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TARGET ACQUISITION SYSTEMS FORCE MIX ANALYSIS (TASFMA). VOLUME --ETC(U)

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STUDY REPORT
CAA-SR-79-9

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TARGET ACQUISITION SYSTEMS FORCE MIX ANALYSIS (TASFMA)

LEVEL II

VOLUME I - EXECUTIVE SUMMARY

JUNE 1979

PREPARED BY
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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Target Acquisition; Force Mix; Methodology; Sensor Systems; Regression Analysis; Nonlinear Goal Programing; Pattern Search, Statistical Design of Experiments; Deterministic Model; Combined Arms; Division Level, DIVOPS; S/SAM.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report summarizes the development of a quantitative methodology for the selection of an optimum systems force mix in any functional area. The methodology is demonstrated by the evaluation of mixes of Army target acquisition systems (for artillery) in a first-day, European, division-level conflict. The methodology provides for both (1) an optimally performing mix within budget and quantity constraints and (2) identification of the mix which attains prescribed levels of performance for least cost. The methodology (over)

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20. ABSTRACT (continued)

requires a prioritization of measures of effectiveness (MOE), cost data on systems, and the results of combat simulation under a variety of systems mixes. Regression analysis is then used to reduce the combat results into equations specifying the contributions of the individual systems to the MOE. These relationships are then employed in a nonlinear goal program or pattern search procedure to arrive at the optimum systems mix for the constraints applied.

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TARGET ACQUISITION SYSTEMS FORCE MIX ANALYSIS

(TASFMA) (U)

VOLUME I - EXECUTIVE SUMMARY

June 1979

Prepared by

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CAA-SR-79-9

DEPARTMENT OF THE ARMY
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REPLY TO
ATTENTION OF:

MOCA-SMS 29 June 1979

SUBJECT: Final Report - Target Acquisition Systems Force Mix Analysis (TASFMA)

Deputy Chief of Staff for Research,
Development and Acquisition
Department of the Army
ATTN: DAMA-CSC-ST
Washington, DC 20310

1. Reference letter, DAMA-CSC-ST, 30 March 1977, subject as above.

2. CAA was tasked to develop a methodology to evaluate the cost and combat effectiveness of mixes of US Army systems in any functional area and to demonstrate the usefulness of that methodology with target acquisition systems. The attached study report documents a powerful, versatile, quantitative tool for use in force mix analysis that is capable of responding to a broad scope of management concerns. A particularly important aspect of the versatility is the ability of the methodology to determine both optimum effectiveness mixes and least-cost, acceptable effectiveness mixes. The study also demonstrates the application of the methodology to investigation of various doctrinal issues as well as the ability to deal with different numbers of system types.

3. The methodology is recommended for application to selected major Army systems mix problems. The computer program packages for the methodology may be directly obtained from CAA (ATTN: MOCA-SMS).

Ennis C Whitehead

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ENNIS C. WHITEHEAD, JR.
Major General, USA
Commanding

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TARGET ACQUISITION SYSTEMS FORCE MIX ANALYSIS (TASFMA)

EXECUTIVE SUMMARY

1. BACKGROUND

a. Historically, the process of determining which materiel systems the Army should acquire in any functional area of interest has been based largely on a combination of engineering and/or performance analyses coupled with military and subjective judgment. In this process, various mixes of systems have been examined for their relative cost effectiveness, but there has been no systematic procedure to optimize the mix against desired goals and objectives. The TASFMA Study, begun in August 1976, has evolved a methodology (using target acquisition systems as a demonstration functional area) to assist the materiel selection decision process in identifying mixes of materiel systems which best meet various operational and cost goals and objectives.

b. Though the TASFMA Study did not address individual sensor* systems to the breadth and detail required by a cost and operational effectiveness analysis (COEA) (since that was not the purpose of the study), the optimization methodology developed is suitable as an extension of COEA methodology. TASFMA couples the usual COEA factors of cost and operational effectiveness for selected mixes of systems with priorities among measures of effectiveness (MOE) and with less rigid procurement quantity constraints to identify optimal systems mixes, whether they are among those mixes initially selected or at some other, intermediate points in the spectrum of possible mixes.

2. PURPOSE. The purpose of the study was twofold:

- To develop a quantitative methodology for determining an optimal systems force mix in any functional area.

- To demonstrate and support the utility of the methodology by using it to optimize mixes of target acquisition systems subject to cost, quantity, and MOE priority constraints.

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*"Sensors" and "target acquisition systems" shall be used interchangeably hereafter.

3. SCOPE

a. Study Phasing and Approach. The study was a two-phase effort; Phase One, Methodology Development, took approximately 24 months; Phase Two, Demonstration, took some 9 months.

(1) The development phase defined the tools (models, scenario, sensor characteristics) and approaches to optimization for use in the demonstration phase. Also, special efforts were applied to sensor characterization, costing methodology, and various mathematical optimization processes.

(2) The demonstration phase applied the final Phase One optimization techniques to three cases: a 5-sensor mix with conventional munitions and expected-value sensor performance characteristics (Set A); a 5-sensor mix with 80 percent improved conventional munitions for Blue and reflecting some suggested doctrinal modifications for the countermortar and counterbattery systems (Set B); and a 10-sensor mix (Set C).

b. Sensor Treatment. Sensors addressed in the demonstration phase were limited to those to be available in the field by 1987. A generic list of candidate systems from which the specific systems analyzed were selected is shown in Table 1.

Table 1. Types of Target Acquisition Systems Considered

Counterfire radar
Moving target indicator radar
Sound/flash ranging systems
Forward observers
Ground surveillance radar
Unattended ground sensors
Security and reconnaissance patrols
Air observers
Airborne sensors
Remotely piloted vehicles
Radio intercept/direction finding
Radar intercept/direction finding
Air Force tactical reconnaissance

Systems not oriented toward targeting, suited only to intelligence collection, or insufficiently well defined were not simulated. Shown below are the specific sensors examined in the study.

- Countermortar radar (AN/TPQ-36)
- Counterbattery radar (AN/TPQ-37)
- Standoff Target Acquisition System (SOTAS)
- Remotely Piloted Vehicle (RPV)
- Remotely Monitored Battle Area Surveillance System (REMBASS)
- Forward observer*
- Air observer*
- Side Looking Airborne Radar (SLAR)*
- Radio direction finder (TRAILBLAZER)*
- Battlefield Surveillance and Target Acquisition Radar (BSTAR)*

Natural environmental factors affecting sensors were handled in an aggregated manner by estimating their average effect on the number of systems actually operating at any time. Enemy countermeasures were treated implicitly by use of duty cycles, assumed levels of sensor attrition and suppression, and degraded detection rate capabilities as believed appropriate. Moving and stationary targets were treated explicitly by assignment of appropriate acquisition factors consistent with those sensors looking for them and with the percentage of forces on the move. Signal intelligence (SIGINT) and human intelligence (HUMINT) were treated only to the extent that particular sensors with those features also contributed to targeting. Basically, however, intelligence collection per se was not played. Survivability, reliability, availability, maintainability, and crew performance were aggregated into a fractional multiplier (i.e., average availability factor) serving to reduce the quantity of sensors assigned to the division to an average number of sensors actually operational at any time.

c. Scenario. The TASFMA Study scenario was adopted from the Training and Doctrine Command (TRADOC) Scenario Oriented Recurring Evaluation System (SCORES), European 1, Sequence 2A, modified as required to represent the 1987 timeframe. The analysis was limited to a nonnuclear, mid-intensity conflict.

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*Notional version of this system used in 10-sensor mix (Set C) for capability demonstration only.

d. Model Treatment. The focus of the study required that modifications to the selected sensor performance and combat effectiveness models be limited to only those necessary to assist in development of the optimization methodology. However, even with the limitations of the available simulation models, some observations regarding selected sensor systems were developed in the process of demonstrating the optimization methodology.

e. Other Factors

(1) Command, control, and communications were explicitly played through a series of decision rules, rules of engagement, and target priorities, as well as through appropriate processing delay times for each sensor system.

(2) Costs used in the study were the 20-year life cycle costs for the sensor systems under consideration. While personnel requirements are noted for different procurement levels and could be the basis of comparison in mix optimization, actual comparisons and optimization were based on combat effectiveness and cost considerations only.

4. ASSUMPTIONS AND LIMITATIONS. The assumptions and limitations of TASFMA were largely model related.

a. Assumptions. Generally, it is assumed that force behavior can be described in a deterministic manner according to tactical rules that can be developed for the model(s) used. Enemy artillery is the top priority target of artillery on both sides, with other type targets next in a prescribed order. The MOE generated by the combat model (mainly kills and detections of weapons and personnel) were assumed to adequately portray the effects of interest and to allow comparison of systems. Alternate rankings of the MOE could be selected and used on a separate, independent basis for mix optimization comparison via the techniques developed in the study.

b. Limitations. The optimization techniques developed were designed for use with deterministic models only. Also, in the case of sensors, the available models did not provide the desired combination of computer running speed, flexibility of input and logic, and representation of all major target acquisition system functions. Of the models examined, DIVOPS was quickest running, did a reasonable job of reflecting target acquisition systems, and was deemed most useful for developing and demonstrating the optimization processes. The particular limitations peculiar to DIVOPS are presented in Chapter 2, paragraph 2-4 of the main report (Volume II).

5. TASFMA METHODOLOGY. The overall optimization methodology developed by TASFMA and used in the demonstration phase of the study is summarized below. Additional detail on the methodology and its elements can be found in the main report and appendices. The TASFMA methodology for optimization is centered around two multiobjective mathematical programing techniques, both of which were developed specifically for this study yet have universal applicability; they are (1) integer nonlinear goal programing (NLGP) and (2) goal program pattern search. These mathematical programs fit into the overall methodology as shown in Figure 1.

a. Initially, in accordance with Figure 1, the systems to be studied are selected (in TASFMA, 5 or 10 sensor types) and a reasonable range of quantities for the possible procurement of each system determined. A scenario is then selected, and parameters of both it and the systems are prepared as inputs to the models to be employed.

b. While TASFMA had originally planned to use sensor performance models (Sensor System Assessment Models (S/SAM) III and IV) feeding into a combat effectiveness model (the Division Operations (DIVOPS) Model), the latter was found to be sufficient for demonstration of the optimization techniques and was used alone. The combat model is run with a representative, balanced selection of mixes (or families) of systems determined, where necessary, by a statistical design of experiments. A regression analysis is then performed to fit equations representing the full spectrum of candidate mixes to the MOE data generated by the combat model. In parallel to the foregoing steps, the 20-year life cycle costs to be used in the optimization process are also determined for the systems in question.

c. The final steps in the optimization process are to set target (desired) values for the MOE based on the optimization objective (obtaining the most effective mix for a given cost or the least-cost adequate mix), prioritize the MOE, determine the quantity and budget (dollars, manpower) constraints, and then perform the optimization with the NLGP or goal program pattern search techniques. While either optimization technique may be used, nonlinear goal programing is preferred with smaller numbers of system types (e.g., 5), and pattern search is preferred with larger numbers (e.g., 10). Computer run time is the principal factor in determining the selection. With faster running computers, the crossover point in technique selection, in terms of number of system types to be examined, would increase.

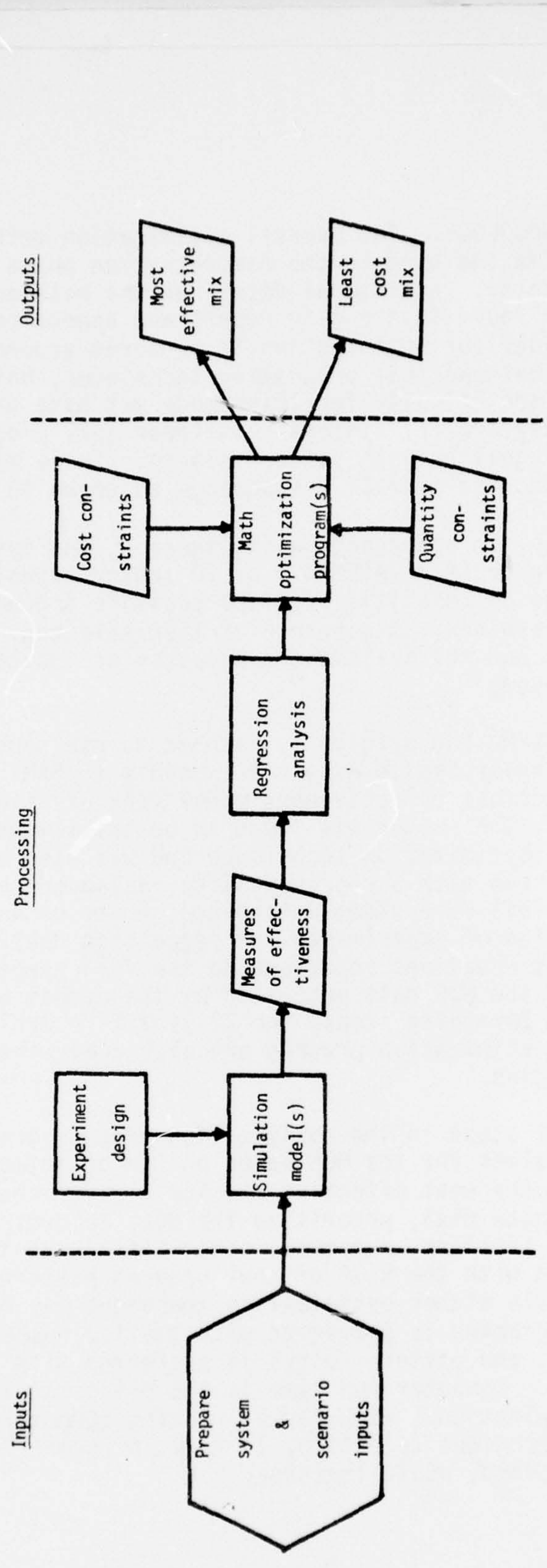

Figure 1. Overall Methodology

6. APPLICABILITY TO OTHER FUNCTIONAL AREAS

a. The applicability of the TASFMA methodology to other functional areas (as well as to sensors) of interest to the Army is a highly pertinent question. The answer rests on the availability of suitable models for measuring the combat effectiveness or technical performance of the systems to be compared. Model availability will depend in turn on the number of system types to be examined, the model run time, and available computer time. It is on these factors that the feasibility of designing an adequate series of mixes for testing the systems in question is based. Only then can the TASFMA optimization process of regression analysis followed by NLGP and/or pattern search be applied.

b. The DIVOPS Model enabled many sensor mixes to be examined in a short period of time (243 mixes in about 8 hours of computer run time). Since longer running models than DIVOPS are the norm, the ability of these models to handle different numbers must be determined. Table 2 illustrates a number of options for examining any number of systems from 3 to 15. It shows how many model runs would be required if all possible combinations of the systems were to be examined at three levels (necessary for systems having nonlinear characteristics) of each system (full factorial) and what reductions in runs are allowable with representations of the information at various lesser levels of detail. The runs indicated in the column headed by "Limited 2-way interactions" are probably the least required to represent all practical situations. The superscripts relate number of runs required with allowed model run times, assuming only 100 computer hours may be assigned to the production runs. For example, the table shows that approaches are available to handle up to 15 different system types in any functional area that can be represented by a model whose run time is one-half hour or less, or up to 9 systems by models of up to 2 hours' run time. If more than 100 hours may be assigned to the production runs, even longer-running models may be allowed.

c. Some particular Army models examined for their applicability to systems comparison in various functional areas were in the categories of combined arms, artillery, air defense, infantry, tank-antitank, and communications-electronics warfare. The wide variation in characteristics and applicability that might be expected from such diverse models is noted in detail in Chapter 6 of the main report; but it appears that as many as 15 system types could be considered for mix optimization analysis with a few of these models and as many as 5 to 10 types with most of the models.

Table 2. Model Run Time Requirements for Applying TASFMA Methodology to Different Numbers of Systems

No of systems	Runs required (at three levels per system)[a]			
			Theoretical minimum	
	Full factorial[b]	Fractional factorial[c]	All 2-way interactions[c]	Limited 2-way interactions[c]
3	$27^{(5)}$	N/A	$19^{(5)}$	$10^{(5)}$
6	729	$243^{(2)}$	$73^{(3)}$	$28^{(5)}$
9	19,683	$243^{(2)}$	$163^{(2)}$	$55^{(4)}$
12	531,441	$259^{(1)}$ to	$289^{(1)}$	$91^{(3)}$
15	14,348,907	$499^{(1)}$	$451^{(1)}$	$136^{(2)}$

[a]Superscripts, by reference to the following list, indicate length of acceptable model run times based on total computer availability of about 100 hours.

(1) 15 min
(2) 30 min
(3) 1 hr
(4) 2 hr
(5) 4 hr

[b]All combinations.

[c]Representative combinations.

7. DEMONSTRATION OBSERVATIONS. As indicated earlier, three sets of demonstration runs (A, B, and C) were performed with DIVOPS, followed by regression analysis, NLGP, and pattern search investigations. DIVOPS proved a useful tool for the generation of data on combat effectiveness contributions of sensor systems. Regression analysis successfully fit the DIVOPS output data with equations relating the MOE to the systems studied and facilitating some separate sensitivity analyses. NLGP demonstrated the ability to determine optimum and least cost mixes with various orders of MOE priority and various budget and system quantity constraints. Subject to the assumptions and limitations affecting the DIVOPS Model performance, the optimum mixes produced by the NLGP were substantially better than the nominal mix in meeting top priority MOE goals and generally better, to varying degrees, at meeting the other MOE goals, all at approximately equal cost. Furthermore, lower cost mixes were derived which still exceeded nominal mix performance. Working with 10 sensors, the pattern search technique gave results comparable to those of the NLGP. However, while the results were comparable, they were of different format. Also, a pattern search solution may be a local optimum or slightly less than optimum while the NLGP solution is, by design, global and best. For particular optimization problems of special interest to a user or decisionmaker, future studies specifically designed to apply the TASFMA methodology to those problems may be in order.

8. METHODOLOGY OBSERVATIONS. A number of specific primary and secondary methodology observations are offered:

a. Primary

(1) TASFMA has produced a methodology that is a powerful, versatile, quantitative tool for use in force mix analysis, capable of answering the "what if's" about mixes of systems.

(2) The methodology has potential applicability to the study of Army systems represented by either combat operations or technical performance models in various functional areas.

(3) Optimum mixes and least cost, acceptable mixes can be determined, subject to user-specified priorities and constraints.

b. Secondary

(1) The methodology allows for suboptimization, e.g., if the budget were reduced or otherwise constrained.

(2) Only a one-time series of runs of the combat effectiveness model is required for any given set of force conditions. In effect, the model can be "thrown away" after the regression equations describing the MOE have been determined.

(3) Quick running combined arms models, such as DIVOPS, are highly useful in optimization studies, allowing many combinations of systems to be examined in a relatively short time.

(4) A DIVOPS improvement or comparable development program should be considered. Short of such an effort, but with the objective of making more reliable sensor system comparisons, DIVOPS might be better utilized by examining selected 15-minute time slices of the battle, with appropriate scenarios and orders of battle for each slice, rather than by amalgamating a 24-hour period. In any case, when directly comparing the simulated performances of different mixes of systems, more reliance should be placed on relative than on absolute values of the MOE.

APPENDIX A

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APPENDIX B

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