.

3. To maximize the number of rounds the FMBT can carry and fire. This will increase the survivability of the system. The longer that it can remain free of the logistical chain, the better mobility and countermobility it can exercise.

4. To minimize the rearm time for the main gun. If it takes the crew a shorter amount of time to rearm the system (or whether it has an autoloader), then the more rounds we will be able to send down range. It will also increase the survivability and lethatlity of the system, because it will enable our system to react quicker to the events on the battlefield.

5. To maximize the range of the main gun. This will enable our system to detect and fire upon the enemy before the enemy has time to react. Not only will this improve the lethality of our system, but it will also increase the chances of our system's survival.

6. To maximize the accuracy of the main gun. This also contributes to the lethality of the system. The more accurate that our system is, then the more kills it will obtain. This objective will also minimize the cost of attack for our system which will aid in relative worth calculations.

DESCRIPTION OF ALTERNATIVES

The only difference between each Electric Tank system is the selection of weapons. Each system will employ a 2nd Generation FLIR.

KILLER (Basecase)

1. Weapon A is capable of defeating all known targets out to 4 km. Its basic load is 38 rounds.

CRUSHER

1. Weapon B is capable of defeating only tanks out to 4 km. Its basic load is 24 rounds.

2. Weapon C is capable of defeating all targets except tanks out to 4 km. Its basic load is 10 rounds.

3. Weapon D is capable of defeating tanks from 2.5-4.0 km and is the preferred weapon over B in this range. Its basic load is 6 rounds.

BRUISER

1. Weapon E is a possible replacement for B and is capable of defeating only tanks out to 4 km. Its basic load is 24 rounds.

2. Weapon C is capable of defeating all targets except tanks out to 4 km. Its basic load is 10 rounds.

3. Weapon D is capable of defeating tanks from 2.5-4.0 km and is the preferred weapon over B in this range. Its basic load is 6 rounds.

MODELS USED IN TRADE-OFF ANALYSIS

DISCUSSION:

We ran our simulations on the JANUS (A) 2.0 Model. This system is an interactive, two-sided, closed, stochastic, ground combat simulation featuring precise color graphics. It takes random numbers inputed by the designer to simulate the outcomes of a scenario. This helps to capture the reality of a battle. It also allows the user to change various factors of the battle to include real time, types of systems employed, artillery fires, and engineering assets (to name a few).

We processed our results using the post processing function in JEDA. This computer program enables the user to analyze his MOE against all or part of the Blue force against the Red force. It provides histograms, circle graphas, and spreadsheet printouts of the results for easy interpretation and presentation. In other words, JEDA transforms the information gathered from the Janus simulation runs (such as number of kills and detections) into useable statistics. These statistics are used to determine the effectiveness of weapon systems during combat. In this case, it helped us to analyze the performance of the weapon systems on the Electric Tank compared to the Soviet weapons.

A comparison of alternatives test allows one to compare alternative systems to a designated basecase. In this case we were comparing Killer to Crusher and Bruiser in order to determine if there was a significant difference in the performance of these systems concerning a particular MOE.

We utilized the Multi-Attribute Utility (MAU) Model to help choose the most effective Electric Tank in accordance with its performance on the MOEs. The MAU technique is useful, because it enables us to model the needs and desires of the engineer and the client through the use of weighting the criteria on the basis of relative importance. The important criteria are represented in the MAU Model and are weighted to reflect the client's priorities. Appropriate modeling of the criteria and scaling of the performance scores completes the model and allows the design engineer to rank order the candidate systems and illuminate the "best" candidate systems (SE402 Handout, Lsn 20).

In order to conduct the MAU and sensitivity analysis, we utilized the HIPRE3+ computer program. After we completed the comparison of alternatives testing, we used the results to order our alternatives according to preferences. Then, we conducted sensitivity analysis on the MOEs to determine the weights at which we became indifferent among the alternatives.

Finally, a relative effectiveness test was performed in order to determine which system is "best" based for performance as determined in the JANUS simulations. We simply compared the tanks by merits of their performance on the MOEs that provided signifigance.

DESIGN OF EXPERIMENT:

Alternative	Killer (base)	Crusher	Bruiser
Run 1	11	21	31
Run 2	12	22	32
Run 3	13	23	33
Run 4	14	24	34
Run 5	15	25	35
Run 6	16	26	36

We used the same random number for Run 1 for each alternative. However, we changed the random number between the runs. For example, Runs 11, 21, and 31 all used the same random number, but Runs 11, 12, 13, etc. used different random numbers.

MEASURES OF EFFECTIVENESS

Note: Due to an error in our fire priority table, alternatives Crusher and Bruiser did not fire at certain systems. I printed the SERs for each of the threat systems to find what the two tanks would not shoot. I realized that Crusher and Bruiser did not fire at the BMP-1, BMP-2, Lt Machine gun, or Rifleman. We therefore removed these systems completely from our analysis. Our subsequent Jeda reports did not include these systems for any of our runs.

After examining our results, I believe this allowed for relevant results. We thought that the Kilier system might be affected because it had take time for it to fire at these systems when the others had not. After studying our results, however, we do not believe this significantly affected our resuls.

SYSTEM EXCHANGE RATIO (SER)

1. *DEFINITION OF THE MEASURE:* The System Exchange Ratio is the ratio of kills by a system and the kills of a system:

SER = Kills by System/Kills of System

We conducted a SER between our tank and the enemy system which posed the greatest threat to our system (ie. T-80s). Because the T-80 was the only system to inflict a significant number of kills on our systems and the primary target for our FMBTs was enemy heavy armor, an analysis with it would be most meaningful.

2. *DIMENSION OF THE MEASURE:* It is a ratio measured by kills inflicted and kills suffered.

3. *LIMITS ON THE RANGE OF THE MEASURE:* The output may be zero or assume any positive value.

4. *RATIONALE FOR THE MEASURE:* If SER is greater than 1, then the system is killing more systems and/or accepting less casualties.

5. *DECISIONAL RELEVANCE OF THE MEASURE:* This MOE is intended to compare the survivability of the FMBT and the lethality of the main gun to the basecase.

6. *ASSOCIATED MEASURES OF PERFORMANCE:*

Proportion of force destroyed

Loss Exchange Ratio (LER)

Force Exchange Ratio (FER)

FRACTIONAL EXCHANGE RATIO (FER)

1. *DEFINITION OF THE MEASURE:* The Fractional Exchange Ratio is the ratio of enemy losses per number of systems employed to the friendly losses per number of systems employed:

$$FER = \frac{\text{\# of Red Losses/Initial Red Strength}}{\text{\# of Blue Losses/Initial Blue Strength}}$$

2. *DIMENSION OF THE MEASURE:* It is a ratio measured by the compared losses in force strength.
3. *LIMITS ON THE RANGE OF THE MEASURE:* The output may be zero or assume any positive value.
4. *RATIONALE FOR THE MEASURE:* If FER is greater than 1, then the Blue side wins the battle.
5. *DECISIONAL RELEVANCE OF THE MEASURE:* This MOE will measure how well our system contributes to the success of our force in general.
6. *ASSOCIATED MEASURES OF PERFORMANCE:*

   Loss Exchange Ratio (LER)

   Proportion of Force destroyed

WEIGHTED KILLS

1. *DEFINITION OF THE MEASURE:* A kill is defined as our system firing at another system on the battlefield and rendering it ineffective. Janus determines what is defined as a kill in the simulations. We weighted our kills according to the ranges that they were inflicted. If we killed an enemy system at 4Km then that kill would be multiplied by a factor of four.

2. *DIMENSION OF THE MEASURE:* A quantitative value of enemy systems that are destroyed by our FMBT. For example, a number of 50 would indicate that our system killed 50 enemy weapon systems.

3. *LIMITS ON THE RANGE OF THE MEASURE:* The output may be zero or assume a positive value.

4. *RATIONALE FOR THE MEASURE:* This measure addresses lethality performance based on the fact that more kills are better.

5. *DECISIONAL RELEVANCE OF THE MEASURE:* This measure is used to distinguish between firepower systems of the FMBT and the basecase tank.

6. *ASSOCIATED MEASURES OR PERFORMANCE:*

   Firing Accuracy

   Lethality of the Payload

   Probability of a Hit

   Probability of a Kill

WEIGHTED DETECTIONS

1. *DEFINITION OF THE MEASURE:* Acquiring an enemy weapon system with the use of sensors. This information will indicate the identity and location of the target on the battlefield. Janus records the number of systems that our FMBT detects during the simulations. Since we wish to detect the enemy as soon as possible, we will weight detections based on the range of the detection. A higher weight will be assigned to a detection as the range to detection increases. Just as with kills, the detections will be multiplied with the range that they occurred.

2. *DIMENSION OF THE MEASURE:* A quantitative value of enemy systems that are detected by our FMBT. For example, a number of 50 would indicate that our system detected 50 enemy weapon systems.

3. *LIMITS ON THE RANGE OF THE MEASURE:* The output may be zero or assume a positive value.

4. *RATIONALE FOR THE MEASURE:* This measures the effectiveness of the sensors based on the fact that more detections are better.

5. *DECISIONAL RELEVANCE OF THE MEASURE:* This measure is used to distinguish between the acquisition capabilities of our FMBT and the basecase.

6. *ASSOCIATED MEASURES OF PERFORMANCE:*

   Time to Detection

   Time to Identification

   Expected Time to Acquisition

KILL EFFICIENCY RATIO (KER) T-80

1. *DEFINITION OF THE MEASURE:* This is the number of fires divided by the number of kills:

KER = Total Number of Fires/Total Number of Kills

2. *DIMENSION OF THE MEASURE:* It is a ratio of the average number of fires to kill an enemy system.

3. *LIMITS ON THE RANGE OF THE MEASURE:* The output value may be zero or assume a positive value.

4. *RATIONALE FOR THE MEASURE:* As the value of the output approaches 1, the system will be performing better. We took the KER for our systems versus the T-80 tank, since it is the most heavily armored threat system. If our sytem was lethal against a T-80, that would be more important than against a mortorcycle, for example.

5. *DECISIONAL RELEVANCE OF THE MEASURE:* This measure will give us and insight to both the accuracy and lethality of our weapon systems.

6. *ASSOCIATED MEASURES OF PERFORMANCE:*

Rate of Fire (ROF)

Probability of Kill

Probability of a Hit

Firing Accuracy

Lethality of Payload

Comparison of Alternatives (See Annex F)

SER vs T-80 70% CI:

At 70% confidence we did not detect significance between Crusher and Killer, but we did find that Bruiser was better than Killer with 70% confidence. Sensitivity Analysis (See Annex F for Sample Calculation): At 48.98% confidence we can say that Killer outperformed Crusher. At 77.63% confidence, we can no longer detect significance between Bruiser and Killer.SER vs T-80 70% CI:

FER 70% CI:

At 70% confidence we did not detect significance between neither Crusher and Killer, nor Bruiser and Killer. Sensitivity Analysis: We could not find significance at any confidence interval.

Weighted Kills 70% CI:

At 70% confidence we found than Killer outperformed both Crusher and Bruiser. Sensitivity Analysis: We found that Killer was still better than Crusher at a 99% CI. At 85.69% confidence we could no longer find significance between Killer and Bruiser.

Weighted Detections 70% CI:

At 70% confidence we found than Killer outperformed both Crusher and Bruiser. Sensitivity Analysis: At 90.52% confidence we could no longer find significance between Killer and Crusher. At 98% confidence we could no longer find significance between Killer and Bruiser.

Fires/Kill vs T-80 70% CI:

At 70% confidence we did not detect significance between Crusher and Killer, but we did find that Bruiser was better than Killer with 70% confidence. Sensitivity Analysis: Even at 1% confidence we could not find significance between Killer and Crusher. Even at 99% confidence we still foud Bruiser was better than Killer.

Relative Effectiveness (See Annex G for Results)

Since Weighted Kills, Weighted Detections, and Fires per Kill were our most significant MOEs (Fires/Kill was sig for Bruiser - Killer), we decided to use them in our RE calculations. In our relative effectiveness calculations these three MOE scores were placed over our basecase (Killer) to achieve a score in relation to the basecase. Although Killer performed better in two MOEs, since Bruiser had a much better Fires/Kill score, it had the best overall Avg. RE score of 1.16. Killer (basecase) had a score of 1 and Crusher had as score of .858.

MAU (See Annex H for chart)

We decided that all of our MOEs should not be weighted equally so we performed a MAU analysis on our decision. We decide that Weighted Kills and Detections should be weighted the highest (most significant) at twice the weight of Fire/Kill. But Fires/Kill should be twice that of SER and FER. Our normalized weights were as follows: WKills(.333), WDets(.333), Fires/Kill(.166), SER(.083), and FER (.083). At this weighting scheme Killer was our best alternative with a score of .609 utiles, Bruiser with as score of .491 utiles, and Crusher a score of .324 utlies.

Sensitivity Analysis

With the Hipre 3+ package we conducted sensitivity analysis on all of our MOEs. The graphs in Annex I show how sensitive each MOE is and at what weights our alternative prefernces change. Except for Weighted Kills, where Killer dominates the entire range, our preferences change when varying each MOE (whereever lines cross is indifference point between two alternatives).

In conclusion, we find that the weapon configuration on Killer is the best all around FMBT. We do find that Bruiser is the more lethal system, however, and with little increase in the importance of lethality (Fires/Kill) Bruiser would be our top alternative.

With our current information, we recomend that the Killer system be forwarded to the Detailed Design phase. We first recomend, however, that the problems in the firing tables need to be corrected and data re-analyzed before a final decision is made. We also recomend that the decision maker analyze Reliability, Maintainability, and Costs of our systems to consider in the final decision. We believe that the Crusher configuration can be eliminated at this time, but Killer and Bruiser should undergo the continued analysis.

SE401 and SE402 Lesson Handouts and Class Notes.

SE485 Class Notes.

SE485 Combat Modeling Notes. United States Military Academy, West Point, NY, Department of Systems Engineering.

[illegible]

[illegible]

The scope of this design is to is to describe our progress toward a "Type A" Specification of the Future Main Battle Tank (FMBT). We are also required to discuss two types of supporting models that are required in our design. Specifically, we must know where and how we plan to use Reliability Theory and Maintainability Theory in our design.

The scope of our system describes the uses and purpose of the FMBT. We want to design a system that is capable of being deployed to almost anywhere in the world on short notice. For example, if a political insurgency arises in Panama again, we would want to be able to provide the Army with a tank that can be deployed there to assist the efforts of the Infantry by providing shock effect. In order for the tank to be deployable, it must be mobile and survivable in a variety of battlefield conditions ranging from an arctic climate to a tropical climate. Therefore, size and weight of the FMBT must be kept to a minimum to ensure that it can be transported easily (by air or by sea) to many ends of the world. Supportability is also a main consideration, since this area is directly correlated to previously mentioned attributes. It must be easily maintained and supported, in order to augment its mobility and deployability. A track that must always be sent to headquarters to fix will take it off-line and will make it ineffective for troop use.

With these concepts in mind, we are tasked with designing the Future Main Battle Tank that will be able to sustain itself in a variety of missions and on different battlefields throughout the world. Therefore, this design is focused towards devising and refining specific areas of the system to include the system definition, system characteristics, and system test and evaluation.

APPLICABLE DOCUMENTS

The following is a bibliography of the documents and other resources that we have used so far in our research of the project:

ARDEC, Adv Sys Con Div. All Electric Tank. 1993.

Caldwell, John, COL. Abrams Tank System. 1990.

Direction for the Next Design Concept: 50 Ton FMBT. Fort Knox, 1993.

Crawford, S. W., MAJ RTR. "The Main Battle Tank: Future Developments--A British Perspective." Armor Magazine. January-February 1993, Vol. CII No. 1. pp. 18-25.

United States Army Tank-Automotive Command. Advanced Vehicle Technologies. Detroit Arsenal, 1992.

United States Army Tank-Automotive Command. Science & Technology Base: Investment for Advanced Land Combat Vehicles. Detroit Arsenal, 1992.

This list is not final. We will need to do additional research as needed.

SYSTEM DEFINITION

1. General Description

The subsystems of the Future Main Battle Tank are grouped into the following main categories: armor, main gun, power, crew, sensors, method of movement, and types of main gun rounds.

FMBT #1 (Block II Type):

Tracked tank with reactive armor, smoothbore cannon with KE round, 4-man crew, and forward looking thermal sensor.

FMBT #2 (Electric Tank):

Tracked tank with active armor, rail gun with KE round, 3-man crew, and forward looking infrared sensor (FLIR).

2. Operational Requirements

Department of Defense recently gave us a primitive need which is our basis for analysis into the Future Main Battle Tank (FMBT). This need can be summarized as follows:

1. A need for reliable and maintainable systems in a variety of combat environments.
2. A need to reduce maintenance, training, and support requirements.
3. A need to reduce the vulnerability of combat systems.

4. A need to deploy and quickly employ force anywhere with little notice.

Many events since the end of the Cold War provide justification for our need to develop a FMBT. These justifications and missions include:

1. A more predictable and less stable multi-polar world.

2. Regional and territorial disputes arising in the post Cold War states.

3. Economic Interdependence. Insurgencies that affect U.S. interest must often be dealt with quickly and effectively.

4. The military's new roles - counter narcotics and counter-terrorist roles, for example.

5. Technology proliferation resulting in a more lethal battlefield (ex. smart mines and munitions).

6. Domestic economic and political environment calling for a reduced military with less forward deployed units. The Army has this need for a more deployable heavy force because of current problems with Intra-CONUS, Intertheater, and Intratheater deployment phases. Problems exist with rail, highway, air, and sea movements of heavy class system. (Desert Shield and Desert Storm confirmed many of these problems.)

There appears to be great justification for a FMBT, and we have validated many of the needs observed by the Department of the Army. Not taken into account in the primitive statement of needs was the need for a more lethal tank system. As mentioned, technology proliferation will make the battlefield more lethal. If we do not develop a FMBT that is more capable of killing enemy systems, we will not keep pace with increases in threat lethality. A more lethal system also advances the need for a less vulnerable system. If we are able to kill an enemy system, that system no longer possesses the capability to destroy our FMBT. In other words, sometimes the best defense is a good offense.

We believe that by the year 2010 we must be able to replace the M1A2 system with a new, more capable, and financially feasible main battle tank. The FMBT must be a reliable and maintainable system, more capable of destroying enemy systems while being less vulnerable to existing and emerging threat technology. This system must be easily deployable and less dependent on maintenance, training, and support requirements.

The FMBT will be placed in a variety of battlefields, because our threats are many and uncertain. Therefore, its mission is to be prepared to be quickly deployed to be used in "police scenarios" such as drug and narcotic wars and in places confronting political insurgencies like Bosnia, Panama, and Somalia. The FMBT will be utilized in small-scale or limited wars in addition to the total wars that the M1A2 was designed. The FMBT will replace the M1A2 at all armored units. The FMBT will also be integrated into fast deployment Infantry units. Its broad mission will make this necessary while its compact, light design will make it feasible.

The utilization profile includes the anticipated usage of the system in accomplishing its mission such as hours of equipment operation per day, duty cycle, and on-off cycles per month. The FMBT will be able to conduct, if necessary, continuous operations for 100 hrs without failure. After operations of this nature maintenance procedures are critical. Maintenance will not be neglected on any length of mission. Any time the FMBT is utilized the crew must perform checks to ensure the FMBT is properly functioning. Whenever The FMBT has been operating for more than 20 hours, the crew must make a more in depth evaluation. Ideally we would like to operate the FMBT at no more than six hours per day, but capable of 100 hours of continuous operations without failure.

As mentioned earlier, the FMBT should be implemented by the year 2010. Therefore, the life cycle of the tank begins now with the research and development stage and continues to the production and implementation stage in 2010. The system should be designed to have a useful life of approximately 15-25 years at which point it will begin the retirement phase and new technologies and new threats will provoke the research and design of another MBT.

3. Maintenance Concept

As Blanchard (p.29) describes, there are three levels of maintenance: organizational, intermediate, and supplier/depot. We will emphasize the use of organizational maintenance to include PMCS checks and corrective action training for on-site repairs. We do not want our system to be tied to maintenance depots, because this will limit the mobility of the tank and its ability to survive on the future battlefield. The best way to avoid higher levels of maintenance lies with the operator. We will stress PMCS checks whenever the FMBT is started. We will also require the crew to perform weekly checks and take corrective measures with any deficiencies. The Army has a policy like this with the M1 series tank. We will, however, broaden the scope of the checks and increase the amount of operator corrections. Parts necessary for this continuous maintenance will be on hand. Testing will give us an idea which parts will be in greatest demand and we will avoid delays in waiting for parts by having them on hand.

4. System Diagrams

We used an input/output model to help define the boundaries and boundary conditions of the system. It also allowed us to analyze the inputs and the demanded outputs of the system. Using this model, we defined the objectives, constraints, variables, parameters, and criteria of the system. We will also need to develop diagrams of the FMBT as we finalize the design. Our input/output model is in Annex A.

5. Interface Criteria

We have looked at how the FMBT is tied into the "bigger picture." Communication systems, command and control, complimentary systems, required support, and deployment requirements are some of the areas we will need to address in the final design of the FMBT. The FMBT cannot be looked at as a single system, but as a piece in the whole force structure. The FMBT must be able to work with the other systems, complementing their functions and having supporting systems complement the FMBT.

6. Environmental Conditions

Since the mission of the FMBT is to be deployable to many parts of the world, the range of the environmental conditions is wide. Some of the variables that may be included are:

1. The number and type of enemy weapon systems.

The FMBT will need to perform its mission against many types of enemy weapon systems. We will need to know if we will be facing direct or indirect fire, enemy mines or other obstacles, enemy airpower, or any other anti-tank weaponry. The tank should not be affected by small arms fire. For enemy armor or anti-tank weaponry (such as TOWs) the sides of the sides of the tank, including the tracks, are the most vulnerable. If the enemy will use helicopters against the FMBT, the top of the tank will be most vulnerable. Mines will disable the tracks or the belly of the tank. The FMBT will be able to detect and fire at the enemy armor faster and at further distances. The FMBT will be capable of detecting enemy minefields and its smaller design will make it less vulnerable to a hit. No area of the tank has been neglected with regards to its armor protection. Increased Offensive capabilities and better defensive systems will give the FMBT an advantage over any enemy weapon system it will face.

2. Number and types of friendly units employed.

We will need to know what the FMBT will be working with before we can determine its actual capabilities. Infantry support, air superiority, and artillery support will all affect how well the FMBT performs its mission.

3. Weather--ranging from an arctic to a tropical climate.

The FMBT should be able to perform its mission in all types of weather. Conditions which will affect its performance are excessive rain, snow, hail, sandstorms, freezing temperatures, and humidity. Conditions like snow could simply cause the tank to get stuck. High humidity could decrease reliability of certain components. We will control the environment inside the tank (temp and humidity control) so that crew errors are not caused by the outside weather.

4. Terrain--ranging from mountainous to flat terrain.

The FMBT will be able to traverse slopes of 45% (dependent on soil conditions). Moisture in the soil will affect trafficability, causing a lack of traction or the FMBT to sink into the mud. The lighter FMBT will be able to traverse more types of soils (clay, sand, and silt) under various saturation levels. Thickness of vegetation will also affect trafficability. Vegetation will hinder movement, generally, if tree diameter is greater than 6 inches and tree spacing is less than 15 feet. The FMBT's smaller design will allow it to travel in thicker vegetation. On the positive side, thick vegetation offers concealment, with an canopy providing overhead concealment. Man-made features and bodies of water (rivers, lakes, and streams) are also terrain factors which affect the performance of the FMBT. With these areas the design of the FMBT eases restrictions on movement, making it more possible to utilize boats, bridges, and to avoid obstacles altogether.(EV203 notes)

5. Length of time FMBT will be engaged in combat.

Length of time the FMBT is engaged in combat affects refueling (or recharging), resupply of food and ammo, and maintenance requirements on the tank itself. Crew weariness after prolonged engagement will also be increased. The FMBT is designed to be more self sufficient and require less maintenance. Ergonomics and automation will also allow the crew to function longer without more operator error.

SYSTEM CHARACTERISTICS

1. Performance Characteristics

Goals

Looking at our given needs, we determined that the Army needed a Future Main Battle Tank. The goals that we must address in our design are the following:

1. To deploy quickly and efficiently

We would like to have the FMBT deployable to anywhere in the world within 48 hours. This is our upper limit. For short notice missions we would like to have the FMBT as a part of any deployment force. We do not want our future "heavy" forces restricted based on deployment delays.

2. To survive in various combat environments

See environmental conditions.

3. To destroy enemy weapon systems and troops

The FMBT will be our primary killer of enemy tank systems. This will be its primary mission. The FMBT will not be limited in its capabilities. Secondary weaponry will not be overlooked. Since we want the FMBT to perform in a variety of combat environments, we cannot overlook any of its functions.

4. To be cost effective

5. To be a reliable and maintainable system

See reliability and maintainability.

We believe that in addressing these goals, we will be able to design an effective FMBT that will meet the needs of the battlefield of the future.

Parameters

The parameters of the system are:

1. Type of fuel (power).

We will be looking an all electric tank (Block III) and a Block II tank using gas, diesel, or jet fuel.

2. The number and type of detection systems.

We will be looking into a 2nd generation FLIR sensor. We will also consider adapting current sensors. No more than two sensors will be utilized on a given tank.

3. The type of main gun and supporting weapon systems.

Main gun - ELECTROMAGNETIC Rail Gun and a 120mm cannon are two options. Different types of chain guns will be used as supporting weapons.

4. The types of munitions.

We will focus on kinetic energy rounds, but also look at new smart round technology.

5. Tank design.

It will be a smaller lightweight design. This will make it harder for the enemy to detect and it will be a faster, more mobile tank. Improvements in technology will allow us to do this without sacrificing the lethality of the FMBT.

6. The number of personnel required to operate the system.

We are currently focusing on a three person crew. This would mean developing an auto-loader to be used in the FMBT.

Constraints

1. System must be completed by the year 2010.

2. Cost to develop and deploy FMBT must not exceed what Congress is willing to procure.

3. FMBT must weigh less than 59 tons.

4. FMBT must be able to engage and destroy enemy heavy weapon systems.

5. FMBT must be socially and legally acceptable.

2. Physical Characteristics

The physical characteristics deal with the actual design of the FMBT. The subsystems that we are concerned with include: armor, main gun, power, crew, sensors, method of movement, and types of main gun rounds. We will need to determine what the best alternatives are for each category utilizing the system alternatives that we have chosen to forward to this part of the design phase and further describe each functional area. New technology we are considering are an electro-magnetic rail gun, lightweight armor panels, a second generation FLIR sensor, and an auto loader.

3. Effectiveness Requirements

According to Blanchard (p.25), this area includes such measures as cost/system effectiveness, operational availability, dependability, MTBF, MDT, MTBM, and personnel skill levels. We will use these measures and other measures we will infer from Janus simulations like range to detections, enemy kill ratio, and P(H) and P(K) data.

4-5. Reliability and Maintainability

Reliability is the "probability a system will perform in a satisfactory manner for a given period of time when used under specified operating conditions." (Blanchard, p.75) We will first need to describe satisfactory performance. This should be done when we describe the operational requirements of the tank. We will next address the time factor. MTBF, MTTF, and MTTR are some ways we could address this area. The last area is specified operating conditions. We will discuss this in our operating environments section. We will need to relate these environment to the tanks performance and reliability. In our reliability discussion we will try to use as much quantitative measures as possible. Poisson equations, bathtub curves, and reliability networks are a few of the tools we will use.

Maintainability is a design parameter which describes how well we can keep our FMBT fulfilling its mission. This involves minimizing time and resources spent on maintenance.

configuration. The reliability of this two wheel system would be .9976 ($R_{sys} = R_a + R_b - R_a * R_b$). The reliability of our entire system would now rise to .9835. These are a few of the options we have with regards to system reliability. Similar analysis can be performed on other components to determine what we van do in order to achieve desired levels of reliability.

6. Human Factors

We have looked at making the tank more compatible with the human body. Things to increase the "userability"" of the FMBT include such ergonomic considerations such as making the seats more comfortable and any handles more designed towards the hand. These improvements will allow the crew to operate with less fatigue and less error. The driver, for example will be sitting in a more comfortable position and his hands will not tire as quickly. Automation, such as the auto-loader will also simplify the tank leaving less room for operator error. Our human factors improvements will increase the reliability and maintainability of our tank and make it a more effective battlefield system.

7. Supportability

Ammo, fuel, and spare parts are a few of the things the FMBT will need after it is deployed. We want to make the tank as self-sufficient as possible, but we want to make it

This is basically uptime vs. downtime at a minimum cost. Quantitative measures we will use are Active maintenance time, logistics delay time, admin delay time, mean corrective maintenance time, and Availability theory.

An example of how we will utilize reliability and maintainability theory is the road wheels on the FMBT. I have said that we wish the FMBT to perform continuous operations for up to 100 hours without failure. Our FMBT's current design projects seven road wheels which will run parallel to the ground at the bottom of the tack. We wish to approach a time of 100 hours on all the wheels where reliability approaches 100%. The reliability on a single road wheel could be given as R = e^-t/M where M is the mean time between failures. If we were able to design a mean time between failure of 500 hours, we could have a reliability of .8187 in any given road wheel. If we could double the MTBF to 1000 hrs, the reliability with a single road wheel would be .9048. Every time we add to our MTBF we get smaller improvement in reliability. For example if we doubled our MTBF again, to 2000 hours, we would only improve our reliability to .9512. This is the reliability of a single road wheel. When we look at all seven road wheels (with a MTBF of 2000 hours each) operating together, our system has a reliability of .7047 ($R_{tot} = R_1 * R_2 * \ldots * R_7$). We could also consider adding a road wheel to make it possible for a road wheel to break and have its back up take over. This could be done using a side by side wheel supportable when it cannot be. The FMBT will carry a basic load of approximately 40 rounds. The kinetic energy rounds it utilizes are dart-shaped so the are not overly cumbersome. Options which can ease fuel requirements of the FMBT are to develop a All-Electric Tank. An electric tank would need recharging, however. A single recharging station might be able to recharge a battalion of tanks in less time and occupy less area than a normal fueling station. In time this tank may be able to operate very efficiently, recharging itself or needing little support. Increase in reliability will ease the burden of spare parts but we will ensure that the parts are available if the system goes down. Field test of trouble areas will allows us to be ready for these difficulties. Lastly, the crew requirements, such as food and water will be supplied as per SOP for the rest of troops engaged in combat.

8. Transportability/Mobility

We will discuss deployment requirements in this section. We will look at sea, land, and air deployments. We want to know what is required to get the FMBT to where it is needed in combat. Size and weight will be important characteristics in this section.

Reliability is the "probability a system will perform in a satisfactory manner for a given period of time when used under specified operating conditions." (Blanchard, p.75) We will first need to describe satisfactory performance. This should be done when we describe the operational requirements of the tank. We will next address the time factor. MTBF, MTTF, and MTTR are some ways we could address this area. The last area is specified operating conditions. We will discuss this in our operating environments section. We will need to relate these environment to the tanks performance and reliability. In our reliability discussion we will try to use as much quantitative measures as possible. Poisson equations, bathtub curves, and reliability networks are a few of the tools we will use.

An example of how we will utilize reliability theory is the road wheels on the FMBT. I have said that we wish the FMBT to perform continuous operations for up to 100 hours without failure. Our FMBT's current design projects seven road wheels which will run parallel to the ground at the bottom of the tack. We wish to approach a time of 100 hours on all the wheels where reliability approaches 100%. The reliability on a single road wheel could be given as $R = e^{-t/M}$ where M is the mean time between failures. If we were able to design a mean time between failure of 500 hours, we could have a reliability of .8187 in any given road wheel. If we could double the MTBF to 1000 hrs, the reliability with a single road wheel would be .9048. Every time we add to our MTBF we get smaller improvement in reliability. For example if we doubled our MTBF again, to 2000 hours, we would only improve our reliability to .9512. This is the reliability of a single road wheel. When we look at all seven road wheels (with a MTBF of 2000 hours each) operating together, our system has a reliability of .7047 ($R_{tot} = R_1*R_2* \ldots *R_7$). We could also consider adding a road wheel to make it possible for a road wheel to break and have its back up take over. This could be done using a side by side wheel configuration. The reliability of this two wheel system would be .9976 ($R_{sys} = R_a+R_b - R_a*R_b$). The reliability of our entire system would now rise to .9835. These are a few of the options we have with regards to system reliability. Similar analysis can be performed on other components to determine what we van do in order to achieve desired levels of reliability.

[illegible]

Maintainability is a design parameter which describes how well we can keep our FMBT fulfilling its mission. This involves minimizing time and resources spent on maintenance. This is basically uptime vs. downtime at a minimum cost. Quantitative measures we will use are active maintenance time, logistics delay time, admin delay time, mean corrective maintenance time, and Availability theory.

As an example of Maintainability Engineering, we will look at system Availability. Availability or A_o = MTBM/(MTBM + MDT). Where MTBM = mean time between maintenace and MDT = mean down time. This term describes what percentage of time our system is ready for use. I can show you how the availability of our tank can be effected whenever we send it to depot for repairs. Even if the tank only requires that type of support once every two years (24 months), it would probably take a few months to send the tank away and get it sent back. So even if they only took one day to correct the tank it would not be available to us. If MTBF = 24 months and MDT = 4 months, A_o = 24/28 = .8571. In other words, our system would be available 85.71% of the time. If we were given the facilities or training to fix the deficiency ourselves within a week, we can see how that effects A_o. Ao = 24/24.25 = .9897. Our system would be available 98.97% of the time! If we could fix our tank ourselves, it could break down every month and a half and still have the same availability as sending it to depot once every two years (.8571 = 1.5/1.75). This analysis shows that if we can handle corrective measures ourselves, in the shortest possible time, our forces will be more combat effective.

We performed operational tests in Janus simulations to ensure that our system performed as we intended it to perform. We specified the parameters of the test and the objectives of the test (what we wished to demonstrate). These tests should highlight the critical aspects of our design and ensure that Janus is correctly incorporating these aspects. The results of these tests should point to parameters that may need correcting or deficiencies in Janus. This is an important step prior to conducting the TOA, because it helps to work out the problems that Janus may have in evaluating our parameters. If a parameter is not specifically represented in Janus in the manner that we intended in our design, then we will not be able to compare the performance of our FMBT to the basecase. Additionally, if a parameter is represented in Janus as we intended it to be, we will be able to adjust the parameter if it does not enable our system to perform as well as we would like it to perform.

The operational tests that we will want to perform in Janus will test the parameters that we input in Part Two of this IPR. Technically, we could make a test for each of the parameters that we input into Janus. However, we chose to simply test the parameters that will most effect the performance of our system.

The first parameter that we tested is the ground speed of the tank. Since the M1A1 has a maximum speed of approximately 60 km/hr, we feel that it is critical to ensure that our FMBT travels at 75 km/hr. This higher rate of speed increases the mobility and survivability of the tank and if it is not correctly modeled in Janus, then our FMBT will not perform as well as we intend. Therefore, the objective of this operational test is to validate that our tank travels at a ground speed of 75 km/hr. In order to test this parameter in Janus, we simply ran a road march type of simulation and tracked how far the tank traveled in one hour. We conducted this road march without the presence of threat elements, so the tank can "open up" without having to vary speeds to avoid the enemy. When we ran the scenario, the tank achieved an on-road speed of 60 km/hr and an off-road speed of 30 km/hr. After conducting more research and consulting with CPT Tillman, we found that we could change the maximum speed of the FMBT in Janus (JSCN I-III) to 75 km/hr.

We also performed an operational test on the range of the main gun. The objective of this test was to ensure that our FMBT would detect and kill an enemy system. In order to perform this test, we set up our FMBT in the direct path and in the line-of-sight of a T-80 and a T-72 tank. We deployed both systems directly toward each other. The result was that our system detected and killed the enemy tanks before the threat systems could even detect our systems. Our system was located at grid coordinate 942534 and it killed the enemy system at 956534. Since we gave our system enhanced main gun and sensors, it makes sense that our system was capable of destroying the enemy before the enemy had time to react.

The final two parameters that we tested were associated with the tank's ability to interact with natural and man-made obstacles. These two parameters are its swim capabilities and its vulnerability to mines. We input into Janus that our FMBT will not be able to swim and it is vulnerable to mines. It will be especially vulnerable to magnetic mines, since our design incorporates an electric transmission and an electromagnetic rail gun. The objective of this test is to ensure that the FMBT cannot swim and is vulnerable to mines. In order to perform these operational tests, we plotted a course through a river and a minefield for the FMBT to traverse. When the tank approached the minefield, it stopped and a message appeared on the screen that a minefield was detected and the tank would not move any further. This proved that our system was vulnerable to a conventional minefield, because the minefield slowed it down, and we had to tell it to go before it would pass through the minefield. The one drawback to the test was that once the tank did move through the minefield, it was not killed. Next, we drove the tank through the river. This operational test was a success, because the tank would not move any further once it entered the river. It could not swim and it became "stuck" in the water. This was the desired outcome of the test.

Sample Calculation for Sensitivity Analysis

on CI for Weighted Kills

Test changes from significant to not significant at a t-value = 2.283.

From Table T1:

$$\frac{2.337 - 2.283}{2.337 - 2.191} = \frac{x}{.9667 - .9600} = .054/.146 = x/.0067$$

$x = 2.478 \times 10^{-3}$ $\qquad$ $Y = .9667 - 2.478 \times 10^{-3} = .9642$

$.9642 = 1 - alpha/c/2 = 1 - alpha/4$ $\qquad$ alpha = .1431

CI = 1 - alpha = 85.69%

		Vs T-80	SER	70% CI		
Run	Killer	Crusher	Z(n)	Bruiser	Z(	
1	5.17	4.2	-0.97	10.33	5.	
2	5.2	5.25	0.05	4.67	-0.	
3	4	4.2	0.2	5.2	1.	
4	4.17	3.67	-0.5	7.75	3.5	
5	5	4	-1	6		
6	2.71	3	0.29	10.33	7	
AVG	4.375	4.053333	-0.32167	7.38	3.0	
VAR	0.93163	0.546867	0.339337	6.30856	9.2	
VAR (Zn)			0.056556		1.53	5
t-value		1.714		1.714		
1/2 Length		0.407615		2.123497		
Upper Bound		0.085949		5.128497		
Lower Bound		-0.72928		0.881503		
Significance		No		Yes		

		Vs T-80	SER		
Run	Killer	Crusher	Z(n)	Bruiser	Z(n)
1	5.17	4.2	-0.97	10.33	5.16
2	5.3	5.35	0.05	4.67	-0.63
3	4.4	4.6	0.2	5.2	0.8
4	3.17	2.67	-0.5	7.75	4.58
5	3	2	-1	6	3
6	3.29	3.58	0.29	10.33	7.04
AVG	4.055	3.733333	-0.32167	7.38	3.325
VAR	1.07875	1.548227	0.339337	6.30856	8.17335
VAR (Zn)			0.056556		1.362225
t-value	48.98% CI	1.35258	77.63% CI	2.85	
1/2 Length		0.321664		3.32636	
Upper Bound		-2.5E-06		6.65136	
Lower Bound		-0.64333		-0.00136	
Significance		Yes		NO	

		FER	70% CI		
Run	Killer	Crusher	Z(n)	Bruiser	Z(n)
31	5.61	2.73	-2.88	3.29	-2.32
32	3.01	1.8	-1.21	1.87	-1.14
33	3.23	4.43	1.2	5.27	2.04
34	5.02	4.69	-0.33	5.38	0.36
35	2.59	2.1	-0.49	2.54	-0.05
36	1.67	5.12	3.45	6.87	5.2
AVG	3.521667	3.478333	-0.04333	4.203333	0.681667
VAR	2.249937	2.069097	4.687747	3.735747	7.045537
VAR (Zn)			0.781291		1.174256
t-value		1.714		1.714	
1/2 Length		1.515016		1.857344	
Upper Bound		1.471683		2.53901	
Lower Bound		-1.55835		-1.17568	
Significance		No		NO	

		FER			
Run	Killer	Crusher	Z(n)	Bruiser	Z(n)
31	5.61	2.73	-2.88	3.29	-2.32
32	0.59	-0.62	-1.21	1.87	1.28
33	5.63	6.83	1.2	5.27	-0.36
34	4.36	4.03	-0.33	5.38	1.02
35	1.61	1.12	-0.49	2.54	0.93
36	8.57	12.02	3.45	6.87	-1.7
AVG	4.395	4.351666667	-0.04333	4.203333	-0.19167
VAR	8.53351	20.56797667	4.687747	3.735747	2.345057
VAR (Zn)			0.781291		0.390843
t-value	CI<1%	0.559		0.559	
1/2 Length		0.494103863		0.349472	
Upper Bound		0.45077053		0.157806	
Lower Bound		-0.537437197		-0.54114	
Significance		No		No	

OK

They look real close too.

		Weight	Kills	70% CI		
	Run	Killer	Crusher	Z(n)	Bruiser	Z(n)
	1	213.5	128.5	-85	184.5	-29
	2	223.5	161.5	-62	193	-30.5
	3	230.5	130	-100.5	163	-67.5
	4	228.5	169.5	-59	214.5	-14
	5	207.5	82	-125.5	184	-23.5
	6	183.5	145	-38.5	198.5	15
	AVG	214.5	136.0833	-78.4167	189.5833	-24.9167
	VAR	308.8	972.3417	997.5417	295.1417	715.1417
	VAR (Zn)			166.2569		119.1903
	t-value		1.714		1.714	
	1/2 Length		22.10043		18.71248	
	Upper Bound		-56.3162		-6.20419	
	Lower Bound		-100.517		-43.6291	
	Significance		Yes		Yes	

✓

		Weight.	Kills		
Run	Killer	Crusher	Z(n)	Bruiser	Z(n)
1	213.5	128.5	-85	184.5	-29
2	223.5	161.5	-62	193	-30.5
3	230.5	130	-100.5	163	-67.5
4	228.5	169.5	-59	214.5	-14
5	207.5	82	-125.5	184	-23.5
6	183.5	145	-38.5	198.5	15
AVG	214.5	136.0833333	-78.4167	189.5833	-24.9167
VAR	308.8	972.3416667	997.5417	295.1417	715.1417
VAR (Zn)			166.2569		119.1903
t-value	CI >99%	6.082	85.69% CI	2.283	
1/2 Length		78.42171093		24.92449	
Upper Bound		0.005044262		0.007826	
Lower Bound		-156.8383776		-49.8412	
Significance		No		No	

	Weigt.	Dets	70% CI		
Run	Killer	Crusher	Z(n)	Bruiser	Z(n)
1	370.5	349.5	-21	343	-6.5
2	433.5	374.5	-59	307	-126.5
3	380	404	24	322	-58
4	457	414	-43	352	-105
5	424.5	374	-50.5	329.5	-95
6	395.5	349.5	-46	350	-45.5
AVG	410.1666667	377.5833333	-32.5833	333.9167	-72.75
VAR	1128.366667	724.7416667	928.6417	310.8417	1954.675
VAR (Zn)			154.7736		325.7792
t-value		1.714		1.714	
1/2 Length		21.32353853		30.93659	
Upper Bound		-11.2597948		-41.8134	
Lower Bound		-53.90687187		-103.687	
Significance		Yes		Yes	

		Weigt.	Dets		
Run	Killer	Crusher	Z(n)	Bruiser	Z(n)
1	370.5	349.5	-21	343	-6.5
2	433.5	374.5	-59	307	-126.5
3	380	404	24	322	-58
4	457	414	-43	352	-105
5	424.5	374	-50.5	329.5	-95
6	395.5	349.5	-46	350	-45.5
AVG	410.1666667	377.5833333	-32.5833	333.9167	-72.75
VAR	1128.366667	724.7416667	928.6417	310.8417	1954.675
VAR (Zn)			154.7736		325.7792
t-value	90.52% CI	2.6195	98% CI	4.031	
1/2 Length		32.58868681		72.75694	
Upper Bound		0.005353476		0.006945	
Lower Bound		-65.17202014		-145.507	
Significance		No		No	

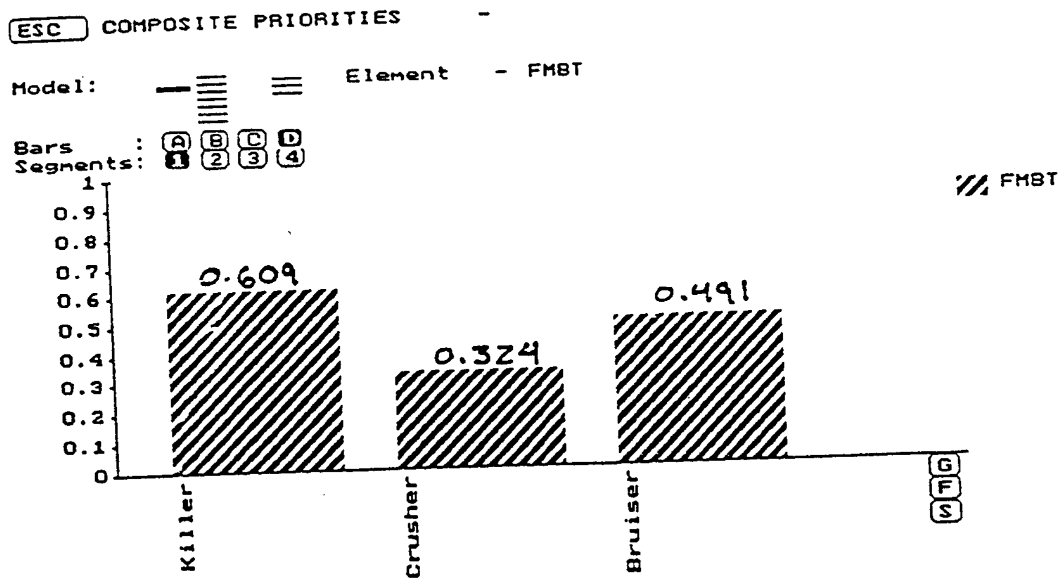
Vs T-80	Fires	Per Kill	70% CI		
Run	Killer	Crusher	Z(n)	Bruiser	Z(n)
1	4.870968	6.285714	1.414746	3.580645	-1.29032
2	5.576923	4.857143	-0.71978	3.25	-2.32692
3	4	5.952381	1.952381	3.076923	-0.92308
4	5.44	5.545455	0.105455	2.903226	-2.53677
5	6.68	4.25	-2.43	3.2	-3.48
6	6.789474	5.66667	-1.1228	2.741935	-4.04754
AVG	5.559560833	5.426227167	-0.13333	3.125455	-2.43411
VAR	1.137811329	0.558990128	2.680285	0.085419	1.462107
VAR (Zn)			0.446714		0.243685
t-value		1.714		1.714	
1/2 Length		1.145580612		0.846106	
Upper Bound		1.012246946		-1.588	
Lower Bound		-1.278914279		-3.28021	
Significance		No		Yes	

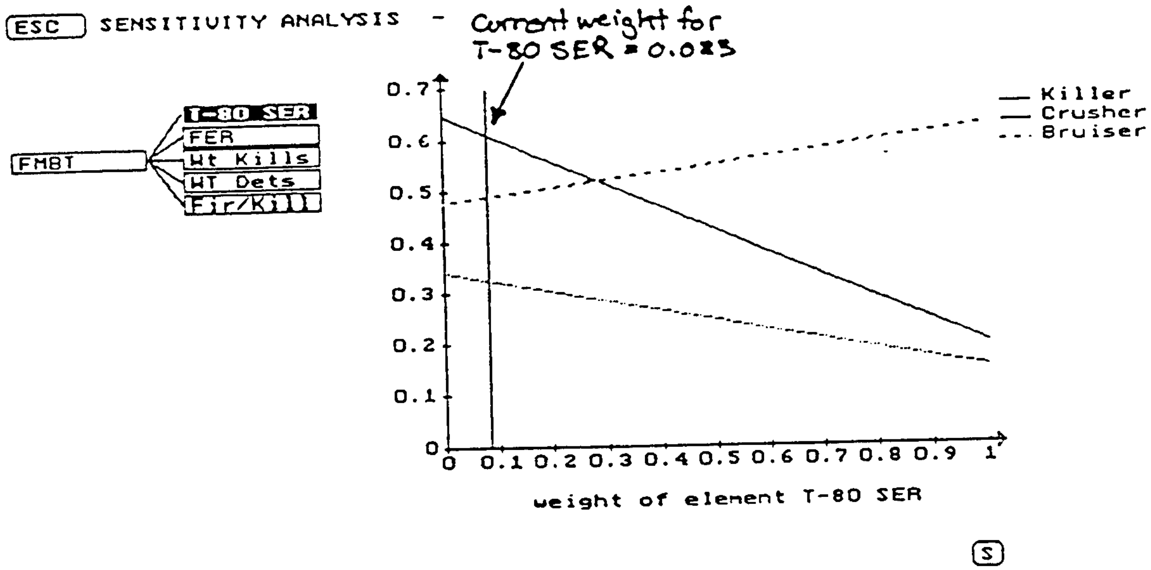
	Vs T-80	Fires	Per Kill		
Run	Killer	Crusher	Z(n)	Bruiser	Z(n)
1	4.870968	6.285714	1.414746	3.580645	-1.29032
2	5.576923	4.857143	-0.71978	-3.25	-2.32692
3	4	5.952381	1.952381	3.076923	-0.92308
4	5.44	5.545455	0.105455	2.903226	-2.53677
5	6.68	4.25	-2.43	3.2	-3.48
6	6.789474	5.66667	-1.1228	2.741935	-4.04754
AVG	5.559560833	5.426227167	-0.13333	3.125455	-2.43411
VAR	1.137811329	0.558990128	2.680285	0.085419	1.462107
VAR (Zn)			0.446714		0.243685
t-value	<1%	0.559	>99%	4.945	
1/2 Length		0.373617014		2.44107	
Upper Bound		0.240283348		0.006964	
Lower Bound		-0.506950681		-4.87518	
Significance		No		No	

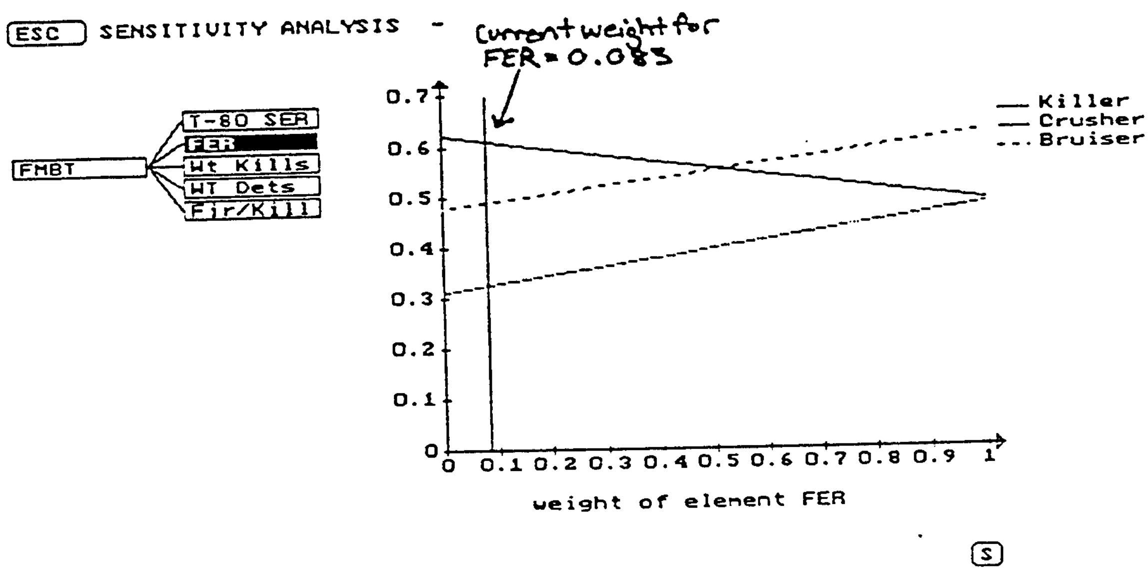
Calculation of Relative Effectiveness			
Measures of Effectiveness	KILLER	CRUSHER	BRUISER
MOE #1 (Weighted Kills)	214.5	136.1	189.6
MOE #2 (Weighted Detects.)	410.2	377.6	333.9
MOE #3 (Fires/Kill)	5.56	5.43	3.13
Relative Effectiveness			
MOE #1	1.00	.634	.884
MOE #2	1.00	.921	.814
MOE #3	1.00	1.02	1.78
TOTAL REL EFFECTIVENESS	3.00	2.575	3.478
AVG REL EFFECTIVENESS	1.00	.858	1.16

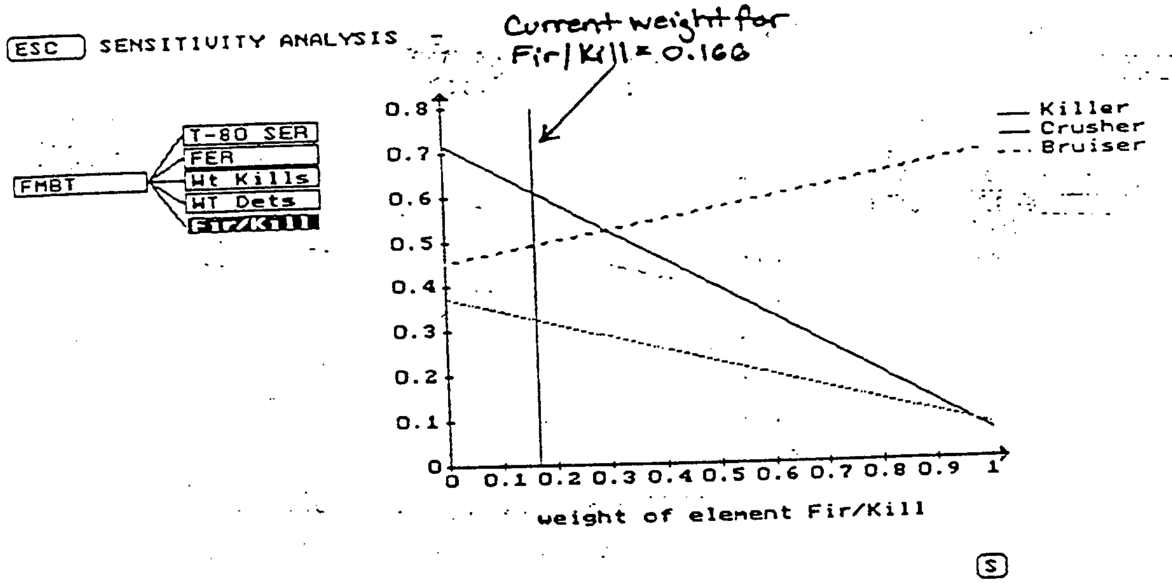
good

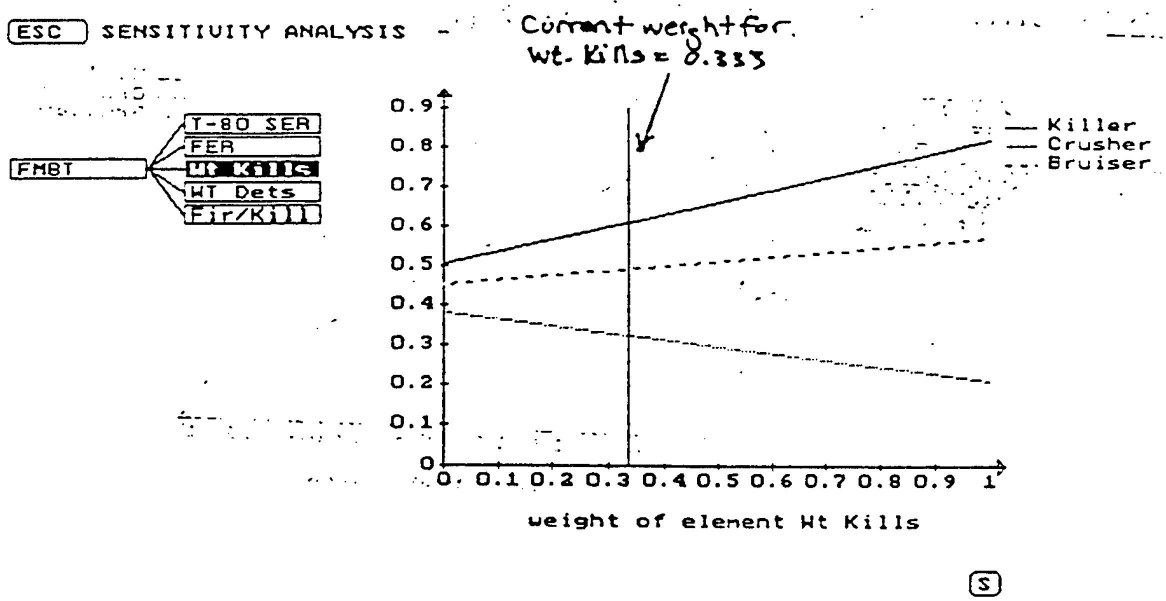
MAU

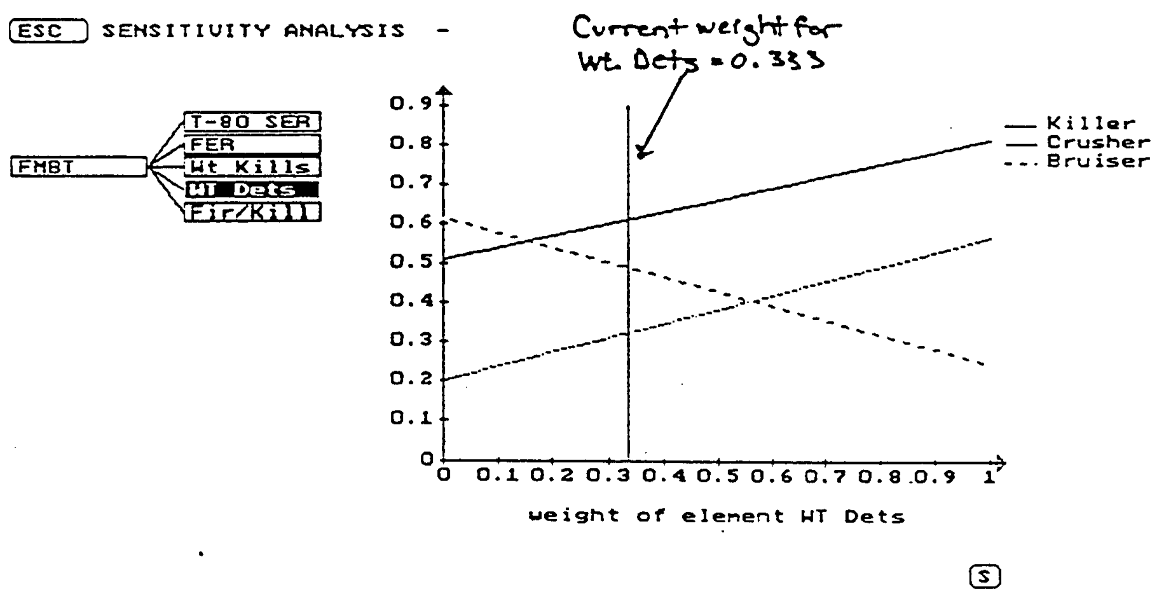

ESC COMPOSITE PRIORITIES
Model:
Element - FMBT
Bars :
Segments:
FMBT
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.609
0.324
0.491
Killer
Crusher
Bruiser
G
F
S


ESC
SENSITIVITY ANALYSIS - Current weight for T-80 SER = 0.083
FMBT
T-80 SER
FER
Wt Kills
WT Dets
Fir/Kill
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1
weight of element T-80 SER
Killer
Crusher
Bruiser
S


ESC
SENSITIVITY ANALYSIS - Current weight for FER = 0.083
FMBT
T-80 SER
FER
Wt Kills
WT Dets
Fir/Kill
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1
weight of element FER
Killer
Crusher
Bruiser
S


ESC
SENSITIVITY ANALYSIS
Current weight for Fir/Kill = 0.166
FMBT
T-80 SER
FER
Wt Kills
WT Dets
Fir/Kill
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1
weight of element Fir/Kill
Killer
Crusher
Bruiser
S


ESC
SENSITIVITY ANALYSIS -
Current weight for Wt. Kills = 0.333
T-80 SER
FER
FMBT
Wt Kills
WT Dets
Fir/Kill
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1
Killer
Crusher
Bruiser
weight of element Wt Kills
S


ESC
SENSITIVITY ANALYSIS -
Current weight for Wt. Dets = 0.333
T-80 SER
FER
FMBT
Wt Kills
WT Dets
Fir/Kill
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1
Killer
Crusher
Bruiser
weight of element WT Dets
S

Appendix H Format for the Detailed Design

1. **Executive Summary**
2. **The Acquisition Issue**

   a. **The Need** Problem Statement. Describes deficiency or opportunity.

   b. **Threat** Facts Bearing on the Problem. Describes projected enemy forces and tactics.

   c. **Environment** Facts Bearing on the Problem. Defines the expected operating environment (terrain, weather, etc.)

   d. **Constraints** Assumptions. Describes underlying assumptions regarding personnel, funding, technologies, etc.

   e. **Operational Concept** Assumptions. Summarizes the organizational and operational plan for the proposed system. Include how tactics and doctrine will support or need to be altered for the proposed system.

3. **Alternatives** Discussion

   a. **Functional Objectives** Quantitatively describes the requirements for the new system.

   b. **Description of Alternatives** Describes the alternatives **and links them to the experimental design.**

4. **Analysis of the Alternatives** Discussion

   a. **Models** Identifies the models used and discusses the reasons for their selection. Also documents input data.

   b. **Measures of Effectiveness** Ids MOEs used. Explains the rationale for their selection. **Fols MOE format.**

   c. **Costs** Shows life-cycle costs.

   d. **Trade-Off Analyses** Establishes cost and performance thresholds. Includes **sensitivity analysis on performance and cost thresholds**.

   e. **Decision Criteria.** Describes criteria used for selecting among alternatives. Incl relative worth calculations. Used only significant MOE. Explains selection of significance level (α). Includes sensitivity analysis of decisional weights of attributes for MAU.

5. **Summary of Results** Recommendation and Conclusion. Summarizes the major findings of the analysis. Highlights factors affecting the acceptability and affordability of the alternatives both individually and in relation to each other.

Appendices

   a. **Statistical Analysis** Include precision calculations

   b. **Response Surface Methodology Predictions**

Appendix I

Sample Work (Detailed Design) from Cadets Torreano and Pratt

Course No.	SE403A
Section No.	01-C
Instructor	CPT Tillman
Date	10 May 1993

INTEGRATING A FMBT INTO THE FORCE STRUCTURE

Name	Yr	Co
Michael Pratt	93	G2
Mickey Torreano	93	G1

PAGE

Purpose of the CEOA

The COEA must:

a. Quantify all possible candidate alternatives in terms of their operational effectiveness, cost, and overall integration of cost and operational effectiveness.

b. Recommend possible and preferred alternative total force mixes and their effectiveness in day and night operations based on the integrated COEA.

Recommended Course of Action

We conclude that the slight improvement in effectiveness of the force obtained by the Future Main Battle Tank is not justified by the increase in cost of this system. Therefore, we recommend that the Department of Defense further evaluates the use of the Block II like tank (Brutus) to integrate into the total force mix. The following is a description of this alternative:

Brutus--the Block II Tank

a. 1st Generation FLIR

b. Weapons

1. Weapon A2 is capable of defeating only tanks out to 3 km. Its basic load is 27 rounds, and it has an enhancement probability of hit.

2. Weapon B2 is capable of defeating all targets except tanks out to 3 km. Its basic load is 13 rounds, and it has an enhancement probability of hit.

As for the type of operations, we prefer to conduct night operations. The Loss Exchange Ratio and the Force Exchange Ration were better at night for our force mix. However, during the day operations, detection capabilities and total kills increased. Yet, during the day the force was able to pursue the enemy further with the improved visibility.

A. The Need

1. To integrate the use of the Janus (A) combat model to determine which type of total force mix is more effective in an environment likened to that of Southwest Asia. The force mixes vary according to the number of companies of the Future Main Battle Tank (FMBT), Bruiser, that are in the force. The need for this evaluation stems from the fact that the Department of Defense (DoD) wants our design team to show that the FMBT is contributing more to the force than other tanks, and that it is tactically sound on battlefields of both today and the future. Our ultimate intention is to display that a fewer number of FMBTs could accomplish what a battalion of other types of tanks could accomplish.

2. To evaluate the effectiveness of the two types of force mixes in day and night operations. A valid case has been made for this type of testing in the Preliminary Design Phase. In that phase, we only conducted testing of Bruiser under conditions of daylight. By conducting night operations, our design team will be able to better assess the performance of the sensors and the other detection capabilities on the FMBT and other systems in the force mix, as well as the accuracy of their main guns. All of these factors are likely to vary under conditions of limited visibility which will show their effects on the overall survivability and lethality of the FMBT and the force mix.

Additionally, the night operations will also increase the realism of the simulations in Janus. Most of our modern operations are conducted under the protection of the night.

B. Threat

In our Janus simulation, the threat forces are composed of Soviet systems characteristic of those used in Cold War scenarios:

1. Soviet Mechanized Infantry (BMP 1 and 2; BRDM A and M; BTR-70)
2. Soviet Armor (T-72 and T-80)
3. Soviet Aviation (HIND and HIP)
4. Soviet Artillery (120mmS, 122mmM, 152mmH, and AGS-17)
5. Soviet Air Defense Artillery (AD TM and ZSU-23)

The enemy will travel in echelon formation. Our forces will most likely encounter the Advance Guard of a Motorized Rifle Regiment (MRR) followed by the main effort. When on the offense, the enemy will attack first with second-echelon regiments of the lead division and then with the second-echelon division.

C. Environment

1. Southwest Asia
    a. Desert
    b. Day or Night
    c. Arid and Mountainous

D. Constraints

Basically, these simulations are run to determine the effect the FMBT has on the performance of the force mix. Therefore, many of the constraints apply to the FMBT.

1. The systems used in our total force mix must be completed by the year 2010. The M1A2 has a projected effective life. When its useful life has come to an end, the FMBT must be ready for deployment. We have projected that the FMBT must be ready for deployment by the year 2010. This is the current time constraint, although it may change if battlefield technology decreases the effective life of the M1A2.

2. The cost to develop and deploy FMBTs must not exceed what Congress is willing to procure. Because of the large federal debt, Congress will be willing to appropriate only so much money towards fielding the FMBT. We must avoid overdrawing our budget. We have not yet determined the amount Congress will appropriate, but the total of all life-cycle costs (R & D, Production & Deployment, Maintenance, and Retirement & Disposal) must be under this spending limit. If we are not able to stay within this constraint, then our future force mix is not feasible.

3. The FMBT must weigh less than 59 tons. This constraint applies to the deployability of the system. The deployability of the system is critical to the success of the force mix. The number of systems that we can concentrate on the battlefield is proportional to the amount of massive firepower that we can supply the force mix. At a lesser weight, more systems are capable of being transported at once as the weight of the system decreases (assuming that

the design dimensions remain the same or decrease). The lesser weight will also contribute to the speed of the force mix. As the weight of the systems in the force mix decreases, the force mix becomes faster and more mobile.

4. The FMBT must be able to engage and destroy enemy heavy weapon systems in order to provide the shock effect necessary for the force mix. The purpose of the main battle tank is to provide shock effect on the battlefield and to counter enemy heavy forces. These systems include tanks, HIND helicopters, and armored troop carriers.

5. The FMBT must be socially and legally acceptable. During peacetime, society tends to want to decrease the size of the Army and cut spending on defense. Therefore, we must ensure that the FMBT appeals to the public in order to obtain support from them which ultimately influences the politicians that control the budget.

6. We must deploy our force mix in a non-nuclear, mid-intensity scenario. The use of nuclear weapons would nullify the effectiveness of our systems.

7. All equipment, structure, and doctrine in year 1992 are in effect in the scenario. A change in these factors could cause our research to become obsolete.

In addition to the general system constraints previously listed, there are also constraints that we encountered while working with Janus.

1. Each simulation that we conducted in Janus only lasted 25 minutes. However, this shortened battle did not affect our analysis, because by this time, our force was well into the pursuit phase.

2. We placed the FMBTs in an offensive posture, and our choice of total force mixes was limited to two. We were only permitted to use Bruiser as our FMBT and Brutus as our Block II tank. There are many other alternative systems, but we are limited to testing the effects of these two on the total force mix. We substituted these systems in for the M1A1 tanks in the scenario.

E. Operational Concepts

As mentioned in the constraints, the Future Main Battle Tank is the crux of our force mixes. Therefore, it is important to focus on the operation concepts of the FMBT. The Future Main Battle Tank can be used in several roles due to its deployability and lethality. Since the FMBT is light-weight and is designed to sustain itself on the battlefield, the FMBT can be used in a scout role. Its high rate of speed (75 km/hr) also helps it to conduct this role with rapid deployment. Its high-quality sensors allow it to gather information at greater distances which enable to provide forward observation and reconnaissance. However, the main operational concept of the FMBT is to provide shock effect to the battlefield with its lethal weapon systems.

It can be used in either the defense or offense to combat enemy heavy forces.

The narrative of Scenario 404 (Southwest Asia is as follows: Two battalions (one tank and one mechanized task force) make contact with the Advance Guard of a Motorized Rifle Regiment (MRR). The tank battalion attacks the flank of the main effort while Task Force Mech sets up a blocking position and supports by fire from key terrain. Within the attacking tank battalion we will mix future tank systems, Bruiser and Brutus. The attack helicopter battalion also maintains contact with the MRRs main body from the other flank supported by fire from both battalions. The MRR breaks contact and the attacking tank battalion conducts a pursuit aided by the helicopter company.

Before starting the actual simulation runs, we ran the scenario several times to get to know the battle and note the performance of the FMBT. Once we decided on our tactical plan, we employed four high density, partially overlapping FASCAM minefields oriented northwest to southeast in the vicinity of grid coordinates 7805 through 7806. The attack helicopter battalion helped to detect the MRR so that we could plan the FASCAM. The FASCAM was fired as a Priority Mission to the designated locations. Their primary mission was to assist the attack helicopters by immobilizing some of the MRR.

When changing between the low and high levels of the force mix, only the companies in the attacking tank battalion were affected. In the low level, we replaced the M1A1 tank companies with one company of the Block II type tank (Brutus) and one company of the Future Main Battle Tank (Bruiser). In the high level, we replaced the M1A1 tank companies with two companies of the FMBT.

During the course of the simulation, we oriented the fires of the attacking tank battalion in the same vicinity as the FASCAM mines (NW-SE in the vicinity of GRID 7805 through 7806). The enemy avenue of approach was from the northeast. We did not use the 155-mm Howitzer Battery or the mortar platoon to provide fire support during the mission. However, we did use the howitzers to employ the minefields ten to sixteen minutes into the scenario. We used AutoJan to replicate the simulations. Basically, the scenarios that we ran were heavy friendly forces against heavy enemy forces.

A. Functional Objectives

A major goal of our Future Main Battle Tank (FMBT) and the total force mix is to destroy enemy weapon systems. A sub-goal associated with this goal is to increase the firepower of our Main Battle Tank and the total force mix. Most of the functional objects relate to the FMBT, but our design team believes that the performance of the FMBT will greatly affect the overall performance of the total force mix. The functional objectives which our system, Bruiser, should meet in order to attain this goal are:

1. To maximize the rate of fire (ROF) of the main guns in our force mix, especially the FMBTs. This objective will allow the system to put more steel on target in a shorter amount of time. Thus, the enemy will have less time to react to the overwhelming volume of fire.

2. To maximize the lethality of our main gun rounds. This will increase our efficiency both technically and economically. If our system in the force mix can kill an enemy target with less rounds, then operating the systems will cost less money. Also, it will increase the survivability of the system, because, blow for blow, our system will withstand the battle longer.

3. To maximize the number of rounds the FMBT can carry and fire. This will increase the survivability of the system. The longer that it can remain free of the logistical chain, the better mobility and countermobility it can exercise.

4. To minimize the rearm time for the main gun for the FMBT. If it takes the crew a shorter amount of time to rearm the system (or whether it has an autoloader), then the more rounds we will be able to send down range. It will also increase the survivability and lethality of the system, because it will enable our system to react quicker to the events on the battlefield.

5. To maximize the range of the main gun of the FMBT. This will enable our system to detect and fire upon the enemy before the enemy has time to react. Not only will this improve the lethality of our system, but it will also increase the chances of our system's survival.

6. To maximize the accuracy of the main gun of the FMBT. This also contributes to the lethality of the system. The more accurate that our system is, then the more kills it will obtain. This objective will also minimize the cost of attack for our system which will aid in relative worth calculations.

Since our design team is also evaluating the effects of night operations on the performance of our total force mixes, detection capabilities are another area of functional objectives. We will want our force mix to be able to "reach out and touch" the enemy well before the Red Force has time to even detect our tanks. The extended range of our weapon systems and sensors should enable the FMBTs to engage the enemy at greater distances. Thus, the combined objectives of increasing firepower and detections enable the Blue Force to put more steel on target in a shorter amount of time which increase the lethality of the force mix.

B. Description of Alternatives

First, we will describe the two types of tanks that we are integrating into the force mix.

1. Bruiser--the Future Main Battle Tank (Electric Tank)

a. 2nd Generation FLIR

b. Weapons

1. Weapon E is a possible replacement for B and is capable of defeating only tanks out to 4 km. Its basic load is 24 rounds.

2. Weapon C is capable of defeating all targets except tanks out to 4 km. Its basic load is 10 rounds.

3. Weapon D is capable of defeating tanks from 2.5-4.0 km and is the preferred weapon over B in this range. Its basic load is 6 rounds.

2. Brutus--the Block II Tank

a. 1st Generation FLIR

b. Weapons

1. Weapon A2 is capable of defeating only tanks out to 3 km. Its basic load is 27 rounds, and it has an enhancement probability of hit.

2. Weapon B2 is capable of defeating all targets except tanks out to 3 km. Its basic load is 13 rounds, and it has an enhancement probability of hit.

The two alternative force mixes are differentiated by the number of Future Main Battle Tank companies that we integrate into the force. Additional alternatives include the running the simulation operations during the day and the night.

1. **The low level (-1)** to our experimental design consists of integrating one company of Block II tanks (Brutus) and one company of FMBTs (Bruiser) to the attack battalion.

2. **The high level (+1)** to our experimental design consists of integrating two companies of FMBTs to the attack battalion.

A. Models

The models we will use in this design are full 2^k factorial design, response surface methodology, multi-attribute utility analysis, and relative worth. To get our data for these calculations, we ran our simulations on the JANUS (A) 3.0 Model.

The JANUS (A) 3.0 Model is an interactive, two-sided, closed, stochastic, ground combat simulation featuring precise color graphics. It takes random numbers inputted by the designer to simulate the outcomes of a scenario. This helps to capture the reality of a battle. It also allows the user to change various factors of the battle to include real time, types of systems employed, artillery fires, and engineering assets (to name a few). In order to perfectly replicate each simulation run, we used AutoJan. This function records the actions in one simulation and exactly transfers them to each of the other simulations.

We processed our results using the post processing function in JEDA. This computer program enables the user to analyze his MOE against all or part of the Blue force against the Red force. It provides histograms, circle graphs, and spreadsheet printouts of the results for easy interpretation and presentation. In other words, JEDA transforms the information gathered from the Janus simulation runs (such as number of kills and detections) into useable statistics. These statistics are used to determine the effectiveness of weapon systems during combat. In this case, it helped us to analyze the performance of the weapon systems on the Electric Tank and on the systems in the total Blue Force compared to the Soviet weapons.

In order to determine whether the factors in our design interact with each other, we used the full 2^k factorial design. Interaction refers to whether the effect of one factor depends on the levels of the others. In this design, we chose two levels (low and high) for each of our two factors. The form of the experiment can be compactly represented in tabular form called the design matrix. Once the design is set up, the main effect and two-way interaction effect of each factor is calculated. The main effect is the average change in the response due to moving the factor from its low level (-1) to its high level (+1). This average is taken over all combinations of the other factor levels in the design. Forming confidence intervals or the expected response at each of the factor levels is an additional calculation in the factorial design process. (Law and Kelton, pp. 659-661)

Another model that we used is the response surface methodology. A response surface is created by plotting the measured responses from simulation output for a particular MOE. We then approximated the response surface with an algebraic model which is sometimes referred to as a metamodel. We used the metamodel (instead of the actual simulation program--JANUS) to learn more about how the response surface would behave over various regions of the input-factor space, to estimate how the response would change at a particular point if the input factors were changed slightly, and to find the approximate optimal settings of the input factors (Law and Kelton, 681). The metamodel that we used was a regression plane.

We utilized the Multi-Attribute Utility (MAU) Model to help choose the most effective force mix in accordance with its performance on the MOEs. The MAU technique is useful, because it enables us to model the needs and desires of the engineer and the client through the use of weighting the criteria on the basis of relative importance. The important criteria are represented in the MAU Model and are weighted to reflect the client's priorities. Appropriate modeling of the criteria and scaling of the performance scores completes the model and allows the design engineer to rank order the candidate systems and illuminate the "best" candidate systems (SE402 Handout, Lsn 20).

In order to conduct the MAU and sensitivity analysis, we utilized the HIPRE3+ computer program. After we completed our factorial design, we used the results to order our alternatives according to preferences. Then, we conducted sensitivity analysis on the MOEs to determine the weights at which we became indifferent among the alternatives.

Finally, a relative effectiveness test was performed in order to determine which system is "best" based for performance as determined in the JANUS simulations. We simply compared the tanks by merits of their performance on the MOEs that provided significance.

B. Measures of Effectiveness

In our last design phase, we were required to determine which tank system was more effective on the battlefield. In order to compare the three types of tanks (Block I, Block II, and Electric Tank), we used several weighted Measures of Effectiveness (MOEs). These weighted measures were focused towards the performance of individual systems. Now that we have decided to forward the Electric Tank system to the next design phase, we are only concerned with its contribution to the total force mix on the battlefield and its effectiveness during day and night operations. Therefore, we decided that we would not use weighted MOEs, since we are now focusing on force performance (not system performance). These general MOEs will allow us to capture the statistics on force performance more readily and accurately, and will satisfy our need for more robust measures.

LOSS EXCHANGE RATIO (LER)

1. *DEFINITION OF THE MEASURE:* The Loss Exchange Ratio (LER) is the ratio of the number of Red equipment losses per the number of Blue equipment losses:

$$LER = \frac{\text{\# of Red Equipment Losses}}{\text{\# of Blue Equipment Losses}}$$

2. *DIMENSION OF THE MEASURE:* It is the ratio measured by the compared losses in equipment strength.

3. *LIMITS ON THE RANGE OF THE MEASURE:* The output may be zero or assume any positive value.

4. *RATIONALE FOR THE MEASURE:* If LER is greater than 1, then the Blue side wins the battle. The higher the exchange ratio the better.

5. *DECISIONAL RELEVANCE OF THE MEASURE:* If we have a high LER, then we could attribute this success to the addition of the Electric Tank to the total force mix on the battlefield. It could also mean that the Blue force is capable of fighting well in both day and night operations.

6. *ASSOCIATED MEASURES OF PERFORMANCE:*

Force Exchange Ratio (FER)

Proportion of Force destroyed

FRACTIONAL EXCHANGE RATIO (FER)

1. *DEFINITION OF THE MEASURE:* The Fractional Exchange Ratio is the ratio of enemy losses per number of systems employed to the friendly losses per number of systems employed:

$$FER = \frac{\text{\# of Red Losses/Initial Red Strength}}{\text{\# of Blue Losses/Initial Blue Strength}}$$

2. *DIMENSION OF THE MEASURE:* It is a ratio measured by the compared losses in force strength.

3. *LIMITS ON THE RANGE OF THE MEASURE:* The output may be zero or assume any positive value.

4. *RATIONALE FOR THE MEASURE:* If FER is greater than 1, then the Blue side wins the battle. The higher the exchange ratio the better.

5. *DECISIONAL RELEVANCE OF THE MEASURE:* This MOE will measure to what extent our force mix effects the outcome of the battle. It will also show the difference between the performance of our force in day and night operations.

6. *ASSOCIATED MEASURES OF PERFORMANCE:*

Loss Exchange Ratio (LER)

Proportion of Force destroyed

TOTAL NUMBER OF KILLS

1. *DEFINITION OF THE MEASURE:* A kill is defined as one of our systems firing at another system on the battlefield and rendering it ineffective. Janus determines what is defined as a kill in the simulations, and we will be able to obtain this number when we post process our simulations. This measure will be based on every kill by every system in the Blue force.

2. *DIMENSION OF THE MEASURE:* A quantitative value of enemy systems that are destroyed by our FMBT. It is also a similar measure for other systems in our total force mix.

For example, a number of 50 would indicate that a system in our force mix killed 50 enemy weapon systems.

3. *LIMITS ON THE RANGE OF THE MEASURE:* The output may be zero or assume a positive value.

4. *RATIONALE FOR THE MEASURE:* This measure addresses the lethality of our force mix based on the fact that more kills are better.

5. *DECISIONAL RELEVANCE OF THE MEASURE:* This measure is used to distinguish between the firepower capabilities of our high and low force mixes. The mix with the greatest number of kills will prove to be more lethal on the battlefield. The goal is to determine if we can kill more enemy systems with less Blue systems. The number of kills will also show the difference between day and night operations (mainly whether we have more or less kills at night).

6. *ASSOCIATED MEASURES OR PERFORMANCE:*

   Firing Accuracy

   Lethality of the Payload

   Probability of a Hit

   Probability of a Kill

FIRES PER KILL

1. *DEFINITION OF THE MEASURE:* This is the number of fires divided by the number of kills:

   Fire/Kill = Total Number of Fires/Total Number of Kills

2. *DIMENSION OF THE MEASURE:* It is a ratio of the average number of fires to kill an enemy system.

3. *LIMITS ON THE RANGE OF THE MEASURE:* The output value may be zero or assume a positive value.

4. *RATIONALE FOR THE MEASURE:* As the value of the output approaches 1, the system will be performing better (it will take less fires to kill an enemy system).

5. *DECISIONAL RELEVANCE OF THE MEASURE:* This measure will give us and insight to both the accuracy and lethality of our weapon systems. This measure will be used mainly for the "night v. day" comparison. It might be possible that our force needs more fires per kill at night, because it is less accurate in limited visibility. However, it is also possible that our force may need less fires per kill at night, because it is able to get closer to the enemy in the dark or it is simply a more lethal force.

6. *ASSOCIATED MEASURES OF PERFORMANCE:*

   Rate of Fire (ROF)

   Probability of Kill

   Probability of a Hit

   Firing Accuracy

   Lethality of Payload

TOTAL NUMBER OF DETECTIONS

1. *DEFINITION OF THE MEASURE:* A detection is the process of acquiring an enemy weapon system with the use of sensors.

This information will indicate the identity and location of the target on the battlefield. Janus records the number of systems that our force mix detects during the simulations.

2. *DIMENSION OF THE MEASURE:* A quantitative value of enemy systems that are detected by our force mix. For example, a number of 50 would indicate that our force detected 50 enemy weapon systems.

3. *LIMITS ON THE RANGE OF THE MEASURE:* The output may be zero or assume a positive value.

4. *RATIONALE FOR THE MEASURE:* This measures the effectiveness of the sensors based on the fact that more detections are better.

5. *DECISIONAL RELEVANCE OF THE MEASURE:* This measure will allow us to determine the capabilities of our sensors. We want to detect as many enemy systems as we can. This will give us more opportunities to eliminate the enemy on the battlefield before he has the opportunity to eliminate us. Thus, our lethality and survivability will increase as the total number of detections increase. This measure will also be critical in the determination of whether the force can fight well in night operations. If our ability to detect greatly diminishes at night, then we will have to adjust our tactics or develop a new force mix.

6. *ASSOCIATED MEASURES OF PERFORMANCE:*

Time to Detection

Time to Identification

Expected Time to Acquisition

AVERAGE RANGE TO DETECTIONS

1. *DEFINITION OF THE MEASURE:* Since we wish to detect the enemy as soon as possible, it is important to evaluate this MOE. It will allow us to take the average range of all of the detections made by our force mix. It will also help us to evaluate the affect of day and night operations on this measure. We expect that the average range to detection will decrease at night due to limited visibility.

2. *DIMENSION OF THE MEASURE:* A quantitative value of the range at which enemy systems are detected by our force mix. For example, a number of 2000 meters would indicate that our force detected the enemy systems at an average range of 2000 meters.

3. *LIMITS ON THE RANGE OF THE MEASURE:* The output may be zero or assume a positive value.

4. *RATIONALE FOR THE MEASURE:* The higher the average range to detection value the better. This will mean that we can "reach out and touch" the enemy before they can have time to acquire us.

5. *DECISIONAL RELEVANCE OF THE MEASURE:* This MOE tells us the average range at which each system in the force mix was able to detect the enemy. We want the detection range to be high, because a higher range gives us more time to be aware of the enemy positions and avenues of approach and to engage the enemy with various weapon systems. This measure is used

to distinguish between the acquisition capabilities of the various force mixes we can utilize in the scenario.

6. *ASSOCIATED MEASURES OF PERFORMANCE:*

Time to Detection

Time to Identification

Expected Time to Acquisition

C. Costs

Some assumptions must be made when dealing with comparing the costs of the Future Main Battle Tanks. The first is that there will be no inflation from now until the year 2015. The second is that the discount rate will remain constant at 12%. We also assumed that there are no sunk costs and no salvage values for the alternatives.

What we are trying to do is compute the costs for each FMBT for the present year, 1993. We have been given dollar estimates of the alternative systems for the years between 2002 to 2015.

The costs are divided into the following two categories: research and development phase (FY02-06) and production phase (FY04-15). These costs are outlined in Annex B along with the net present value calculations. To calculate the net present value for fiscal year 1993 for the FMBT, our client, CPT Tillman, totaled the costs for each year from 2002 to 2015 and then "brought" each of these totals back to 1993.

The formulas used to bring the costs of the tanks back to year 1993 are:

$$P = F\ (1 + i)^{-n}$$

$$P = A\ [((1 + i)^{n} - 1)\ /\ i\ (1 + i)^{n}]$$

where: F = future value   P = present value

i = discount rate   n = number of years

A = annual value

For fiscal year 1993, the FMBT (Bruiser) costs $6.36 million. Similar calculations were conducted by CPT Tillman to determine the cost of the Block II like tank (Brutus) which is $3.15 million.

In order to calculate the total force mix cost, we first had to determine the number of each system for the force mix. However, there is no need to count systems that remain constant in each alternative force mix. Thus, we only need to determine how many FMBTs (Bruiser) and Block II like tanks (Brutus) are in the force. In the low level of the force mix, there is one company of Bruisers and one company of Brutuses. Each company has 14 tanks assigned to them. Therefore, the low level of the force mix costs $133.14 million:

Brutus => 14 tanks * $3.15 M = $44.10 M

Bruiser => 14 tanks * $6.36 M = $89.04 M

Total => $44.10 M + $89.04 M = $133.14 M

In the high level of the force mix, there are two companies of Bruisers. Each company has 14 tanks assigned to them. Therefore, the high level of the force mix costs

$178.08 million:

Bruiser => 28 tanks * $6.36 M = $178.08 M

These costs are used in the relative worth calculations found in Annex C and in the MAU calculations found in Annex E. The cost analysis information is found in Annex B.

D. Trade-Off Analysis

For our Trade-Off analysis, we performed sensitivity analysis on our MAU analysis and factorial testing. We also constructed linear regression equations using response surface methodology. Our MAU analysis showed that our decision is very insensitive to change. This is due to the dominance of cost in our testing. While our FMBT (Bruiser) edged out the Block II mix in most of our effectiveness criteria, the high cost of the FMBT made it the less cost effective mix. We weighted the effectiveness criteria .75 and total cost .25. We would need to almost not weight cost (.03) for the FMBT force to be the top choice. As far as sensitivity on cost values, we do not believe that it is necessary. The cost data we have on the FMBT does not include developmental costs. The values we are using are definitely low-end cost estimates. If any sensitivity analysis was done it would only be unfavorable for our Bruiser force. See Annex E for HIPRE sensitivity analysis.

For our factorial sensitivity we decided to test for significance at different alpha levels. We first tested at

60% confidence, if the MOE was significant, at 95% confidence. See Annex A for Factorial Designs.

Finally, as a Trade-Off we developed regression equations to predict the performance scores at different factor levels. Annex D is a chart which shows how we extrapolate factor levels which we did not include in our original simulation. In our simulation we conducted runs with a 2 FMBT companies and runs where we substituted a company of Block II tanks. Annex D shows how we could find the factor level when we had 2 Block II companies engaging the Red force. The factor level at any force mix can be determined using this linear assumption. The new MOE score can be found by substituting factor levels into any of the linear regression equations we have developed. For some of our MOE, such as LER, the force performed better in night operations. Although night operations have a factor level of -1, the regression coefficients are negative, therefore the -1 factor level improves our performance score. See Annex D for regression equations.

E. Decision Criteria

We used relative effectiveness, relative worth, MAU, and factorial testing with precision calculations as our decision criteria. We first conducted a full factorial experiment for each of our MOE. We tested the significance of the force mix, day vs. night operations, and the interaction of the two factors. We decided to use a CI of

60%, because although it is difficult to gain statistical significance with only three design point repititions, we did still wanted to be confident in our results. With less than 60% confidence our decisions would not have been very meaningfull. If our test showed significance at 60% we then tested at 95% confidence. It is very difficult to find confidenc eat 95% with only 3 runs, yet we did find significance for several MOE. See Annex A for factorial testing. We then performed relative error analysis on our results to deterrmine the precision. We wanted our results to be precise to 20%, but if we were to be confident in our results, we would have to be within an adjusted relative error of 18.2%. Only one of our design points had a relative error of less than 18.2%. The variance with only three design points is too great. By conducting more runs at each design point we could improve our results. See Annex F for Precision Calculations.

For our relative effectiveness and relative worth calculations we used the Bruiser-Brutus mix as our basecase because we wanted to test the effectiveness of our Bruiser force against this force mix. The relative effectiveness results showed that the Bruiser mix slightly increased the performance of our force. This advantage in performance was overshadowed by cost considerations in the relative worth calculations. The Bruiser-Brutus force proved to be the more cost effective mix. See Annex C for Relative Worth calculations.

We used the HIPRE+3 software for our MAU analysis. We decided to weight FER and Total Kills slightly more heavily than the other effectiveness criteria because we felt they best measure our foce performance. We felt that performance was more important than cost, but cost is more important than any one MOE so we weighted Relative Effectiveness at .75 and Total Cost at .25. Our final MAU scores are .496 for the Bruiser Force and .600 for the force mix.

Results

Factorial Design

Force Mix:

LER) Significant at 60%. Top Performer - Bruiser Force Mix.

FER) Significant at 60%. Top Performer - Bruiser Force Mix.

Fires/Kill) No Significance.

Total Kills) Significant at 60%. Top Performer - Bruiser Force Mix.

Avg Range to Detection) Significant at 60%. Top Performer - Bruiser-Brutus Force Mix.

Total Detection) Significant at 60% and 95%. Top Performer - Bruiser-Brutus Force Mix.

Ops Type:

LER) Significant at 60%. Top Performer - Night Ops.

FER) Significant at 60%. Top Performer - Night Ops.

Fires/Kill) No Significance. Increase visibility in day cancelled close range at night.

Total Kills) Significant at 60%. Top Performer - Day Ops.

Avg Range to Detection) Significant at 60% and 95%. Top Performer - Day Ops.

Total Detection) Significant at 60% and 95%. Top Performer - Day Ops.

Interaction:

LER) Not Significant at 60%.

FER) Not Significant at 60%.

Fires/Kill) No Significance.

Total Kills) Significant at 60%. Top Performer - Positive Interaction.

Avg Range to Detection) Significant at 60%. Top Performer - Negative Interaction.

Total Detection) Significant at 60%. Top Performer - Negative Interaction.

Precision only less than 20% for Operation Type for Total Detections.

Relative Effectiveness

Bruiser Force 1.098

Force Mix 1.00

Relative Worth

Bruiser Force .8209

Force Mix 1.00

MAU Analysis

Bruiser Force .496

Force Mix .600

Conclusions and Recommendations

We conclude that the slight improvement in effectiveness of the force obtained by the Future Main Battle Tank is not justified by the increase in cost of this system. Therefore, we recommend that the Department of Defense further evaluates the use of the Block II like tank (Brutus) to integrate into the total force mix.

As for the type of operations, we prefer to conduct night operations. The Loss Exchange Ratio and the Force Exchange Ration were better at night for our force mix. However, during the day operations, detection capabilities and total kills increased. Yet, during the day the force was able to pursue the enemy further with the improved visibility.

Kelton, W. David and Averill M. Law. <u>Simulation Modeling & Analysis</u>. New York: McGraw-Hill, Inc. 1991.

FULL FACTORIAL DESIGN

LOSS EXCHANGE RATIO

ALL BLUE VS. ALL RED

	FACTOR			RESPONSE FROM RUN #		
DP	Mix	Ops Type	IA	1	2	3
1	-	-	+	10.36	8.00	5.28
2	+	-	-	10.36	10.50	5.33
3	-	+	-	4.30	2.14	2.09
4	+	+	+	4.10	2.32	5.77
			SUM:	-.20	2.68	3.73
			$SUM/2^{k-1}$:	-.10	1.34	1.87

FACTOR 1 EFFECT: 60% C.I. t = 1.061

Mean	+1.035
Variance	+1.035
1/2 Length	+.6232
Upper Bound	+1.658
Lower Bound	+.4118
Significance	YES

FACTOR 1 EFFECT: 95% C.I. t = 4.303

Mean	+1.035
Variance	+1.035
1/2 Length	+2.527
Upper Bound	+3.562
Lower Bound	-1.492
Significance	NO

FULL FACTORIAL DESIGN

LOSS EXCHANGE RATIO

ALL BLUE VS. ALL RED

	FACTOR			**RESPONSE FROM RUN #**		
DP	Mix	Ops Type	IA	1	2	3
1	-	-	+	10.36	8.00	5.28
2	+	-	-	10.36	10.50	5.33
3	-	+	-	4.30	2.14	2.09
4	+	+	+	4.10	2.32	5.77
			SUM:	-12.32	-14.04	-2.75
			$SUM/2^{k-1}$:	-6.16	-7.02	-1.375

FACTOR 2 EFFECT: 60% C.I. t = 1.061

Mean	-4.85
Variance	+9.25
1/2 Length	+1.863
Upper Bound	-2.987
Lower Bound	-6.715
Significance	YES

FACTOR 2 EFFECT: 95% C.I. t = 4.303

Mean	-4.85
Variance	+9.25
1/2 Length	+7.56
Upper Bound	+2.71
Lower Bound	-12.41
Significance	NO

FULL FACTORIAL DESIGN

LOSS EXCHANGE RATIO

ALL BLUE VS. ALL RED

	FACTOR			RESPONSE FROM RUN #		
DP	Mix	Ops Type	IA	1	2	3
1	-	-	+	10.36	8.00	5.28
2	+	-	-	10.36	10.50	5.33
3	-	+	-	4.30	2.14	2.09
4	+	+	+	4.10	2.32	5.77
			SUM:	-.20	-2.32	3.63
			$SUM/2^{k-1}$:	-.10	-1.16	1.82

IA EFFECT: 60% C.I. t = 1.061

Mean	+.185
Variance	+2.28
1/2 Length	+.9253
Upper Bound	+1.11
Lower Bound	-.740
Significance	NO

FULL FACTORIAL DESIGN

FORCE EXCHANGE RATIO

ALL BLUE VS. ALL RED

	FACTOR			RESPONSE FROM RUN #		
DP	Mix	Ops Type	IA	1	2	3
1	-	-	+	8.38	6.47	4.27
2	+	-	-	8.38	8.50	4.32
3	-	+	-	3.48	1.73	1.69
4	+	+	+	3.32	1.88	4.67
			SUM:	-.16	2.18	3.03
			SUM/2^{k-1}:	-.08	1.09	1.515

FACTOR 1 EFFECT: 60% C.I. t = 1.061

Mean	.8417
Variance	+.682
1/2 Length	+.5060
Upper Bound	+1.348
Lower Bound	+.176
Significance	YES

FACTOR 1 EFFECT: 95% C.I. t = 4.303

Mean	+.8417
Variance	+.682
1/2 Length	+2.05
Upper Bound	+2.89
Lower Bound	-1.211
Significance	NO

FULL FACTORIAL DESIGN

FORCE EXCHANGE RATIO

ALL BLUE VS. ALL RED

	FACTOR			RESPONSE FROM RUN #		
DP	Mix	Ops Type	IA	1	2	3
1	-	-	+	8.38	6.47	4.27
2	+	-	-	8.38	8.50	4.32
3	-	+	-	3.48	1.73	1.69
4	+	+	+	3.32	1.88	4.67
			SUM:	-9.96	-11.36	-2.23
			SUM/2^{k-1}:	-4.98	-5.68	-1.115

FACTOR 2 EFFECT: 60% C.I. t = 1.061

Mean	-3.925
Variance	+6.045
1/2 Length	+1.506
Upper Bound	-2.419
Lower Bound	-5.431
Significance	YES

FACTOR 2 EFFECT: 95% C.I. t = 4.303

Mean	-3.925
Variance	+6.045
1/2 Length	+8.67
Upper Bound	+4.745
Lower Bound	-12.59
Significance	NO

FULL FACTORIAL DESIGN

FORCE EXCHANGE RATIO

ALL BLUE VS. ALL RED

	FACTOR			RESPONSE FROM RUN #		
DP	Mix	Ops Type	IA	1	2	3
1	-	-	+	8.38	6.47	4.27
2	+	-	-	8.38	8.50	4.32
3	-	+	-	3.48	1.73	1.69
4	+	+	+	3.32	1.88	4.67
			SUM:	-.16	-1.88	2.93
			$SUM/2^{k-1}$:	-.08	-.94	1.465

IA EFFECT: 60% C.I. t = 1.061

Mean	+.1483
Variance	+1.485
1/2 Length	+.7465
Upper Bound	+.8948
Lower Bound	-.5982
Significance	NO

FULL FACTORIAL DESIGN

FIRES PER KILL

ALL BLUE VS. ALL RED

	FACTOR			RESPONSE FROM RUN #		
DP	Mix	Ops Type	IA	1	2	3
1	-	-	+	3.43	3.43	3.80
2	+	-	-	3.45	3.42	3.96
3	-	+	-	3.70	3.86	3.56
4	+	+	+	3.64	4.36	3.01
			SUM:	-.0417	.4919	-.4021
			SUM/2^{k-1}:	-.021	.246	-.2011

FACTOR 1 EFFECT: 60% C.I. $t = 1.061$

Mean	+.0080
Variance	+.0506
1/2 Length	+.1378
Upper Bound	+.1460
Lower Bound	-.1298
Significance	NO

FULL FACTORIAL DESIGN

FIRES PER KILL

ALL BLUE VS. ALL RED

	FACTOR			RESPONSE FROM RUN #		
DP	Mix	Ops Type	IA	1	2	3
1	-	-	+	3.43	3.43	3.80
2	+	-	-	3.45	3.42	3.96
3	-	+	-	3.70	3.86	3.56
4	+	+	+	3.64	4.36	3.01
			SUM:	.4563	1.372	-1.188
			$SUM/2^{k-1}$:	.228	.686	-.594

FACTOR 2 EFFECT: 60% C.I. t = 1.061

Mean	+.1067
Variance	+.4207
1/2 Length	+.3973
Upper Bound	+.5040
Lower Bound	-.2906
Significance	NO

FULL FACTORIAL DESIGN

FIRES PER KILL

ALL BLUE VS. ALL RED

	FACTOR			**RESPONSE FROM RUN #**		
DP	Mix	Ops Type	IA	1	2	3
1	-	-	+	3.43	3.43	3.80
2	+	-	-	3.45	3.42	3.96
3	-	+	-	3.70	3.86	3.56
4	+	+	+	3.64	4.36	3.01
			SUM:	-.0693	.5094	-.7179
			SUM/2^{k-1}:	-.0347	.255	-.3590

IA EFFECT: 60% C.I. t = 1.061

Mean	-.0463
Variance	+.0942
1/2 Length	+.1881
Upper Bound	+.1418
Lower Bound	-.2344
Significance	NO

FULL FACTORIAL DESIGN

TOTAL KILLS

ALL BLUE VS. ALL RED

	FACTOR			RESPONSE FROM RUN #		
DP	Mix	Ops Type	IA	1	2	3
1	-	-	+	145	144	132
2	+	-	-	145	147	128
3	-	+	-	185	152	169
4	+	+	+	201	160	248
			SUM:	16	11	75
			$SUM/2^{k-1}$:	8	5.5	37.5

FACTOR 1 EFFECT: 60% C.I. t = 1.061

Mean	+17
Variance	+316.75
1/2 Length	+10.90
Upper Bound	+17.90
Lower Bound	+6.10
Significance	YES

FACTOR 1 EFFECT: 95% C.I. t = 4.303

Mean	+17
Variance	+316.75
1/2 Length.	+44.21
Upper Bound	+61.21
Lower Bound	-27.21
Significance	NO

FULL FACTORIAL DESIGN

TOTAL KILLS

ALL BLUE VS. ALL RED

	FACTOR			RESPONSE FROM RUN #		
DP	Mix	Ops Type	IA	1	2	3
1	-	-	+	145	144	132
2	+	-	-	145	147	128
3	-	+	-	185	152	169
4	+	+	+	201	160	248
			SUM:	96	21	157
			$SUM/2^{k-1}$:	48	10.5	78.5

FACTOR 2 EFFECT: 60% C.I. t = 1.061

Mean	+45.67
Variance	+1160.1
1/2 Length	+20.86
Upper Bound	+66.53
Lower Bound	+24.81
Significance	YES

FACTOR 2 EFFECT: 95% C.I. t = 4.303

Mean	+45.67
Variance	+1160.1
1/2 Length	+84.62
Upper Bound	+130.28
Lower Bound	-38.95
Significance	NO

FULL FACTORIAL DESIGN

TOTAL KILLS

ALL BLUE VS. ALL RED

	FACTOR			RESPONSE FROM RUN #		
DP	Mix	Ops Type	IA	1	2	3
1	-	-	+	145	144	132
2	+	-	-	145	147	128
3	-	+	-	185	152	169
4	+	+	+	201	160	248
			SUM:	16	5	83
			$SUM/2^{k-1}$:	8	2.5	41.5

IA EFFECT: 60% C.I. t = 1.061

Mean	+17.33
Variance	+445.58
1/2 Length	+12.93
Upper Bound	+30.26
Lower Bound	+4.40
Significance	YES

IA EFFECT: 95% C.I. t = 4.303

Mean	+17.33
Variance	+445.58
1/2 Length	+52.44
Upper Bound	+69.77
Lower Bound	-35.11
Significance	NO

FULL FACTORIAL DESIGN

AVG RANGE TO DETECTION

ALL BLUE VS. ALL RED

DP	FACTOR Mix	Ops Type	IA	RESPONSE FROM RUN # 1	2	3
1	-	-	+	2.16	2.13	2.17
2	+	-	-	2.14	2.20	2.15
3	-	+	-	4.19	4.27	4.20
4	+	+	+	3.99	4.11	4.10
			SUM:	-.215	-.101	-.118
			$SUM/2^{k-1}$:	-.1075	-.0505	-.059

FACTOR 1 EFFECT: 60% C.I. t = 1.061

Mean	-.0723
Variance	+.0009
1/2 Length	+.0188
Upper Bound	-.0535
Lower Bound	-.0911
Significance	YES

FACTOR 1 EFFECT: 95% C.I. t = 4.303

Mean	-.0723
Variance	+.0009
1/2 Length	+.0764
Upper Bound	+.0041
Lower Bound	-.1487
Significance	NO

FULL FACTORIAL DESIGN

AVG RANGE TO DETECTION

ALL BLUE VS. ALL RED

	FACTOR			RESPONSE FROM RUN #		
DP	Mix	Ops Type	IA	1	2	3
1	-	-	+	2.16	2.13	2.17
2	+	-	-	2.14	2.20	2.15
3	-	+	-	4.19	4.27	4.20
4	+	+	+	3.99	4.11	4.10
			SUM:	3.877	4.057	3.986
			SUM/2^{k-1}:	1.9385	2.0285	1.993

FACTOR 2 EFFECT: 60% C.I. t = 1.061

Mean	+1.987
Variance	+.00206
1/2 Length	+.0278
Upper Bound	+2.014
Lower Bound	+1.959
Significance	YES

FACTOR 2 EFFECT: 95% C.I. t = 4.303

Mean	+1.987
Variance	+.00206
1/2 Length	+.1126
Upper Bound	+2.099
Lower Bound	+1.874
Significance	YES

FULL FACTORIAL DESIGN

AVG RANGE TO DETECTION

ALL BLUE VS. ALL RED

DP	FACTOR Mix	Ops Type	IA	RESPONSE FROM RUN # 1	2	3
1	-	-	+	2.16	2.13	2.17
2	+	-	-	2.14	2.20	2.15
3	-	+	-	4.19	4.27	4.20
4	+	+	+	3.99	4.11	4.10
			SUM:	-.183	-.227	-.07
			$SUM/2^{k-1}$:	-.0915	-.1135	-.035

IA EFFECT: 60% C.I. t = 1.061

Mean	-.080
Variance	+.0016
1/2 Length	+.0248
Upper Bound	-.0552
Lower Bound	-.1048
Significance	YES

IA EFFECT: 95% C.I. t = 4.303

Mean	-.080
Variance	+.0016
1/2 Length	+.1006
Upper Bound	+.0206
Lower Bound	-.1806
Significance	NO

FULL FACTORIAL DESIGN

TOTAL DETECTIONS

ALL BLUE VS. ALL RED

	FACTOR			RESPONSE FROM RUN #		
DP	Mix	Ops Type	IA	1	2	3
1	-	-	+	220	209	182
2	+	-	-	197	162	168
3	-	+	-	949	857	927
4	+	+	+	836	823	871
			SUM:	-136	-81	-70
			$SUM/2^{k-1}$:	-68	-40.5	-35

FACTOR 1 EFFECT: 60% C.I. t = 1.061

Mean	-47.83
Variance	+312.58
1/2 Length	+10.83
Upper Bound	-37.00
Lower Bound	-58.66
Significance	YES

FACTOR 1 EFFECT: 95% C.I. t = 4.303

Mean	-47.83
Variance	+312.58
1/2 Length	+43.92
Upper Bound	-3.911
Lower Bound	-91.75
Significance	YES

FULL FACTORIAL DESIGN

TOTAL DETECTIONS

ALL BLUE VS. ALL RED

DP	FACTOR Mix	Ops Type	IA	RESPONSE FROM RUN # 1	2	3
1	-	-	+	220	209	182
2	+	-	-	197	162	168
3	-	+	-	949	857	927
4	+	+	+	836	823	871
			SUM:	1368	1309	1448
			$SUM/2^{k-1}$:	684	654	724

FACTOR 2 EFFECT: 60% C.I. t = 1.061

Mean	+687.5
Variance	+1216.75
1/2 Length	+21.37
Upper Bound	+708.87
Lower Bound	+666.13
Significance	YES

FACTOR 2 EFFECT: 95% C.I. t = 4.303

Mean	+687.5
Variance	+1216.75
1/2 Length	+86.67
Upper Bound	+774.17
Lower Bound	+600.83
Significance	YES

FULL FACTORIAL DESIGN

TOTAL DETECTIONS

ALL BLUE VS. ALL RED

	FACTOR			RESPONSE FROM RUN #		
DP	Mix	Ops Type	IA	1	2	3
1	-	-	+	220	209	182
2	+	-	-	197	162	168
3	-	+	-	949	857	927
4	+	+	+	836	823	871
			SUM:	-90	13	-42
			$SUM/2^{k-1}$:	-45	6.5	-21

IA EFFECT: 60% C.I. t = 1.061

Mean	-19.83
Variance	+664.08
1/2 Length	+15.79
Upper Bound	-4.048
Lower Bound	-35.62
Significance	YES

IA EFFECT: 95% C.I. t = 4.303

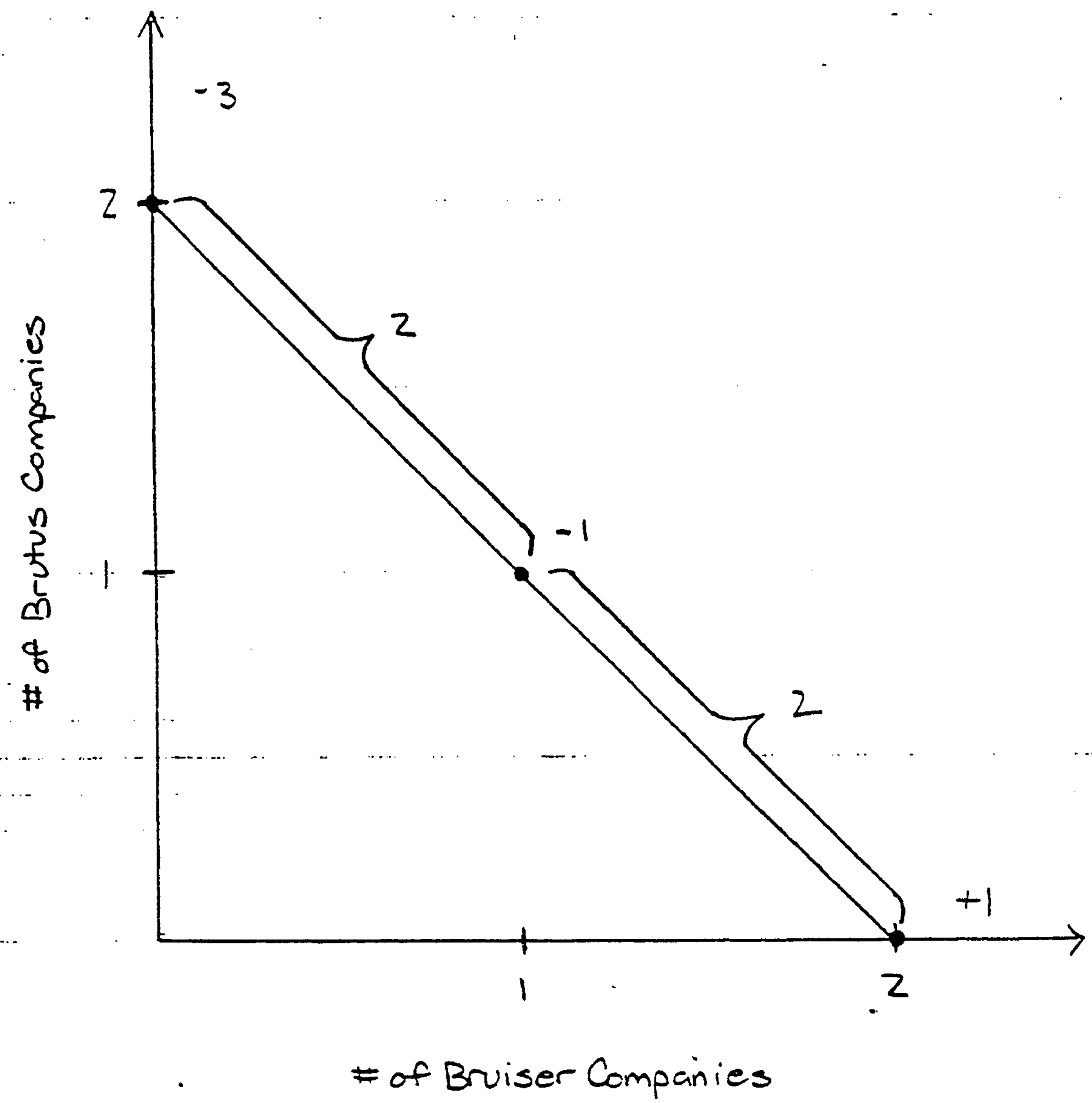
Mean	-19.83
Variance	+664.08
1/2 Length	+64.04
Upper Bound	+44.20
Lower Bound	-83.87
Significance	NO

Calculation of Relative Worth		
Measures of Effectiveness	BRUISER	FORCE MIX
MOE #1 (LER)	6.397	5.362
MOE #2 (FER)	5.178	4.337
MOE #3 (FIRES PER KILL)	3.64	3.63
MOE #4 (TOTAL KILLS)	171.5	154.5
MOE #5 (AVG RANGE DETECT)	3.113	3.185
MOE #6 (TOTAL DETECTIONS)	509.5	557.33
Relative Effectiveness		
MOE #1	1.294	1.00
MOE #2	1.194	1.00
MOE #3	Not Sign.	Not Sign.
MOE #4	1.110	1.00
MOE #5	.9774	1.00
MOE #6	.9142	1.00
TOTAL REL EFFECTIVENESS	5.490	1.00
AVG REL EFFECTIVENESS	1.098	1.00
Relative Cost	1.3375	1.00
Relative Worth	.8209	1.00

Calculation of Relative Worth		
Measures of Effectiveness	BRUISER	FORCE MIX
MOE #1 (LER)	✓6.397	✓5.362
MOE #2 (FER)	5.178	4.337
MOE #3 (FIRES PER KILL)	3.64	3.63
MOE #4 (TOTAL KILLS)	171.5	154.5
MOE #5 (AVG RANGE DETECT)	3.113	3.185
MOE #6 (TOTAL DETECTIONS)	509.5	557.33
Relative Effectiveness		
MOE #1	1.294	1.00
MOE #2	1.194	1.00
MOE #3	Not Sign.	Not Sign.
MOE #4	1.110	1.00
MOE #5	.9774	1.00
MOE #6	.9142	1.00
TOTAL REL EFFECTIVENESS	5.490	1.00
AVG REL EFFECTIVENESS	1.098	1.00
Relative Cost	1.3375	1.00
Relative Worth	.8209	1.00

Day and Night avg together

Response Surface Methodology Factor Level
Linear Extrapolation



AMPAD 22-141 50 SHEETS 22-142 100 SHEETS 22-144 200 SHEETS

			Low Level (-1)	High Level (+1)
Factor 1:	Force Mix	1 Co	Bruiser (FMBT)	2 Co Bruiser
		1 Co	Brutus (Block II)	
Factor 2:	Operation Type		Night	Day

Response Surface Methodology

Moe: LER

	Factor		Interaction	Respons from Run #:		
DP	Mix	Ops		1	2	3
1	-	-	+	10.36	8	5.28
2	+	-	-	10.36	10.5	5.33
3	-	+	-	4.3	2.14	2.09
4	+	+	+	4.1	2.32	5.77

Mean Effects

Mix:	1.035
Ops:	-4.85167
Interactio	0.185

Regression Equation

b0 = grand avg =	5.879167
b1 = e1/2 =	0.5175
b2 = e2/2 =	-2.42583
b3 = e3/2 =	0.0925

E(LER) = b0 + b1x1 + b2x2 + b3x1x2

$$E(LER) = 5.879167 + 0.5175 x1 - 2.42583 x2 + 0.0925 x1 x2$$

Prediction of LER with 2 Co. Brutus (-3) in Night Operations

$$E(LER) = 5.879167 + 0.5175(-3) - 2.42583(-1) + 0.0925(-3)(-1)$$

$$= 7.029997$$

Response Surface Methodology

Moe: FER

	Factor		Interaction	Respons from Run #:		
DP	Mix	Ops		1	2	3
1	-	-	+	8.38	6.47	4.27
2	+	-	-	8.38	8.5	4.32
3	-	+	-	3.48	1.73	1.69
4	+	+	+	3.32	1.88	4.67

Mean Effects

Mix:	0.841667
Ops:	-3.925
Interactio	0.148333

Regression Equation

b0 = grand avg =	4.7575
b1 = e1/2 =	0.420833
b2 = e2/2 =	-1.9625
b3 = e3/2 =	0.074167

E(FER) = b0 + b1x1 + b2x2 + b3x1x2

E(FER) = 4.7575 + 0.420833x1 − 1.9625x2 + 0.074167x1x2

Response Surface Methodology

Moe: Tota Kills

	Factor		Interaction	Respons from Run #:		
DP	Mix	Ops		1	2	3
1	-	-	+	145	144	132
2	+	-	-	145	147	128
3	-	+	-	185	152	169
4	+	+	+	201	160	248

Mean Effects

Mix:	17
Ops:	45.66667
Interactio	17.33333

Regression Equation

b0 = grand avg =	163
b1 = e1/2 =	8.5
b2 = e2/2 =	22.83333
b3 = e3/2 =	8.666667

E(# of Kills) = b0 + b1x1 + b2x2 + b3x1x2

E(# of Kills) = 163 + 8.5x1 + 22.83333x2 + 8.666667x1x2

Response Surface Methodology

Moe: Fire per Kill

	Factor		Interaction	Respons from Run #:		
DP	Mix	Ops		1	2	3
1	-	-	+	3.434483	3.430556	3.80303
2	+	-	-	3.448276	3.421769	3.960938
3	-	+	-	3.697297	3.861842	3.568047
4	+	+	+	3.641791	4.3625	3.008065

Mean Effects

Mix:	0.008014
Ops:	0.106749
Interactio	-0.04629

Regression Equation

b0 = grand avg =	3.636549
b1 = e1/2 =	0.004007
b2 = e2/2 =	0.053374
b3 = e3/2 =	-0.02315

E(Fires per Kill) = b0 + b1x1 + b2x2 + b3x1x2

E(Fires per Kill) = 3.636549 + 0.004007 x1 + 0.053374 x2 − 0.02315 x1x2

Response Surface Methodology

Moe: Tot Detects

DP	Factor Mix	Factor Ops	Interaction	Respons from Run #: 1	2	3
1	-	-	+	220	209	182
2	+	-	-	197	162	168
3	-	+	-	949	857	927
4	+	+	+	836	823	871

Mean Effects
Mix: -47.8333
Ops: 687.5
Interactio -19.8333

Regression Equation
b0 = grand avg = 533.4167
b1 = e1/2 = -23.9167
b2 = e2/2 = 343.75
b3 = e3/2 = -9.91667

E(# of Detections) = b0 + b1x1 + b2x2 + b3x1x2

E(#ofDetections) = 533.4167 - 23.9167x1 + 343.75x2 - 9.91667x1x2

Response Surface Methodology

Moe: Avg Range to Detect.

	Factor		Interaction	Respons from Run #:		
DP	Mix	Ops		1	2	3
1	-	-	+	2.155	2.132	2.169
2	+	-	-	2.139	2.195	2.145
3	-	+	-	4.185	4.274	4.197
4	+	+	+	3.986	4.11	4.103

Mean Effects

Mix:	-0.07233
Ops:	1.986667
Interactio	-0.08

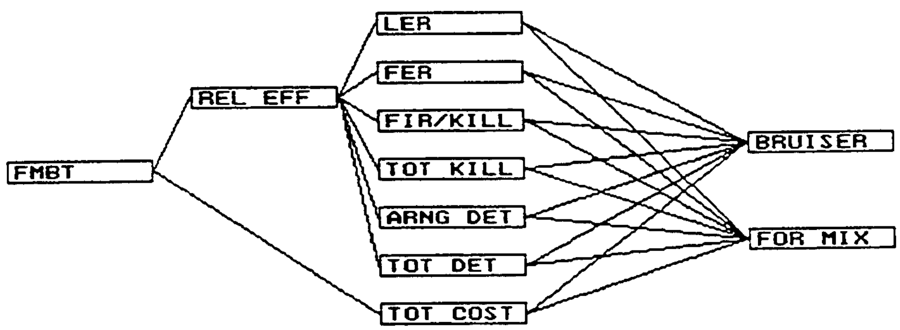
Regression Equation

b0 = grand avg =	3.149167
b1 = e1/2 =	-0.03617
b2 = e2/2 =	0.993333
b3 = e3/2 =	-0.04

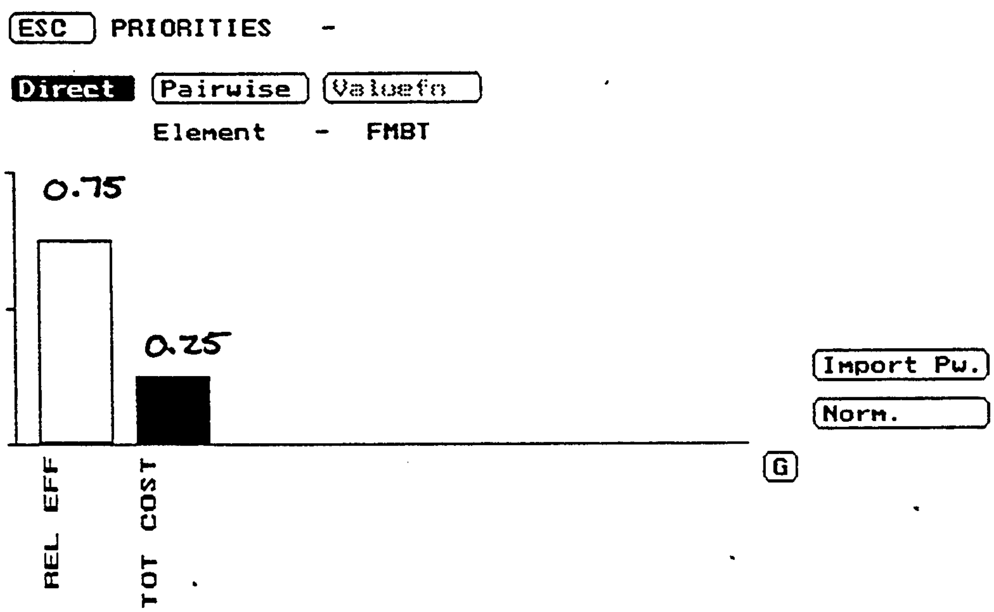
E(Detection Range)= b0 + b1x1 + b2x2 + b3x1x2

E(Detection Range) = 3.149167 − 0.03617x1 + 0.993333x2 − 0.04x1x2

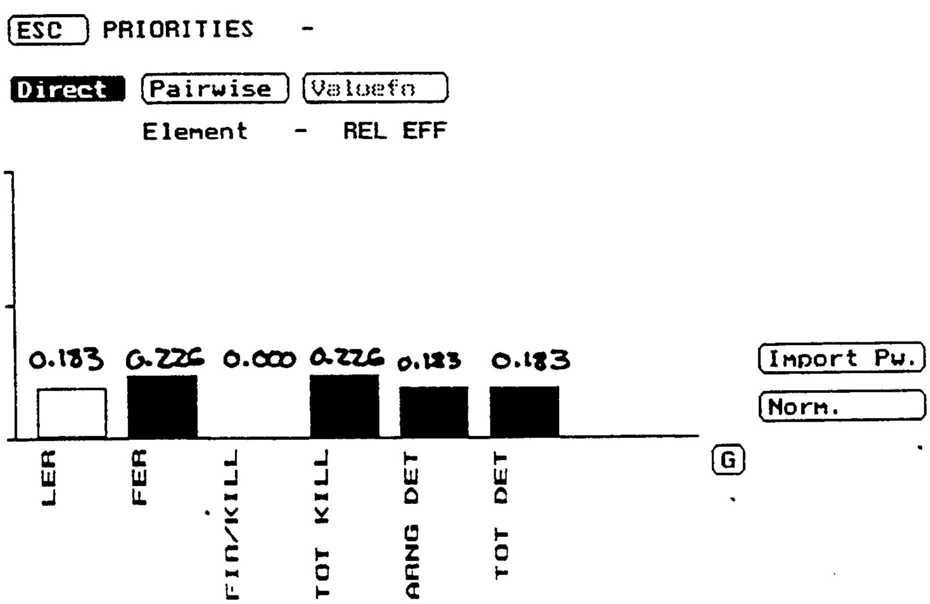
HIPRE3+ SCHEMATIC OF RELATIVE WORTH CALCULATIONS



WEIGHTS OF RELATIVE EFFECTIVENESS AND TOTAL COST



WEIGHTS OF MEASURES OF EFFECTIVENESS



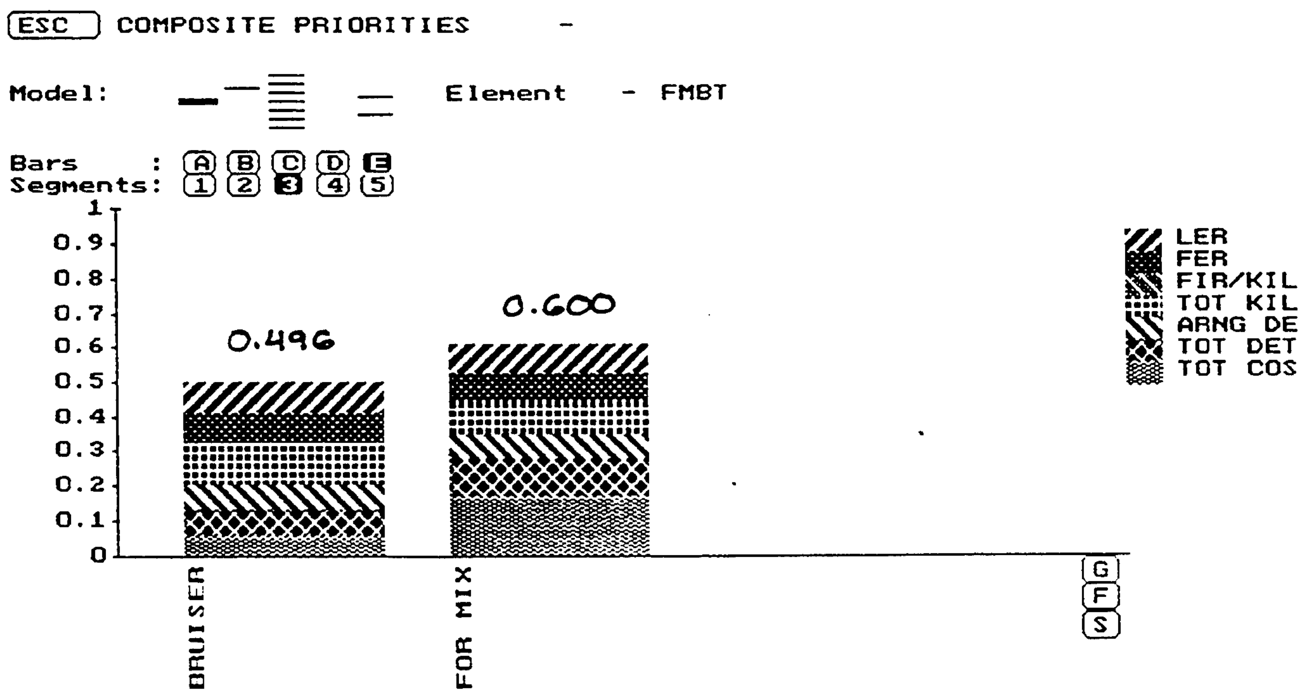
MEASURE OF EFFECTIVENESS SCORES FOR BRUISER ALTERNATIVE

ESC PERFORMANCE Of Alternative BRUISER

Attribute:	Rating:	Min:	Max:	Unit:
LER	6.397	0	10	
FER	5.178	0	10	
FIR/KILL	3.64	1	8	
TOT KILL	171.5	100	200	
ARNG DET	3.113	1	5	
TOT DET	509.5	400	600	
TOT COST	178.08	100	200	

Update Clear All

BEST ALTERNATIVE FOR FORCE MIX: 1 CO BRUTUS AND 1 CO BRUISER



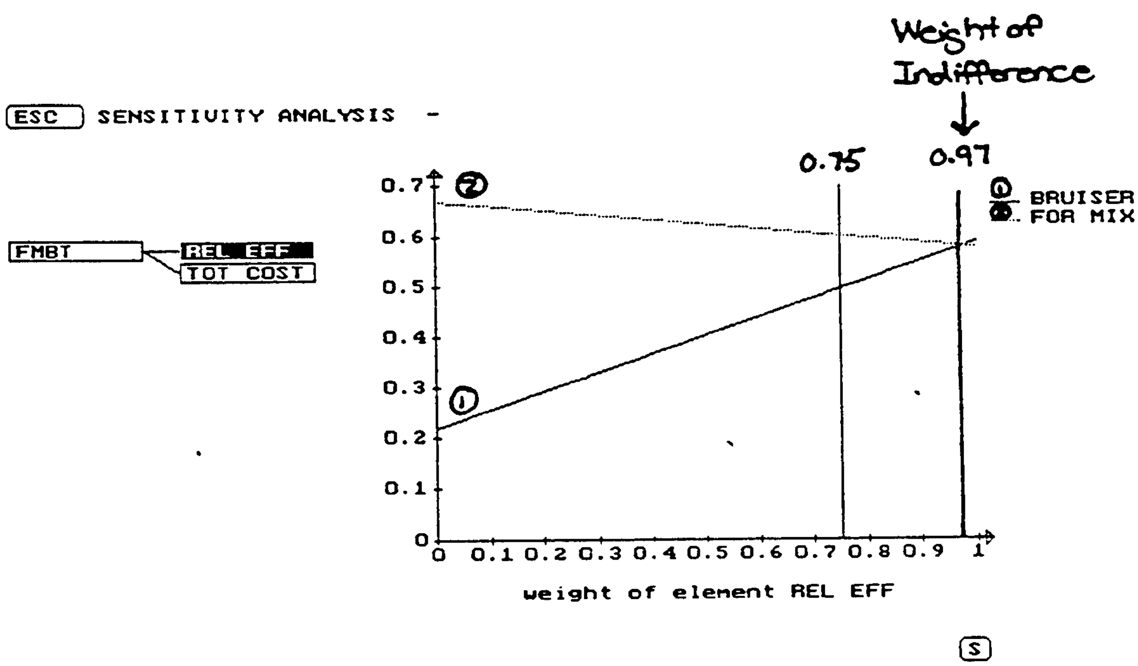
MEASURE OF EFFECTIVENESS SCORES FOR FORCE MIX ALTERNATIVE

ESC PERFORMANCE Of Alternative FOR MIX

Attribute:	Rating:	Min:	Max:	Unit:
LER	5.362	0	10	
FER	4.337	0	10	
FIR/KILL	3.63	1	8	
TOT KILL	154.5	100	200	
ARNG DET	3.185	1	5	
TOT DET	557.33	400	600	
TOT COST	133.14	100	200	

Update Clear All

SENSITIVITY ANALYSIS FOR RELATIVE EFFECTIVENESS WEIGHT



Appendix J

Briefing Slides

Operations Research Center
United States Military Academy
West Point, New York 10996

Briefing to MORS WG 31 23 JUN 93

MAJ Joseph Waldron
CPT(P) Mark E. Tillman

Combat Simulation Laboratory
Department of Systems Engineering
West Point, NY 10996
(914) 938-5672 (DSN: 688-5672)

Agenda

I. Overview of Cadet Education

II. Overview of Systems Engineering Program

III. Automation Tools Available to Cadets

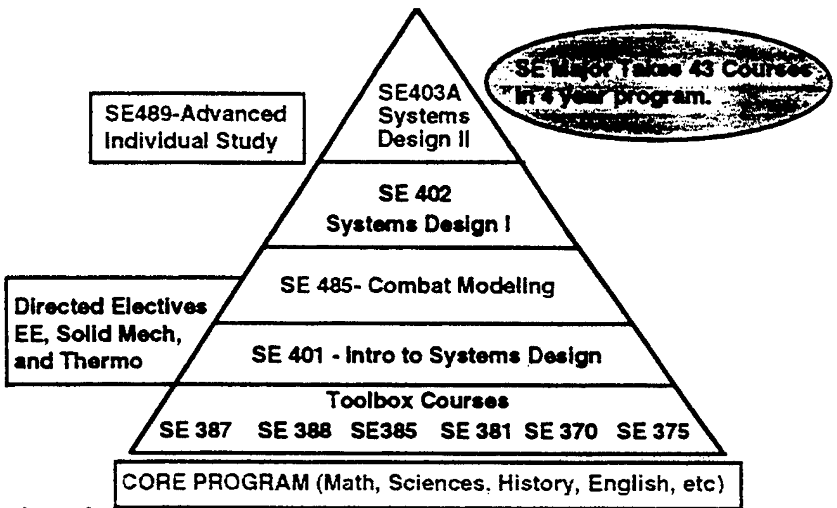
1. Combat Systems Generator
2. Janus (Army)
3. JEDA
4. HIPRE3+

IV. The Future at West Point

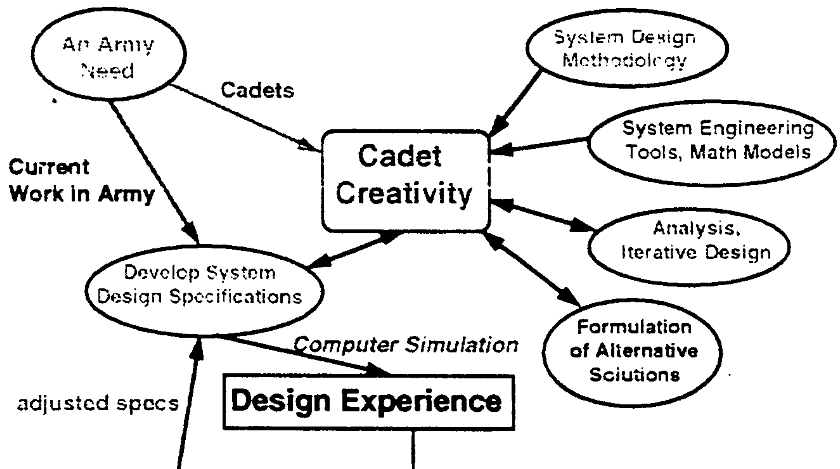
V. FMBT Study Methodology

VI. FMBT Results

Systems Engineering



Capstone Design SE403A



What Cadets Do

Learn:

1. Strengths and limitations of simulation
2. How to handle mainframe hardware and software in use by Army combat developers.
3. Networking tools to transfer files.
4. Cost of simulation (time, effort, etc) and the appropriateness of using simulation to evaluate a system.

Conduct Scientific Simulation Experiments:

1. Set-up valid experimental design to address design questions.
2. Establish methodology to evaluate the effectiveness of design by synthesizing knowledge of simulation and system design objectives.

Conduct Research:

1. That addresses real Army needs
2. Linked to many different Army agencies and labs.

Operations Research Center

Capabilities

Unique Role:

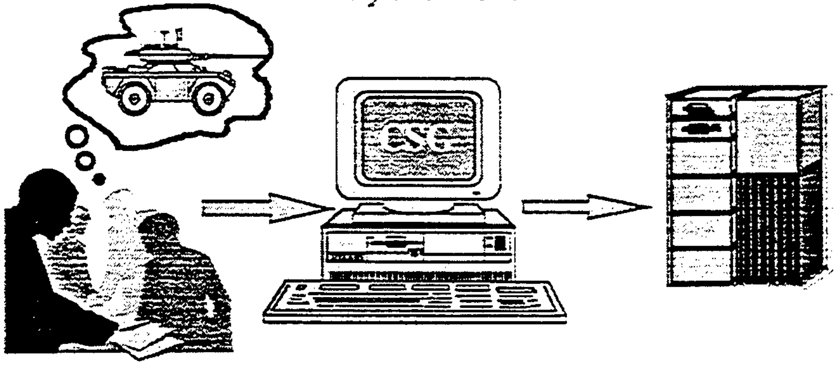
1. Only facility north of Washington of East Coast running Janus. Currently, one of only 20-25 in the country.
2. May be the most modern lab (hardware and software) in the active Army using Janus. We currently have the most powerful mainframe in use by Janus in the Army. Sun configuration will be the most powerful set-up also.
3. Acts as a model simulation laboratory for many visitors to the academy (including foreign nations) inquiring about combat simulation.

Post Processing (Janus Enhanced Data Analyzer)

1. JEDA is the fastest processor of Janus runs available anywhere (Developed to save cadet's time and effort).
2. Easy to use and Cadet friendly.
3. Being purchased by the Army as off-the-shelf post-processor for 40 installations in part as a result of cadet use.

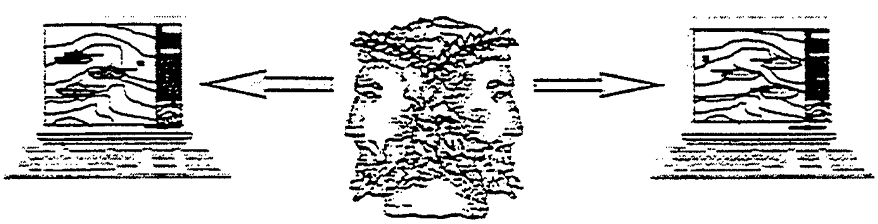
Operations Research Center

Database Interface
Combat Systems Generator



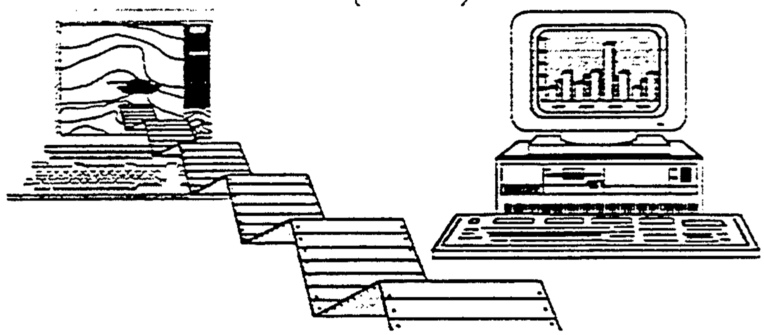
- Establishes minimum data requirements for systems in Janus
- Queries user for applicable parameter values
- Builds appropriate tables for input into Janus database
- Reference document for future

Simulation Tool
Janus



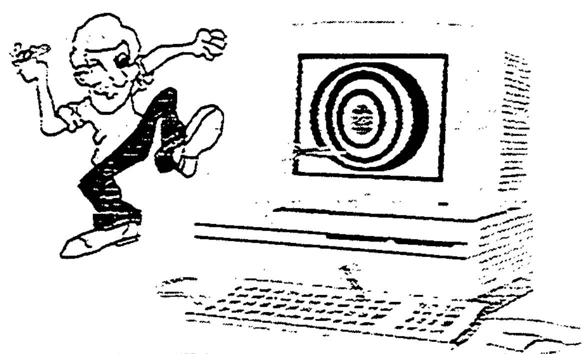
- Brigade on brigade scenarios down to individual soldier/system
- Flexible enough to build/modify systems with minimal frustration
- Simulation is animated with graphical user interface
- Simulation can be replicated using Auto Janus

Post Processing Tool
Janus Enhanced Data Analyzer (JEDA)

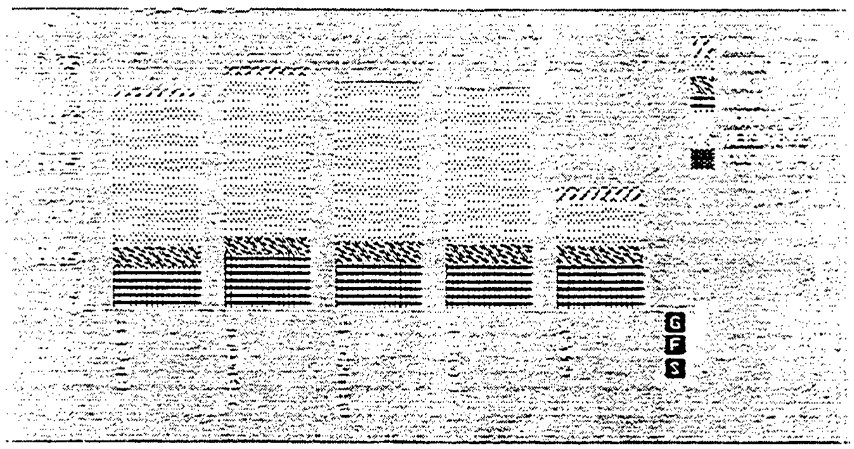


- FTP Janus post processing files from Vax or Sun
- Flexible creation of MOE
- Compiles replications
- Very fast!

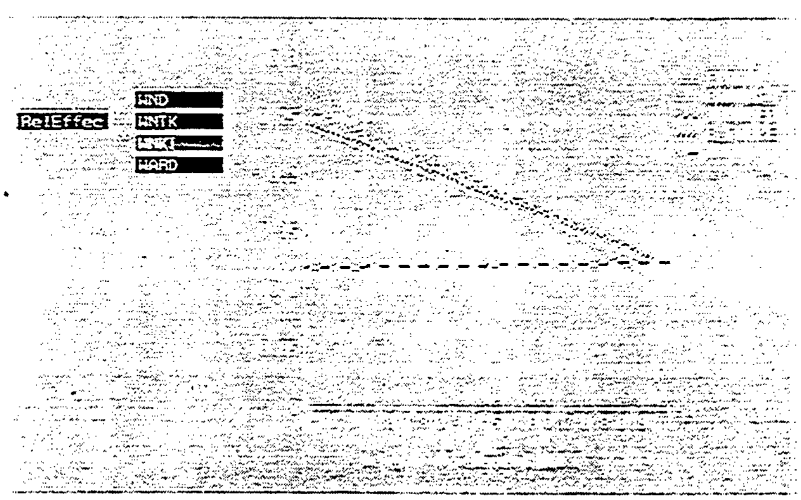
Decision Aid
HIPRE 3+



- MAU, AHP
- Priorities and weighting schemes
- Allows building of utility functions & curves
- Sensitivity analysis on performance levels and attribute weights available

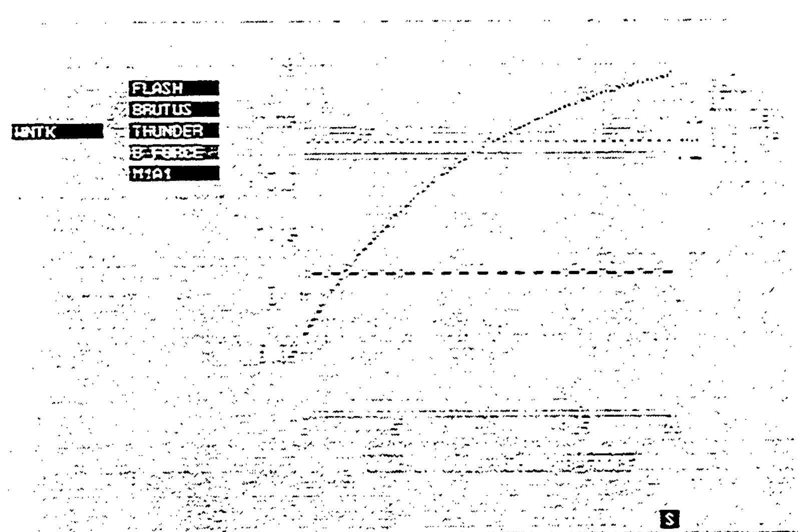


Composite Priorities of 5 Alternatives



Sensitivity of Weighting Scheme

HIPRE3+

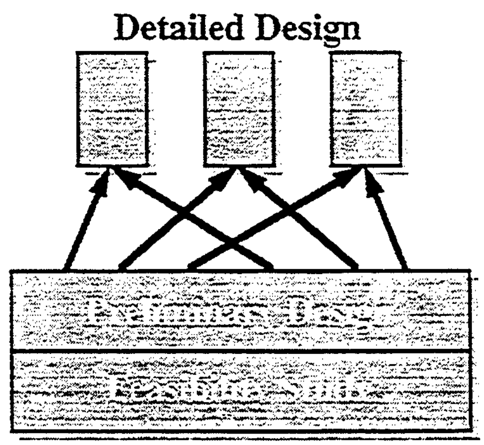


Sensitivity of Prototype Performance

Laboratory Projects

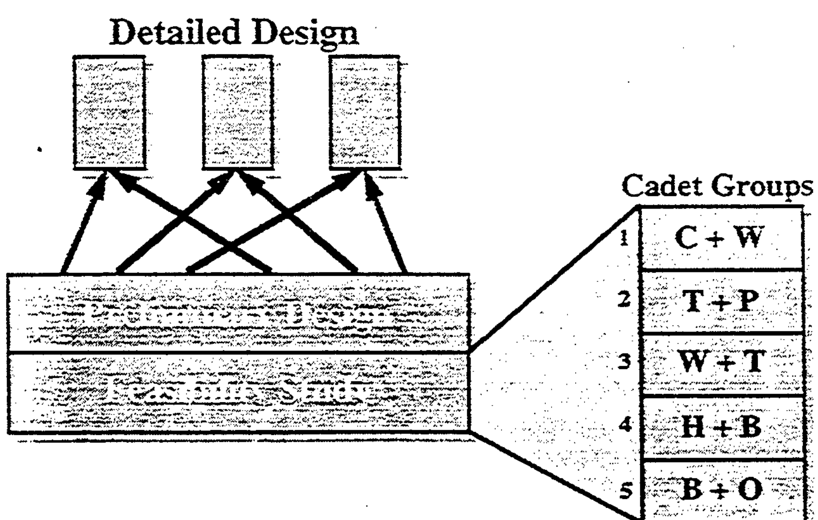
1. **The Future Main Battle Tank (SE403A)**
2. The Future Light Helicopter (SE4[illegible])
3. The Enhanced Infantry Soldier System (SE489)
4. The Warfighting Value of Reconnaissance (SE489)
5. Historical Reenactments of (SE489):
   The Battle of Gettysburg
   The Fight for West Point (circa 1778)
6. **Combat Modeling and Simulation Textbook (SE489)**

Design Methodology

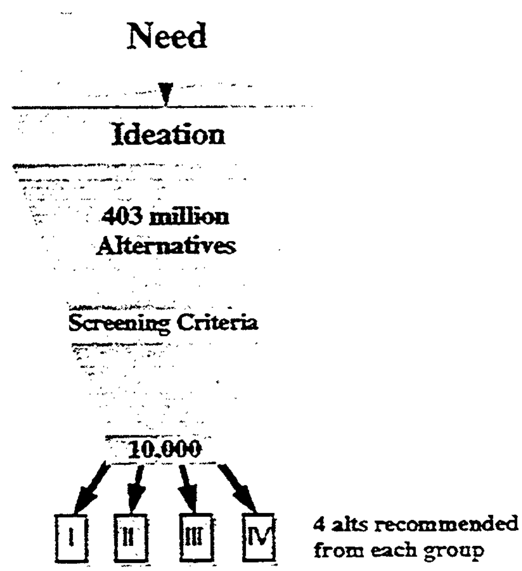


Future Main Battle Tank

Design Methodology

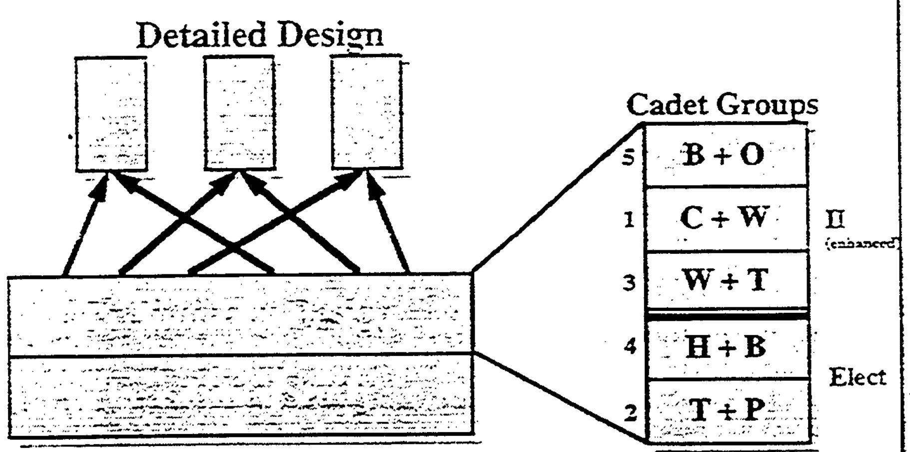


Feasibility Study



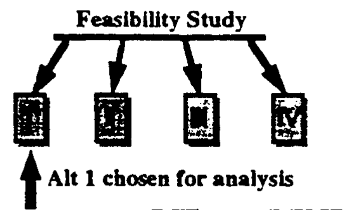
Operations Research Center

Preliminary Design



Operations Research Center

Preliminary Design



Group 1

(Coslin + Walker)

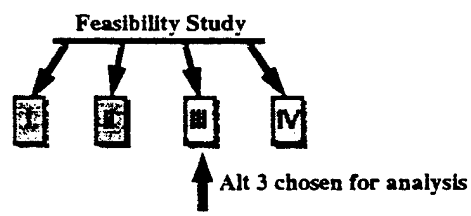
Assigned the Block IIE option for analysis

	P(H)	P(K|H)
MG I Flash	–	–
MG II Brutus	+	–
MG III T-Bolt	–	+
MG IV Brute Force	+	+

Main Gun Configurations (enhancements used)

Operations Research Center

Preliminary Design



Group 4

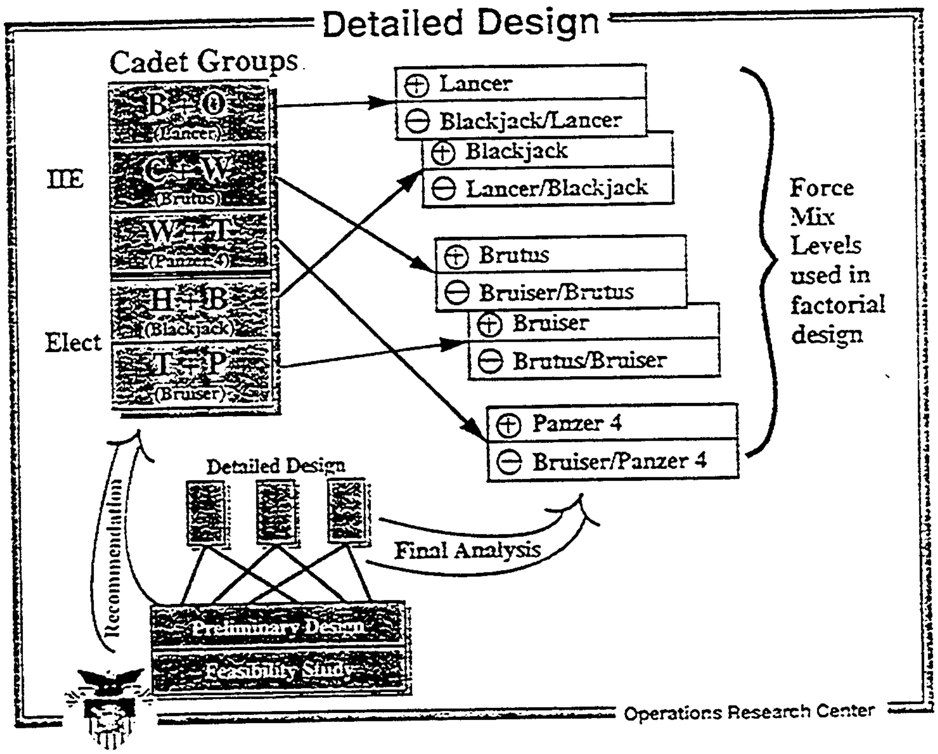
(Hodges + Bogdan)

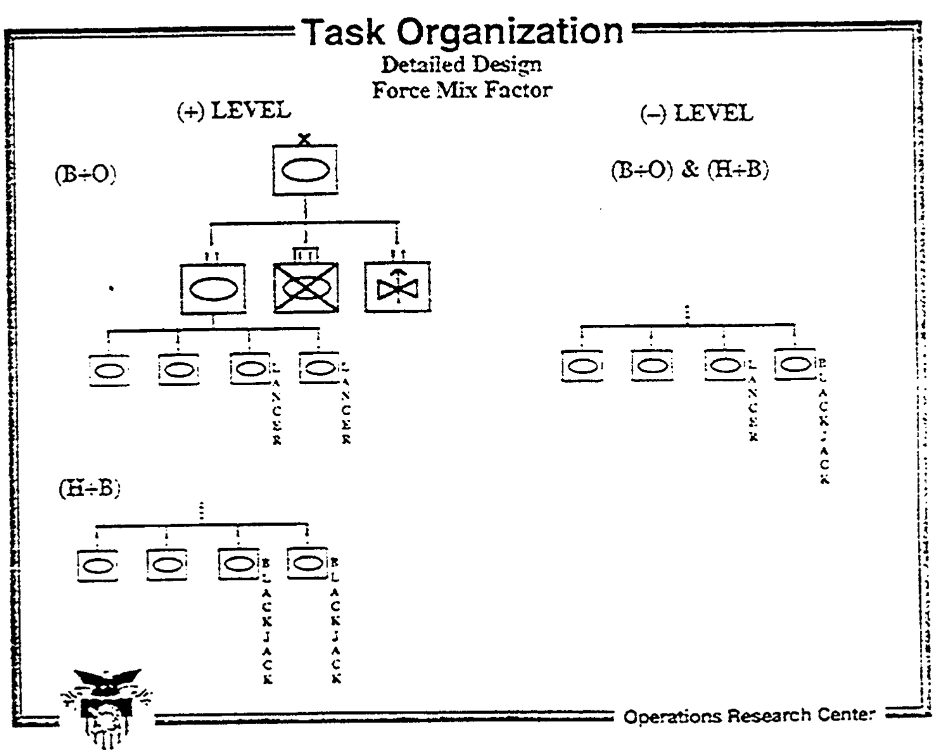
Assigned the Electric Tank option for analysis

Round Type	A	B	C	D	E
BL I Blackjack	✔				
BL II Terminator		✔	✔	✔	
BL III Rouge			✔	✔	✔

Basic Load Altered

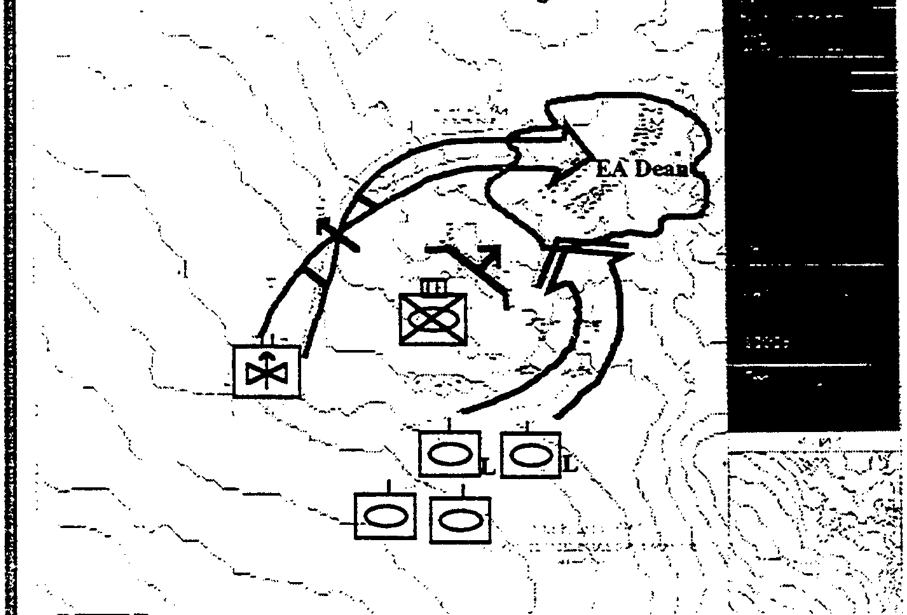
Operations Research Center


Detailed Design
Cadet Groups
B+O (Lancer)
C+W (Brutus)
W+T (Panzer 4)
H+B (Blackjack)
T+P (Bruiser)
IIE
Elect
⊕ Lancer
⊖ Blackjack/Lancer
⊕ Blackjack
⊖ Lancer/Blackjack
⊕ Brutus
⊖ Bruiser/Brutus
⊕ Bruiser
⊖ Brutus/Bruiser
⊕ Panzer 4
⊖ Bruiser/Panzer 4
Force Mix Levels used in factorial design
Detailed Design
Final Analysis
Recommendation
Preliminary Design
Feasibility Study
Operations Research Center


Task Organization
Detailed Design
Force Mix Factor
(+) LEVEL
(–) LEVEL
(B+O)
(B+O) & (H+B)
(H+B)
LANCER
LANCER
LANCER
BLACKJACK
BLACKJACK
BLACKJACK
Operations Research Center

COA Sketch

Detailed Design



Future

- Transition from VMS based software to Unix based Software.
- Eliminate Mainframe Hardware
  1. **DEC 8530 replaced by Sun SparcServer 670 (in place) and augmented by Sun Sparc Stations.**
  2. **Tektronix 4225s replaced by HP X-Terminals.**
- Reduce/Eliminate Dependency on USMA LAN.
- Develop High-Speed Data Processor for DIS Experiments and Bring DIS into the Classroom.
- Help Develop Link From Janus to DIS.