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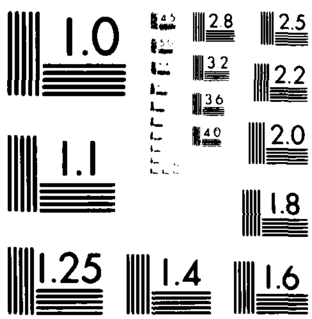

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May 1981

FINAL REPORT PR 81-15-324

Decision-Analytic Workshops

Dennis M. Buede
Kathleen A. Waslov

DECISIONS and DESIGNS, INC.

Prepared for
Command and Control Technical Center
Washington, D.C. 20301

FINAL REPORT PR 81-15-324

DECISION-ANALYTIC WORKSHOPS

by

Dennis M. Buede and Kathleen A. Waslov

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Command and Control Technical Center
Washington, D.C.
Contract DCA100-80-C-0028

May 1981

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This final report describes the decision analysis workshops conducted by analysts of Decisions and Designs, Inc. (DDI) for members of the J-5 staff, at the Command and Control Technical Center (CCTC). The intent of the workshops was to apply decision-analytic support to current J-5 problems while providing CCTC with the knowledge and techniques necessary to support future J-5 decision analysis needs. Some of the workshops were tutorials on computerized decision aids developed at DDI, methodologies employed by decision analysts, and various problems DDI's analysts have encountered.

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This report is a chronological listing of the completed workshops (1 July 1980 to 21 April 1981) and their content with emphasis on the decision-analysis techniques applied or discussed.

A

CONTENTS

CONTENTS (Cont'd)

FIGURES

1.0 INTRODUCTION

This final report describes the decision analysis workshops conducted by analysts of Decisions and Designs, Inc. (DDI) for members of the J-5 staff, at the Command and Control Technical Center (CCTC). The intent of the workshops was to apply decision-analytic support to current J-5 problems while providing CCTC with the knowledge and techniques necessary to support future J-5 decision analysis needs. However, some of the workshops were tutorials on decision analysis software, methodologies, and problems that DDI has encountered.

This report is a chronological listing of the completed workshops (1 July 1980 to 21 April 1981) and their content with emphasis on the decision analysis techniques applied or discussed.

2.0 WORKSHOPS

2.1 Worldwide Digital System Architecture Evaluation (Workshops 1 and 2)

The 1 and 3 July 1980 workshops were attended by members of the Defense Communications Agency (DCA) and representatives from Mitre Corporation. Their task was to evaluate nine alternative design concepts for a Worldwide Digital System Architecture (WWDSA), proposed by Mitre, with respect to criteria developed by DCA. Prior to the conference, a DCA analyst had structured the criteria for the evaluation in a form that corresponded to DDI's hierarchical evaluation (HIVAL) model.

Using this structure, the analysts at the conference focused on selecting a subset of criteria for the evaluation process and on assessing the values of the alternatives. Because the meeting was restricted to two days, it was necessary to reduce the set of criteria to a manageable size. For the first day's analysis the original tree structure, shown in Figure 2-1, was pruned from 52 to 17 bottom-level criteria; the revised structure is shown in Figure 2-2. The group decided to address only "Effectiveness" parameters and only in a broad sense. If, during the evaluation procedure, the group had experienced difficulty with broad criteria, more detail could have been added.

For the second day's analysis, a new set of criteria was added to the structure, as shown in Figure 2-3.

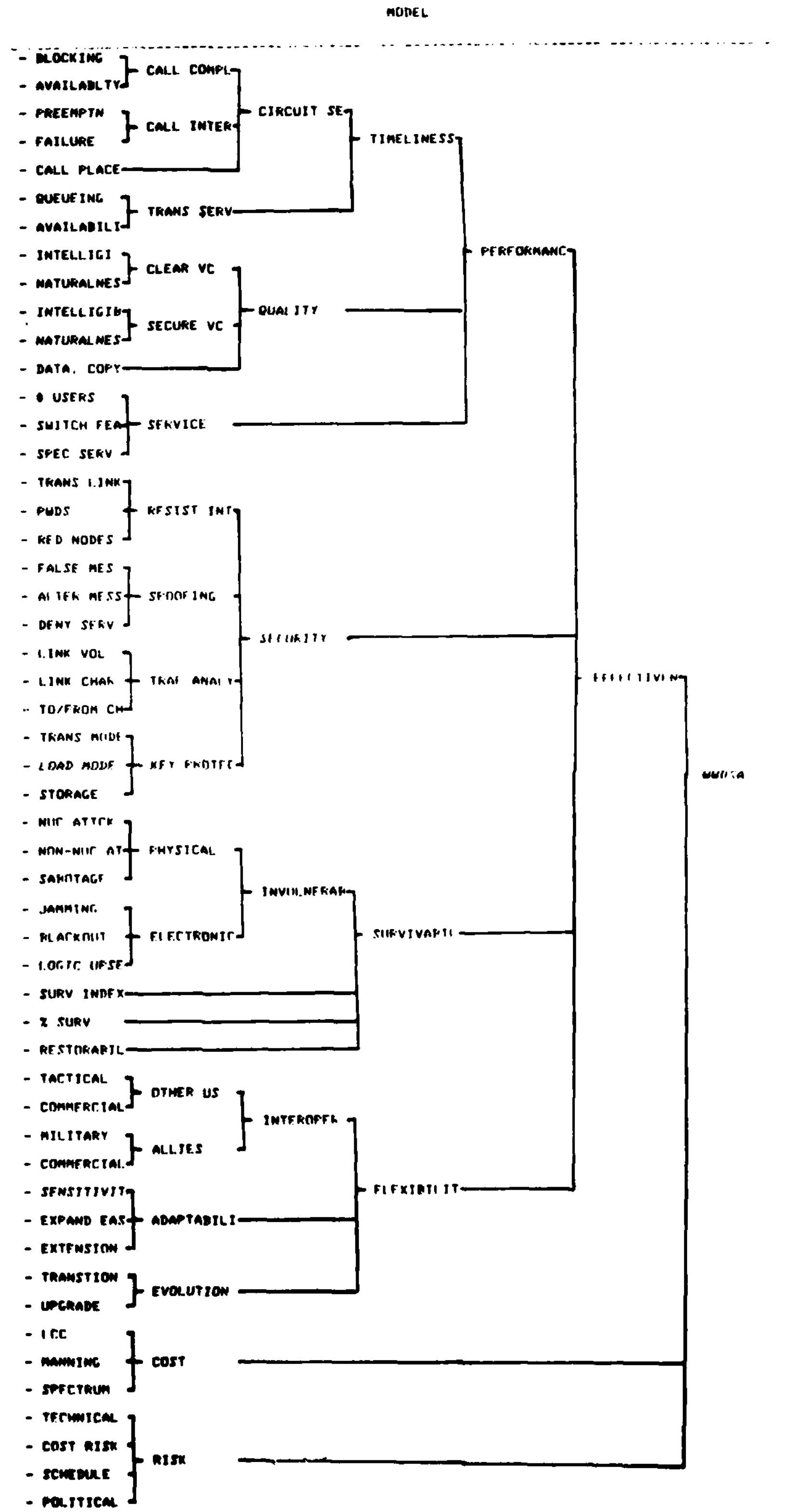


Figure 2-1

INITIAL WWDSA EVALUATION STRUCTURE - FIRST SESSION

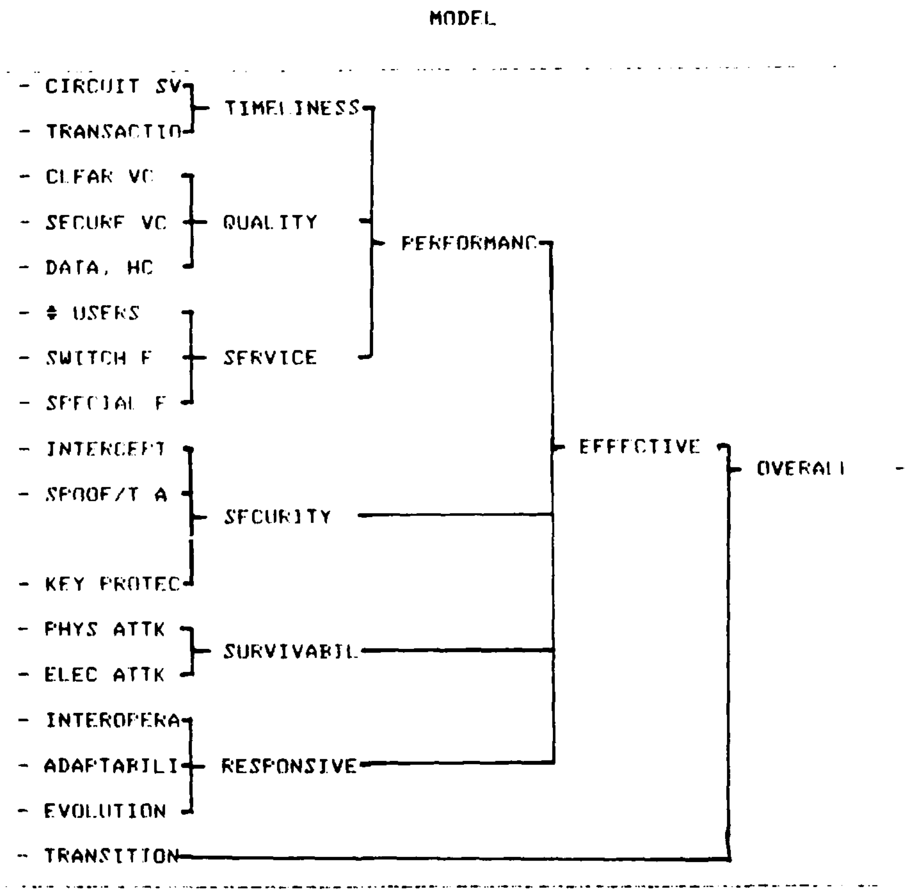


Figure 2-2
REVISED WWDSA EVALUATION STRUCTURE - FIRST SESSION

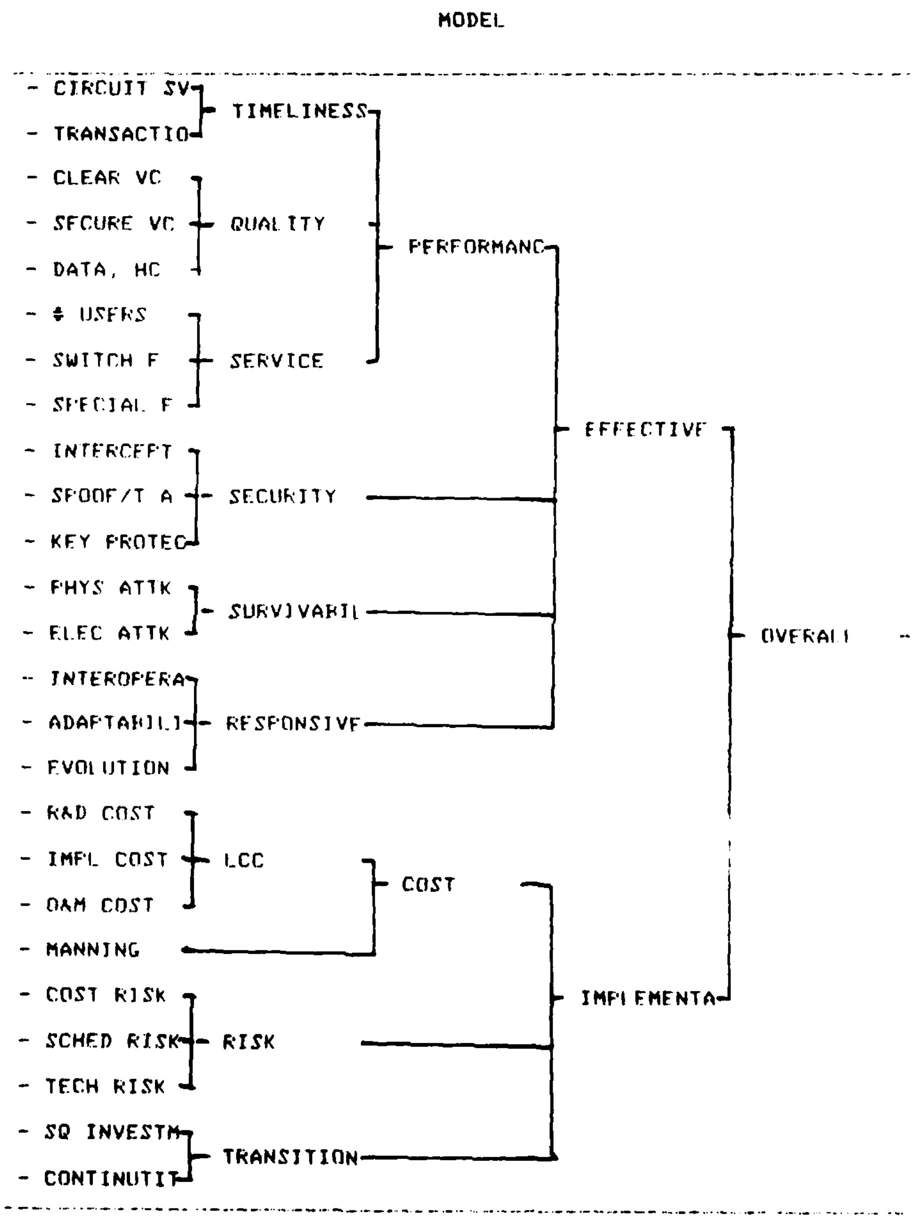


Figure 2-3
FINAL WWDSA EVALUATION STRUCTURE - FIRST SESSION

The nine alternative design concepts were scored with respect to each bottom-level criterion, and the criteria were weighted. The resulting overall scores for the analysis are displayed in Figure 2-4. System Design 2 includes variations 2A, 2B, and 2C. These variations received overall scores of 63, 59, and 60, respectively, and were the superior design alternatives or options. The performance of these options on Effectiveness and Implementation criteria is displayed in the matrices labeled 1 and 2.

Figure 2-5 charts the options' scores on Effectiveness versus Implementation. (Here option 1 is BL, 2 is 1A, 3 is 1B, etc.) A perfect option would appear in the upper right-hand corner. Note that options 3A and 3B (8 and 9) score very high on Effectiveness but would be the most difficult options to implement. Options 2A, 2B, and 2C (5, 6, and 7) dominate all others when both criteria are considered.

Figure 2-6 shows how the options fare when the weight of the Implementation criterion varies. System Designs 2A, 2B, and 2C, which score moderately well on all criteria, appear consistently strong and dominate in the mid-range.

As a result of this analysis, the group decided to concentrate on System Design 2 and experiment with variations during future sessions.

2.2 Decision Structuring Tutorial (Workshop 3)

DDI analysts met with three CCTC analysts on 10 July to discuss the aspects of structuring decision models. The group exercised an example, "The Rambo Crisis," and built a

0 - OVERALL

FACTOR	WT	BL	1A	1B	1C	2A	2B	2C	3A	3B	CUMWT
1) EFFECTIVE	(50)	1	14	28	19	52	60	63	97	93	50.00
2) IMPLEMENTA	(50)	76	94	40	80	74	58	56	13	15	50.00
TOTAL		39	54	34	49	63	59	60	55	54	100.00

1 - OVERALL - EFFECTIVE

FACTOR	WT	BL	1A	1B	1C	2A	2B	2C	3A	3B	CUMWT
1) PERFORMANC	(19)	5	36	36	40	59	56	60	95	95	9.41
2) SECURITY	(19)	0	6	29	11	17	33	44	95	95	9.41
3) SURVIVABIL	(37)	0	0	30	10	60	60	60	100	86	18.32
4) RESPONSIVE	(26)	0	23	20	23	59	82	82	95	100	12.87
TOTAL		1	14	28	19	52	60	63	97	93	50.00

2 - OVERALL - IMPLEMENTA

FACTOR	WT	BL	1A	1B	1C	2A	2B	2C	3A	3B	CUMWT
1) COST	(40)	66	97	16	74	64	53	51	30	35	20.11
2) RISK	(25)	66	80	19	78	86	67	64	5	3	12.64
3) TRANSITION	(34)	97	100	83	87	75	57	57	0	0	17.24
TOTAL		76	94	40	80	74	58	56	13	15	50.00

Figure 2-4

WWDSA EVALUATION SCORES - FIRST SESSION

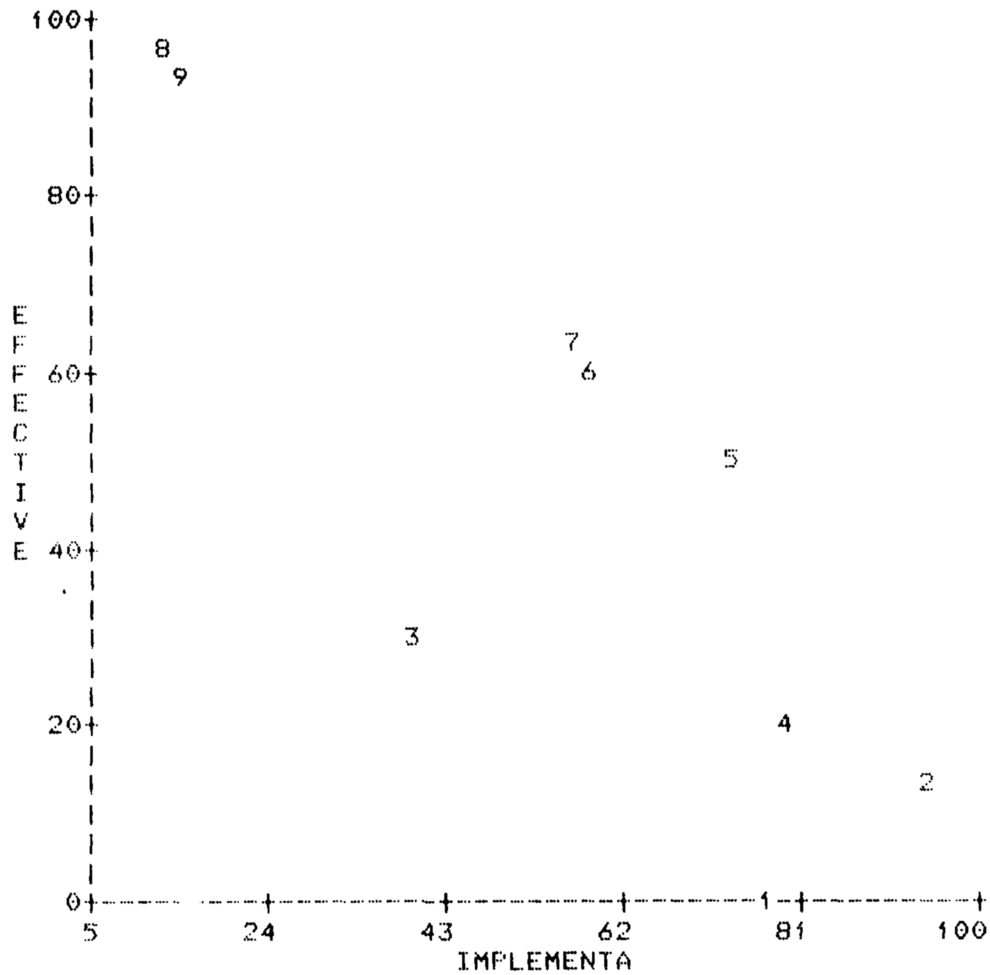


Figure 2-5
WWDSA SENSITIVITY PLOT - FIRST SESSION

2 IMPLEMENTA- CURRENT CUMWT: 50.00

CUMWT	BL	1A	1B	1C	2A	2B	2C	3A	3B
.0	1	14	28	19	52	60	63	97*	93
10.0	8	22	30	25	54	60	62	89*	85
20.0	16	30	31	31	56	59	61	80*	77
30.0	24	38	32	37	58	59	61	72*	70
40.0	31	46	33	43	60	59	60	64*	62
50.0	39	54	34	49	63*	59	60	55	54
60.0	46	62	35	55	65*	59	59	47	46
70.0	54	70*	36	61	67	58	58	38	38
80.0	61	78*	38	68	69	58	58	30	31
90.0	69	86*	39	74	71	58	57	22	23
100.0	76	94*	40	80	74	58	56	13	15

Figure 2-6

WWDSA SENSITIVITY ANALYSIS - FIRST SESSION

hierarchical multi-attribute evaluation model and a decision tree model. In addition, they practiced building the models on the computer.

2.3 Analysis of a Contingency Problem (Workshops 4 and 5)

Two workshops were held on 7, 8, and 11 August to address a potential contingency problem under the supervision of Colonel J. D. Beans. The analytical approach was multi-attribute utility analysis: first, the problem and its alternatives were identified. Then a set of attributes were developed that could be used to evaluate the alternatives. Because the output of this analysis was deemed classified, all results were left with Colonel Beans.

2.4 Resource Allocation Software (Workshop 6)

A DDI analyst met with CCTC representatives on 2 and 3 September at their offices to display and describe two DDI decision-analytic software packages that can be used for resource allocation problems. The group was briefed on POM, the software that supports the resource allocation methodology used by the services to prepare their Program Objecives Memorandum, and DESIGN, another DDI resource allocation methodology. DESIGN is a decision-analytic technique that is useful for decisions that involve choosing a set of optimal (cost-beneficial) levels of various items that compete simultaneously for resources.

2.5 Middle East/Africa Division Briefings (Workshop 7)

DDI analysts briefed representatives of the Middle East/Africa Division (MEAF), J-5 on 19 September 1980. The workshop addressed a classified problem of alternative courses of action selection utilizing hierarchical multi-attribute utility modeling. During the course of the workshop, two decision problems of the resource allocation type were identified for possible analysis in future workshops.

2.6 Rapid Deployment Joint Task Force (RDJTF) Briefings/ Discussions (Workshop 8)

On 17 and 20 October, DDI analysts attended briefings and held discussions with RDJTF representatives to identify decision problems. The most promising problems were force structuring decisions.

2.7 Second WWDSA Evaluation (Workshops 9 and 10)

Representatives from the Defense Communications Engineering Center and Mitre Corporation returned to DDI on 29 October and 5 November for a second decision conference to evaluate a new set of alternate architectural system designs. The group, led by DDI analysts, used the multi-attribute hierarchical evaluation model (HIVAL) to analyze eight options. The set of criteria remained the same as before. The simplest or baseline option was a design derived from "Strawman 2" of the previous analysis and was entitled 2A. The other options were variations of the basic system, i.e., with one or more of the following features added: Interoperability (I), COMSEC (C), and Satellites (S). For instance, Option IS is the design 2A plus Interoperability and Satellites.

Each alternative was scored on each criterion relative to all other alternatives, and the criteria were weighted. Figure 2-7a displays the resulting scores beneath each option on the row called TOTAL.

Except for the COMSEC-only option, the alternatives score similarly when EFFECTIVENESS and IMPLEMENTATION are weighted equally. Matrices 1 and 2 show the scores in these two overall categories.

Figure 2-7b is a sensitivity analysis of the weight on IMPLEMENTATION (which is the criteria category that includes COSTS). Note that when IMPLEMENTATION has a weight of 40 or less, that is, when one IMPLEMENTATION point is spent and the return on EFFECTIVENESS is judged to be 1.5 points or more, the design, ISC is superior. In terms of cost, the next best item is IS; S follows, then 2A. The graph in Figure 2-7c demonstrates that options 2A, S, IS, and ISC (#1, 6, 5, and 7) dominate as the weight of IMPLEMENTATION varies.

0 - OVERALL

	FACTOR	WT	2A	I	C	IC	IS	S	ISC	SC	CUMWT
1)	EFFECTIVE	(50)	8	32	42	66	60	38	93	66	50.00
2)	IMPLEMENTA	(50)	81	61	36	28	53	69	19	27	50.00
	TOTAL		45	46	39	47	56	54	56	47	100.00

1 - OVERALL - EFFECTIVE

	FACTOR	WT	2A	I	C	IC	IS	S	ISC	SC	CUMWT
1)	PERFORMANC	(30)	2	17	31	46	68	65	94	79	15.00
2)	SECURITY	(25)	17	13	100	100	2	0	90	92	12.50
3)	SURVIVABIL	(15)	21	71	39	85	66	20	85	19	7.50
4)	RESPONSIVE	(30)	0	42	7	50	96	51	100	56	15.00
	TOTAL		8	32	42	66	60	38	93	66	50.00

Figure 2-7a

WWDSA EVALUATION SCORES - SECOND SESSION

2 IMPLEMENTA- CURRENT CUMWT: 50.00

CUMWT	2A	I	C	IC	IS	S	ISC	SC
.0	8	32	42	66	60	38	93*	66
10.0	15	35	42	63	59	41	86*	62
20.0	23	38	41	59	58	44	78*	58
30.0	30	41	40	55	58	47	71*	55
40.0	37	43	40	51	57	50	64*	51
50.0	45	46	39	47	56*	54	56	47
60.0	52	49	38	43	56	57*	49	43
70.0	59	52	38	39	55	60*	41	39
80.0	66*	55	37	35	54	63	34	35
90.0	74*	58	36	32	53	66	26	31
100.0	81*	61	36	28	53	69	19	27

Figure 2-7b

WWDSA SENSITIVITY ANALYSIS - SECOND SESSION

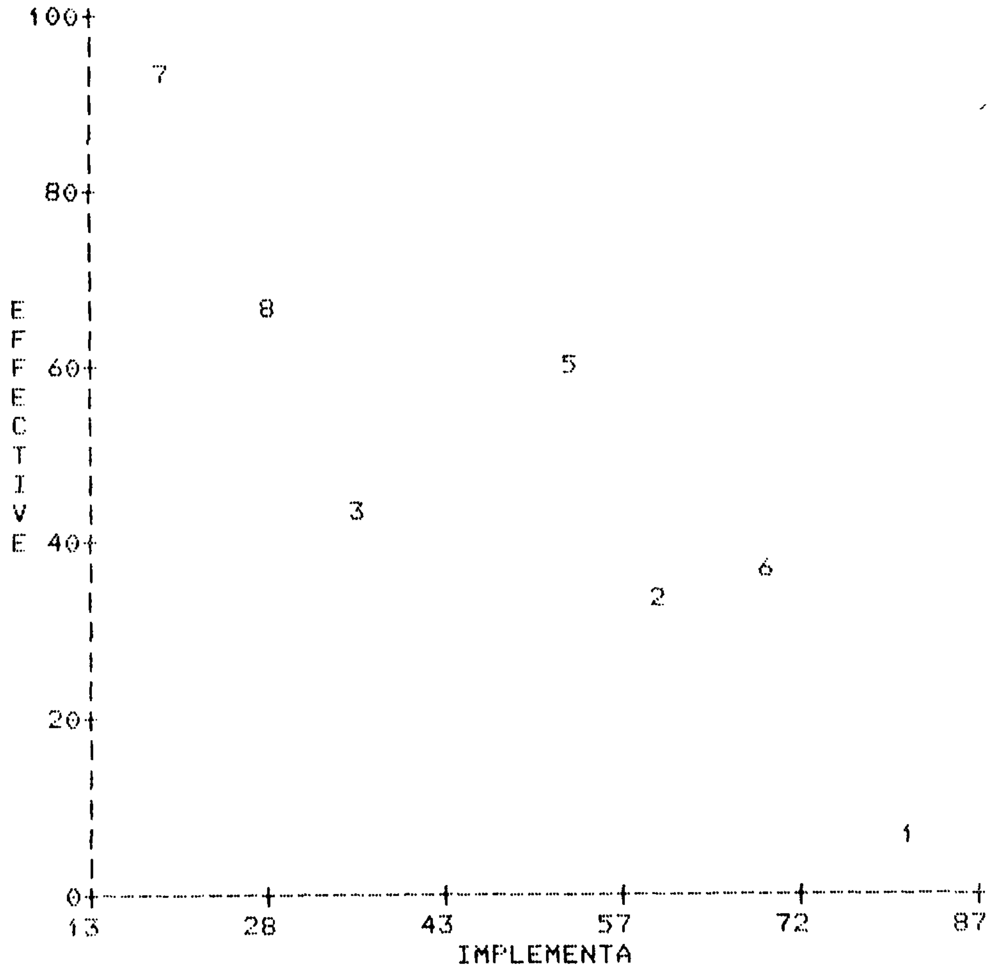


Figure 2-7c
WWDSA SENSITIVITY PLOT - SECOND SESSION

2.8 Sea-Based Air Study Tutorial (Workshop 11)

This tutorial, on 7 November, consisted of a survey of models that were constructed for the evaluation of sea-based air alternatives:

> "Decisions and Designs, Inc. (DDI) has recently concluded an extensive decision-analytic modeling effort for the Sea-Based Air Studies Office (SBASO). Using various decision analysis techniques, DDI has helped SBASO to organize and understand the immense volume of data that has been generated by the numerous studies that SBASO has performed. DDI has sought to provide a systematic decision-analytic framework for the evaluation of sea-based air alternatives. This framework incorporates both the results of SBASO studies and the accumulated knowledge and judgment of experts in sea-based air.
>
> The decision-analytic models described below offer more flexibility in evaluation than do operations research modeling techniques. Decision-analytic models can be altered rapidly and at little expense. Changes in assumptions can quickly be incorporated. Although more conventional techniques do accommodate change, changes are sometimes quite difficult and are sure to consume considerable additional time and expense. In fact, simulation studies conducted for SBASO have consumed several years and millions of dollars, and changes in assumptions often involved months of waiting for

results. Decision analysis also allows for the inclusion of factors not typically incorporated in simulations, such as risks and cost and transition uncertainties. Factors considered too trivial and inconsequential for a simulation, such as weather interference, required resupply, and ability to stage and base from alternative platforms, are also easily included.

The most important factor underlying the choice of sea-based air alternatives is the operational effectiveness of the options being considered. The DDI/SBASO team examined this factor from two perspectives. The first perspective is embodied in the Mission Area Analysis Model (MAAM). This model compared four sea-based air alternatives:

(1) a CTOL force based on CVN's (CTOL-CVN);

(2) a V/STOL force based on CVN's (V/STOL-CVN);

(3) a V/STOL force based on a mixture of CVN's and VSS's (V/STOL-CVN/VSS); and

(4) a V/STOL force based on VSS's (V/STOL-VSS).

(The STOL, STOVL, and STOAL options were not evaluated, because preliminary decision-analytic modeling had demonstrated that these approaches were not cost effective, tended to compound the Navy's problems, and did not contribute to the Navy's objective of operational flexibility.) Each alternative was evaluated in relation to the six warfare scenarios identified by the Center for Naval Analysis (CNA). For example, the scenarios included a major war at sea in the Greenland-Iceland-United Kingdom Gap and power projection in

Korea. The MAAM results suggested that V/STOL-CVN/VSS is best in operational effectiveness, CTOL-CVN is second, V/STOL-CVN is third, and V/STOL-VSS is worst.

Although the MAAM and Operational Effectiveness Submodel (OES) do not entirely agree on the ordering of sea-based air alternatives, they are close. For instance, both suggest that V/STOL-CVN/VSS is best. In the MAAM, this represents an advantage due to placing small platforms in scenarios that do not require a large CVN. In other words, V/STOL-CVN/VSS offers flexibility in platform allocation. In the OES, the preference for V/STOL-CVN/VSS represents both flexibility and the operational advantage of V/STOL over CTOL. The MAAM and OES also agree that V/STOL-VSS is the worst option. In both cases, this reflects the vulnerability of the VSS. As for the intermediate options (CTOL-CVN and V/STOL-CVN), the two models disagree. This is due to the emphasis that the MAAM places on aircraft quantity, which favors CTOL-CVN, and the emphasis that the OES places on aircraft and platform quality, which favors V/STOL-CVN. Although this conflict between quantity and quality is not fully resolved in these models, the predominance of V/STOL-CVN/VSS in both models suggests that V/STOL is a viable option.

While operational effectiveness is the most important criterion for judging sea-based air alternatives, it is not the only one. To capture the additional factors, DDI constructed a Comprehensive Evaluation Model (CEM) that considered the following five factors:

(1) Operational Effectiveness;
(2) Transition Difficulties;

(3) Cost Factors;
(4) Risks; and
(5) Technological Impacts.

The results of the OES were used to score the first factor. The other four factors were then evaluated for each of the four sea-based air alternatives. The results of the CEM suggested that V/STOL-CVN/VSS is best, V/STOL-CVN is second, CTOL-CVN is third, and V/STOL-VSS is worst.

Although this finding parallels the OES results, it can be shown that the results are quite sensitive to the weight placed on Risk. At present, Operational Effectiveness and Risks are weighted 41% each. If the weight on Risk were increased by as little as 5% in relation to Operational Effectiveness, CTOL-CVN would become the preferred option. This underscores the importance of obtaining accurate estimates of the risks involved in the V/STOL technology.

The three models described thus far adhered to the ground rules laid down by the SBASO: All forces were equal-cost forces, and the CTOL and V/STOL designs were assumed equivalent on all performance factors not related to take-off and landing. A number of additional DDI models allowed these stipulations to be relaxed; these models are called Design models. Three such models were constructed, the most valuable of which was the V/STOL Design Model.

The V/STOL Design model asks whether V/STOL might be made less expensive without loss of performance, whether V/STOl is well designed for accomplishing a mix of missions, and whether it might be advisable to design two rather than one V/STOl aircraft. The model embodies cost and benefit assessments for aircraft performance factors (e.g., speed, crew size, and payload) as they relate to four missions: air-to-air against a bomber, air-to-air against a fighter, air-to-surface (all weather), and air-to-surface (visual). The results suggested that V/STOl could be redesigned at 10% less expense without loss of benefit, that the current proposed design favors the air-to-air against a fighter mission at the expense of other missions, and that two V/STOl designs tailored to different missions could potentially decrease the cost by 10% or more without loss of benefit. This final result is only speculative, however, because the V/STOL design model did not incorporate the increased costs of Research and Development, maintenance, or training for two designs rather than one.

In addition to the substantive models described above, DDI's effort on behalf of SBASO included an Influence Diagram Model. This model organized the factors relating to the sea-based air decision and documented each factor according to the studies that provide information about that factor. Thus, the Influence Diagram model offers an index to the sea-based air studies.

Based on the models developed by DDI, the conclusions and recommendations regarding the future of sea-based air are straightforward. V/STOL is an attractive option, especially if based on a mixture of large and small platforms. Besides the operational flexibility offered by such a mixture of platforms, V/STOL is, in its own right, a qualitatively better aircraft than

CTOL. This qualitative difference is, in many cases, sufficiently great to overcome the quantitative loss of aircraft due to V/STOL's greater cost. Also, there is some suggestion that the quantitative differences could be at least partially ameliorated by a more efficient V/STOl design.

One factor that argues against V/STOL, in favor of CTOL, and therefore demands careful attention, is the technological risk involved in the V/STOL technology. If the risks are substantially less than the current estimates, then V/STOL is clearly favored. If they are much greater, then CTOL is favored. The present estimate is at the break point for proceeding in either direction. This suggests that a more valid assessment of risk is needed. Since this can only be obtained by initiating research on technologies that are both risky and differentially risky, for V/STOL and CTOL it is recommended that such research should begin immediately.

Stated so crisply, the conclusions belie the amount of careful thought and effort that is captured in the models. With the aid of experts from the SBASO, DDI has attempted to capture all of the factors that might influence one's judgment about the choice of sea-based air alternatives. Wherever possible, the results of other studies have been incorporated. Issues have not been neglected, however, simply because data were unavailable. In these cases, the judgments of experts were taken as data, and they may be open to debate. It cannot be denied, however, that the issues being raised are relevant. The models are a strucutred representation of human judgment, a fact freely admitted, but a such they are both comprehensive and well organized.

With careful scrutiny of this decision-analytic modeling effort, factors influencing the choice of sea-based air alternatives should become apparent and the implications of the models more easily understood."

2.9 Program Objectives Memorandum (POM) Tutorial (Workshops 12 and 13)

The three members of CCTC attended a two-day tutorial at DDI on 20-21 November that addressed the resource allocation methodology used by DDI to assist the USMC with their Program Objectives Memorandum (POM). The tutorial covered the contents of a recent DDI report (then in draft):

> Kenneth P. Kuskey, Kathleen A. Waslov, and Dennis M. Buede. Decision-Analytic Support of the United States Marine Corps' POM Development: A Guide to the Methodology. Final Report PR 81-6-158. McLean, VA: Decisions and Designs, Inc., 1981.

During the first day, a DDI analyst described the general form of assistance provided to USMC, and outlined the procedures for program identification and prioritization. This included a review of examples from the 1982-1986 POM and a discussion of the USMC-DDI interaction in the process.

The second day of the session was spent discussing the underlying mathematical model that represents the problem, and the method for the model's application. A DDI analyst described the axiomatic conditions necessary for the quantification of preferences for USMC program items, and the analytical means for obtaining a cost-benefit prioritization.

The group worked problems that utilized different techniques for the assignment of numbers to items that represent preferences for the items, and discussed procedural problems that are encountered by analysts applying the techniques.

2.10 Cost Forecast Planning Tutorial (Workshop 14)

This tutorial on 25 November began by discussing a factory cost forecasting model and ended with discussions of military applications.

The cost model's purpose is to quickly estimate the resource implications of marginally changing the production levels of one or more products in a factory. The military analogy would be to estimate the resources required to accomplish changes to force structure. Figure 2-8 illustrates that the estimate made by the cost model is just one aspect of the information a decision maker would need to analyze changes in production level. It is, however, one of the more time-consuming estimates to make, normally taking two weeks at the factory for which the model was automated by DDI. With the model, estimates are made in minutes rather than weeks.

The basic elements of the model, products and cost categories, are illustrated in Figure 2-9. As shown in Figure 2-10, the model lets the user describe a proposed schedule of changes to production levels for the products. From this schedule of changes, the model computes cost estimates for factory operation which can be displayed in terms of unit product costs, cost category budgets, and annual expense by product or cost category. Figures 2-11 and 2-12 show the generic types of cost that are accounted for in the model, including fixed costs, variable costs, mixed fixed-variable costs, investment costs, and one-time start-up costs.

THE DECISION PROBLEM

MARKET OPPORTUNITIES

REVISED PRICES

DECISION
MAKERS

PRODUCTION RESOURCES

REVISED PRODUCTION PLAN

QUERIES

COMPETITION
?

? LABOR ?
?

PRODUCTION
COSTS?

FORECAST
MODEL

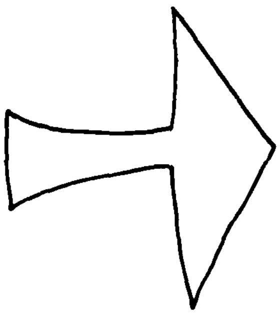
Figure 2-8

COST FORECAST - DECISION-MAKING OVERVIEW

PRODUCTS

EXISTING PRODUCTS
- PRODUCT A
- PRODUCT B
- PRODUCT C
- PRODUCT D
- PRODUCT E
- PRODUCT F
- PRODUCT G
- PRODUCT H
- PRODUCT I
- PRODUCT J

POTENTIAL PRODUCTS
- PRODUCT K
- PRODUCT L
- PRODUCT M
- PRODUCT N
- PRODUCT P



CATEGORIES

MANUFACTURING EXPENSE
PURCHASING
SHIPPING
COE ENGINEERING
LINE MAINTENANCE ENGINEERING
STRATEGIC ENGR (INCL TOOLING)
OTHER STRAT (MAJOR REARRANGE)
FINANCE
SYSTEMS
RECORDS
OPERATION STAFF
FACTORY STAFF
PERSONNEL RELATIONS
RELIABILITY STAFF
INSURANCE AND TAXES
DEPRECIATION
COMM PEOPLE COSTS: PRODUCTION
COMM PEOPLE COSTS: EXP/SALARY
TRANSPORTATION
INACTIVE AND OBSOLETE STOCK
MISCELLANEOUS OVERHEAD
DIRECT LABOR $•S(INCL LAB VAR)
DIRECT MAT•L $•S(INCL VAR)
PROD FACTORY EXPENSE $
CAPITAL EQUIPMENT
ADDITIONAL BUILDING SPACE
CHANGES TO INVENTORY LEVELS
CHAGES TO PAYABLES
CHANGES TO RECEIVABLES
PROD INTRO $ (INCL MOVE/REARR)

Figure 2-9
BASIC ELEMENTS OF THE COST FORECAST MODEL

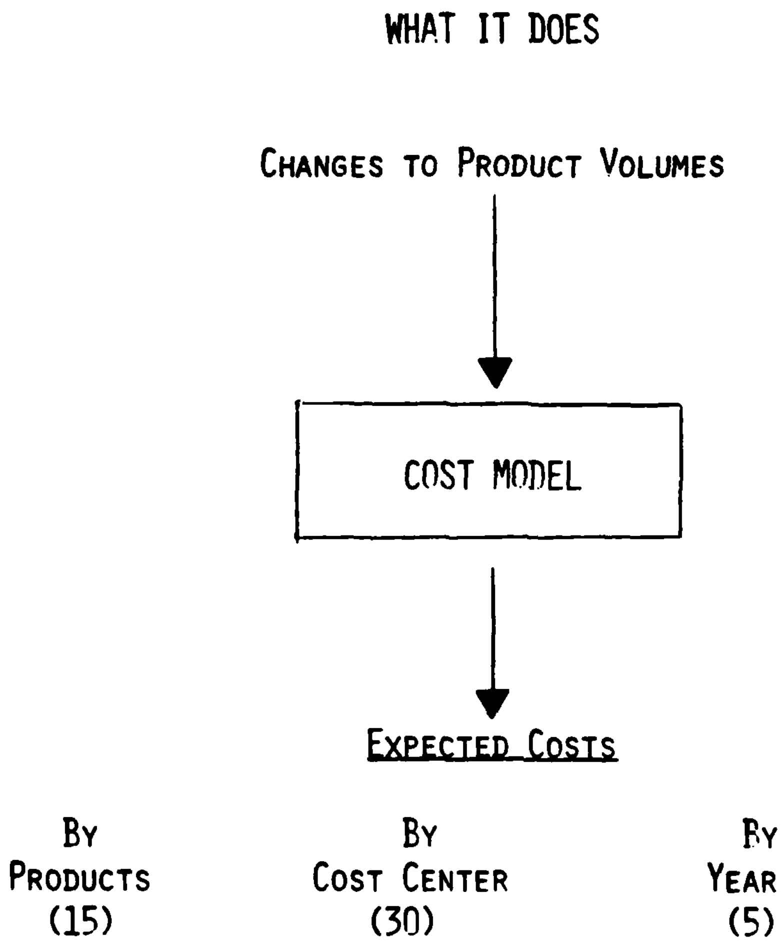


Figure 2-10

USES OF THE COST FORECAST MODEL

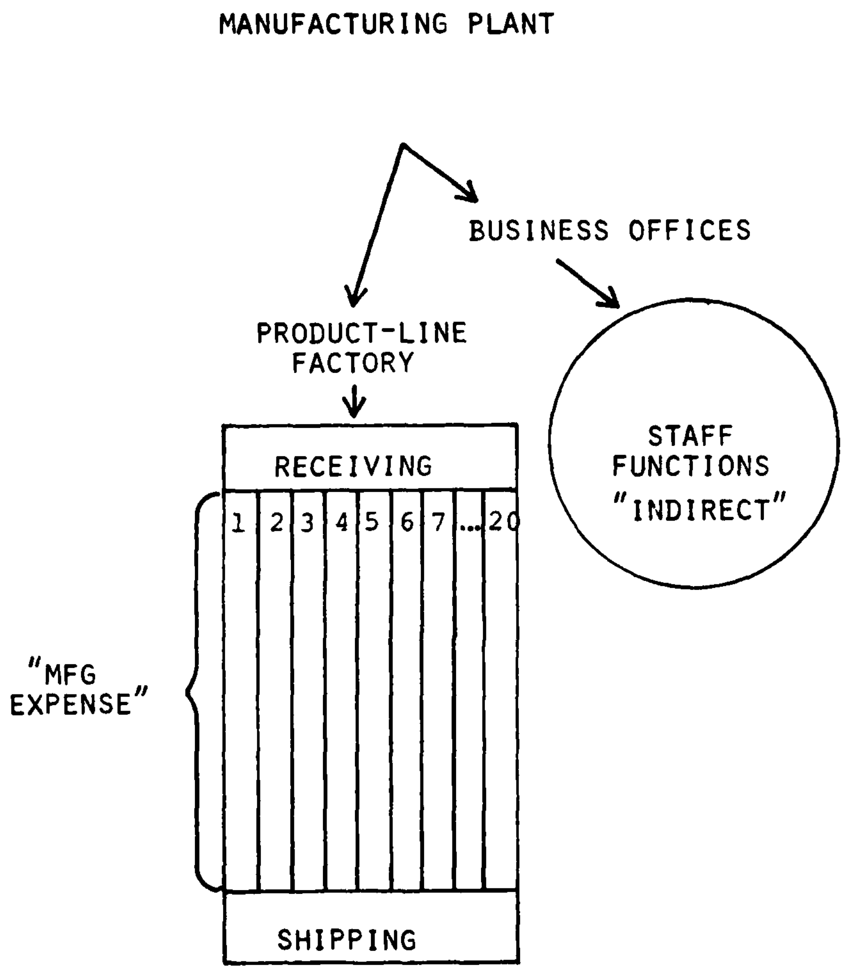


Figure 2-11

AGGREGATE COSTS INCLUDED IN COST MODEL

HOW YOU BUILD IT & MODIFY IT

STRUCTURE

- Specify Products
- Specify Production-Level Break-Points
- Specify Cost Categories
- Revise Any of Above at Any Time

NUMBERS

- Variable
  --Base cost
  --Unit-cost "adjusters"
- Mixed Ongoing
  --Split Variable and Fixed
  --Split pie across products for Variable
  --Show relative changes by product across production levels
- Mixed One-Time
  --Investment $ by product and production level
- Fixed One-Time
  --$ by product
- Escalation Rates by Cost Type
- Revise Any of the Above at Any Time

Figure 2-12
DETAILED COSTS INCLUDED IN COST MODEL

Figure 2-13 gives an idea of how the model is used; typical outputs are shown in Figures 2-14 and 2-15. Figure 2-16 summarizes the major benefits are (1) fast response to management; and (2) a nonaccounting approach to estimation, based on managerial judgments about relative costs rather than accountant estimates of absolute costs. The military example worked by the CCTC staff concerned a hypothetical restructuring of the relative sizes of the Air Force, Army, Navy, Marine Corps, and Rapid Deployment Force.

2.11 Structuring Design Models Tutorial (Workshop 15)

A tutorial was given on 26 November 1980 to present information on some of the important concerns in structuring Design models. The methodology represented by the Design software aids decision makers in the allocation of limited resources among competing programs. The major concerns in structuring a Design model involve providing a structure in which variables under consideration are independent.

The session began with a discussion of the steps in the design process: model structuring, assessment of costs and benefits, calculation of results, and sensitivity analyses. Then several sources of interaction were presented.

- Impossible levels - Variables are defined so that certain combinations are impossible.

- Cost interaction - The costs of the levels of one variable depend on the levels chosen for other variables. For example, this interaction would be present in a model containing the two variables, number of systems and system quality. The cost of

HOW YOU USE IT

--Review Model at Aggregate Level

--See Cost Ratios at Status Quo

--See Effect of New Production Mix on Total Costs, Cost Ratios, Unit Costs

--Enter Multi-Year Production Plan; See

- Year-by-year effects on cost growth by product or by broad category
- Year-by-year budgeting needs by cost center

Figure 2-13
HOW TO USE THE COST MODEL

COSTS FOR YEAR 1 :

	PRODUC LEVEL	DIRECT COST ($K)	MFG COST ($K)	INDIR COST ($K)	INTRO COST ($K)	ANNUAL INVEST ($K)	TOTAL INVEST ($K)	TOTAL COST ($K)	MFG+IND/ DIRECT (PCT)	MFG/ DIRECT (PCT)	INDIR/ MFG+DIR (PCT)	NO OF UNITS	UNIT COST ALL ($)	UNIT COST OPERATION ($)
PRODUCT A	100	2987	971	3351	0	0	0	7309	144.7	32.5	84.7	360	20303	20303
PRODUCT B	100	1419	461	1391	0	0	0	3271	130.5	32.5	74.0	360	9086	9086
PRODUCT C	100	2542	587	1923	0	0	0	5052	98.7	23.1	61.5	36000	140	140
PRODUCT D	100	569	240	1020	0	0	0	1829	221.4	42.2	126.1	840	2177	2177
PRODUCT E	100	198	125	647	0	0	0	970	389.9	63.1	208.3	840	1155	1155
PRODUCT F	100	1254	366	1376	0	0	0	2996	138.9	29.2	84.9	840	3567	3567
PRODUCT G	100	142	80	429	0	0	0	651	358.5	56.3	193.2	840	775	775
PRODUCT H	100	344	126	663	0	0	0	1133	229.4	36.6	141.1	840	1349	1349
PRODUCT I	100	291	107	514	0	0	0	912	213.4	36.8	129.1	840	1086	1086
PRODUCT J	0	0	0	0	0	0	0	0	.0	.0	.0	0	0	0
*PRODUCT X-1	0	0	0	0	0	0	0	0	.0	.0	.0	0	0	0
*PRODUCT X-2	0	0	0	0	0	0	0	0	.0	.0	.0	0	0	0
*PRODUCT X-3	0	0	0	0	0	0	0	0	.0	.0	.0	0	0	0
*PRODUCT X-4	0	0	0	0	0	0	0	0	.0	.0	.0	0	0	0
TOTAL		9746	3062	11315	0	0	0	24123	147.5	31.4	88.3	41760	578	578

COSTS FOR YEAR 2 :

	PRODUC LEVEL	DIRECT COST ($K)	MFG COST ($K)	INDIR COST ($K)	INTRO COST ($K)	ANNUAL INVEST ($K)	TOTAL INVEST ($K)	TOTAL COST ($K)	MFG+IND/ DIRECT (PCT)	MFG/ DIRECT (PCT)	INDIR/ MFG+DIR (PCT)	NO OF UNITS	UNIT COST ALL ($)	UNIT COST OPERATION ($)
PRODUCT A	85	2591	970	3149	0	0	0	6710	159.0	37.4	88.4	306	21928	21928
PRODUCT B	90	1292	489	1382	0	0	0	3163	144.8	37.8	77.6	324	9762	9762
PRODUCT C	100	2542	664	2088	0	0	0	5294	108.3	26.1	65.1	36000	147	147
PRODUCT D	90	520	252	998	0	0	0	1770	240.4	48.5	129.3	756	2341	2341
PRODUCT E	85	173	127	601	0	0	0	901	420.8	73.4	208.3	714	1262	1262
PRODUCT F	80	1038	358	1238	0	0	0	2634	153.8	34.5	88.7	672	3920	3920
PRODUCT G	75	112	75	364	0	0	0	551	392.0	67.0	194.7	630	875	875
PRODUCT H	70	254	111	535	0	0	0	900	254.3	43.7	146.6	588	1531	1531
PRODUCT I	110	316	129	585	0	0	0	1030	225.9	40.8	131.5	924	1115	1115
PRODUCT J	0	0	0	0	0	0	0	0	.0	.0	.0	0	0	0
*PRODUCT X-1	0	0	0	0	0	0	0	0	.0	.0	.0	0	0	0
*PRODUCT X-2	0	0	0	0	0	0	0	0	.0	.0	.0	0	0	0
*PRODUCT X-3	0	0	0	0	0	0	0	0	.0	.0	.0	0	0	0
*PRODUCT X-4	0	0	0	0	0	0	0	0	.0	.0	.0	0	0	0
TOTAL		8838	3175	10940	0	0	0	22953	159.7	35.9	91.1	40914	561	561

COSTS FOR YEAR 3 :

	PRODUC LEVEL	DIRECT COST ($K)	MFG COST ($K)	INDIR COST ($K)	INTRO COST ($K)	ANNUAL INVEST ($K)	TOTAL INVEST ($K)	TOTAL COST ($K)	MFG+IND/ DIRECT (PCT)	MFG/ DIRECT (PCT)	INDIR/ MFG+DIR (PCT)	NO OF UNITS	UNIT COST ALL ($)	UNIT COST OPERATION ($)
PRODUCT A	125	3633	1102	3518	0	0	0	8253	127.2	30.3	74.3	450	18340	18340
PRODUCT B	120	1667	497	1391	0	0	0	3555	113.3	29.8	64.3	432	8229	8229
PRODUCT C	115	2876	615	1830	0	0	0	5321	85.0	21.4	52.4	41400	129	129
PRODUCT D	110	618	251	991	0	0	0	1860	201.0	40.6	114.0	924	2013	2013
PRODUCT E	105	206	126	618	0	0	0	950	361.2	61.2	186.1	882	1077	1077
PRODUCT F	135	1628	435	1543	0	0	0	3606	121.5	26.7	74.8	1134	3180	3180
PRODUCT G	160	214	106	575	0	0	0	895	318.2	49.5	179.7	1344	666	666
PRODUCT H	145	475	159	810	0	0	0	1444	204.0	33.5	127.8	1218	1186	1186
PRODUCT I	167	452	146	704	0	0	0	1302	188.1	32.3	117.7	1403	928	928
PRODUCT J	0	0	0	0	0	0	0	0	.0	.0	.0	0	0	0
*PRODUCT X-1	0	0	0	0	0	0	0	0	.0	.0	.0	0	0	0
*PRODUCT X-2	0	0	0	0	0	0	0	0	.0	.0	.0	0	0	0
*PRODUCT X-3	0	0	0	0	0	0	0	0	.0	.0	.0	0	0	0
*PRODUCT X-4	0	0	0	0	0	0	0	0	.0	.0	.0	0	0	0
TOTAL		11768	3436	11981	0	0	0	27185	131.0	29.2	78.8	49187	553	553

Figure 2-14

OUTPUTS OF THE COST MODEL

COSTS FOR PRODUCT A :

	PRODUC LEVEL	DIRECT COST ($K)	MFG COST ($K)	INDIR COST ($K)	INTRO COST ($K)	ANNUAL INVEST ($K)	TOTAL INVEST ($K)	TOTAL COST ($K)	MFG+INDIR/ DIRECT (PCT)	MFG/ DIRECT (PCT)	INDIR/ MFG+DIR (PCT)	NO OF UNITS	UNIT COST ALL ($)	UNIT COST OPERATION ($)
YEAR 1	100	2987	971	3351	0	0	0	7309	144.7	32.5	84.7	360	20303	20303
YEAR 2	85	2591	970	3149	0	0	0	6710	159.0	37.4	88.4	306	21920	21920
YEAR 3	125	3633	1102	3518	0	0	0	8253	127.2	30.3	74.3	450	18340	18340
TOTAL		9211	3043	10018	0	0	0	22272	144.7	32.5	84.7	1116	19957	19957

MANUFACTURING COSTS :

	YEAR 1 ($K)	YEAR 2 ($K)	YEAR 3 ($K)
PRODUCT A	971	970	1102
PRODUCT B	461	489	497
PRODUCT C	587	664	615
PRODUCT D	240	252	251
PRODUCT E	125	127	126
PRODUCT F	366	358	435
PRODUCT G	80	75	106
PRODUCT H	126	111	159
PRODUCT I	107	129	146
PRODUCT J	0	0	0
*PRODUCT X-1	0	0	0
*PRODUCT X-2	0	0	0
*PRODUCT X-3	0	0	0
*PRODUCT X-4	0	0	0
TOTAL	3062	3175	3436

COSTS FOR SHIPPING SUMMED OVER ALL PRODUCTS :

YEAR	COST ($)
YEAR 1	672
YEAR 2	651
YEAR 3	683

COSTS FOR COE ENGINEERING SUMMED OVER ALL PRODUCTS :

YEAR	COST ($)
YEAR 1	1058
YEAR 2	1050
YEAR 3	1070

Figure 2-15

OUTPUTS OF THE COST MODEL (Continued)

- INSTANT RESPONSE TO MANAGEMENT

- "SPLITS THE PIE" RATHER THAN "COUNTS THE BEANS"

- DEPENDS ON MANAGERIAL JUDGMENT, NOT ACCOUNTING RECORDS

Figure 2-16
BENEFITS OF THE COST MODEL

a greater number of systems depends on whether they are high quality or low quality.

- o Benefit interaction - The benefits of the levels of one variable depend on the levels chosen for other variables.

- o Systematic interaction - A design variable interacts with other variables such that the structure of the decision problem depends on the level of that variable.

When interactions are minor, they may often be ignored without significant impact on the results of the model. More serious interactions require modification in the structure. Four corrective measures were presented.

- o Combining variables - Interacting variables can often be combined into a single variable. This method works well when the interaction is between two variables only.

- o Redefining variables - For more serious interactions, it is often possible to redefine the variables so that the interaction is reduced.

- o Combine several analyses - For systematic interactions, it may be helpful to perform several analyses conditional on the level of the offending variable. These analyses may later be combined to obtain an overall result.

- o Model interactions - When there is sufficient time, it may be useful to develop a model which incorporates the interactions into the calculations of the model. The interaction between quantity and quality is an interaction which may be addressed by this method.

Examples describing each of these methods were presented.

2.12 Probability Assessment Tutorial (Workshop 16)

The tutorial on Probability Assessment covered the following outline of topics on 3 December:

I. Philosophies of Probability

- A. Bayesian/Subjective/Personalistic
- B. Frequency Approach--Von Mises
- C. Objectivistic--Fisher, Neyman-Pearson

II. Axioms of Probability

III. Algebra of Events

IV. Topics in Probability

- A. Theorems
- B. Clairvoyant's Test
- C. Conditional Probability
- D. Independence
- E. Chain Rule and Expansion
- F. Bayes' Rule
- G. Probability Trees

V. Assessing Probabilities

A. Heuristics and Biases

   1. Representativeness
   2. Availability
   3. Adjustment and Anchoring

B. Assessment Procedures

   1. Measure of Uncertainty

      a. Probability
      b. Odds
      c. Log odds

   2. Response

      a. Value
      b. Fractile

C. Proper Scoring Rules

D. General Interview Process

2.13 Aiding Tactical Intelligence Analysis Tutorial (Workshops 17 and 18)

The work on tactical intelligence analysis that DDI is performing for the Army Research Institute (ARI) was presented in a two-day session (4-5 December). The session focused on two different decision aids being developed to help tactical intelligence analysts determine the most likely enemy courses of action in a particular situation. The different decision aids incorporate slightly different normative approaches to decision making. Session participants analyzed a tactical intelligence problem using the different aids; this enabled them to evaluate the applicability of such aids (and approaches) to their working environment.

On the first day, session participants used a multi-attribute utility assessment (MAUA) aid called ENCOA (Enemy Courses of Action) to evaluate four potential enemy avenues of approach represented in a tactical intelligence scenario. To accomplish this, the following four procedural steps were implemented.

First, each participant studied the scenario and then briefed the others on what avenue of approach he considered best for the enemy and why. Although the participants had similar views, they did arrive at different conclusions about the most likely avenue of approach.

Second, each participant scored each approach on the twenty-four factors in ENCOA and weighted the relative importance of the factors to obtain an overall score for each avenue of approach. The overall scores obtained with ENCOA generally agreed with those conclusions obtained in Step #1; again, the participants arrived at different conclusions about the most likely avenue for the main enemy attack. These results indicate that ENCOA was accurately reflecting the position of each participant.

Third, each participant predicted the scores and weights assigned by his counterpart prior to seeing the ENCOA results. These predictions were much poorer than anticipated based on the length of the participants' discussion. For example, one participant predicted that his counterpart would not even consider "Disposition" when scoring the four enemy approaches; in fact, his counterpart considered this to be the most important factor. The participants discussed the possible reasons for this breakdown in communication at considerable length. Both agreed that using a MAUA data sheet with clear definitions of the factors would greatly facilitate communication in many of the problems they are tasked to analyze within their working environment.

Fourth, each participant estimated the relative likelihood of each avenue of approach on the basis of each of the five categories of factors in ENCOA. All estimates were in the form of odds estimates; the first avenue of approach was compared to each of the other three. This permitted one to evaluate the correspondence between the overall utility scores resulting from ENCOA and the overall probability scores resulting from asking the same questions, but using a different rating scale. If ENCOA is reflecting the true position of each participant, there should be a good correspondence between the overall utility and probability scores. This was indeed found to be the case.

On the second day, session participants used a Bayesian decision aid to evaluate the likelihood of the same four courses of action, but not on the basis of new information. Procedurally, each of the three participants sequentially received ten messages describing enemy activity. After receiving each message, the participants individually estimated the likelihood ratios and posterior odds for approach #1 versus each of the other three approaches. This permitted one to evaluate (a) the similarity in the participants' judgments and (b) the correspondence between the participants' posterior odds after each message with those prescribed by Bayes' Theorem, assuming conditionally independent data.

In general, the participants' likelihood ratios and posterior odds were quite similar. All participants thought one course of action was clearly most likely on the basis of the ten messages, although there was some disagreement on the relative likelihood of two of the other three enemy approaches. Furthermore, the posterior odds for each participant were less extreme than those prescribed by Bayes' Theorem. This "conservatism" finding replicates that obtained in previous research. One finding not demonstrated in the literature, however, is that participants' behavior may not be conservative even if their judgments are. Two of the three participants indicated that they would notifiy the friendly commander than an enemy attack was imminent after the sixth message even though that at that time, neither their posterior odds nor Bayes' Theorem suggested such extreme action.

Both the Defense Communications Agency (DCA) and the DDI analysts learned a great deal during the second day. This was the first time that the DCA participants had been given an opportunity to address a problem using a Bayesian decision aid. They thought it unlikely that such an aid would be used frequently in their working environment. This was also the first time that the DDI analysts had pilot-tested the Bayesian aid being developed for ARI to help tactical intelligence analysts revise their opinions on the basis of incoming data. Interaction with the DCA participants indicated that they (1) felt it would have been easier and more meaningful working with probabilities rather than odds; (2) had considerable difficulty maintaining the operational distinction between likelihood ratios and posterior odds and between conditional independent and dependent data; and (3) would be averse to relying on the posterior odds prescribed by Bayes Theorem because they differed so much from their own estimates, and it was not at all clear to them that the Bayesian odds were "better" in some qualitative sense. Such information should prove valuable during the development of a Bayesian aid for tactical intelligence analysis.

2.14 Third WWDSA Evaluation (Workshops 19 and 20)

The analysis at the third WWDSA decision conference at DDI (8 and 9 December) was an evaluation of eight architectural system designs which represented refinements of former design variations. Again, the baseline system, Option A, could be made more effective with additional features that are incorporated in Options B through H. However, the costs of Implementation for the enhanced systems are higher, thus they score lower in the analysis with respect to Implementation criteria.

The alternatives received scores for each criterion in the hierarchy that was established at the first DCEC conference, and the criteria were weighted. Figure 2-17a shows how the overall scores of the alternatives vary as the weight of Implementation changes. When its weight is low and the Effectiveness criteria are considered to be the best discriminators for the options, then Options G and H dominate. But as the costs of Implementation enter the evaluation as significant discriminating factors, Options G and H become less attractive because they are expensive and risky designs.

Figure 2-17b plots Effectiveness versus Implementation and demonstrates that all eight options are approximately equally cost-effective, i.e., spending more Implementation dollars on an enhanced design will return a proportionate amount of Effectiveness.

2 IMPLEMENTA- CURRENT CUMWT: 50.00

CUMWT	A	B	C	D	E	F	G	H
.0	3	21	37	46	73	63	90*	79
10.0	12	27	40	46	68	61	83*	74
20.0	22	33	44	47	64	59	76*	69
30.0	31	40	47	47	60	56	68*	64
40.0	40	46	51	48	55	54	61*	59
50.0	49	52	54*	49	51	52	54	54
60.0	58	58*	57	49	46	49	47	48
70.0	68*	65	61	50	42	47	39	43
80.0	77*	71	64	50	38	45	32	38
90.0	86*	77	68	51	33	43	25	33
100.0	95*	84	71	52	29	40	17	28

Figure 2-17a

WWDSA SENSITIVITY ANALYSIS - THIRD SESSION

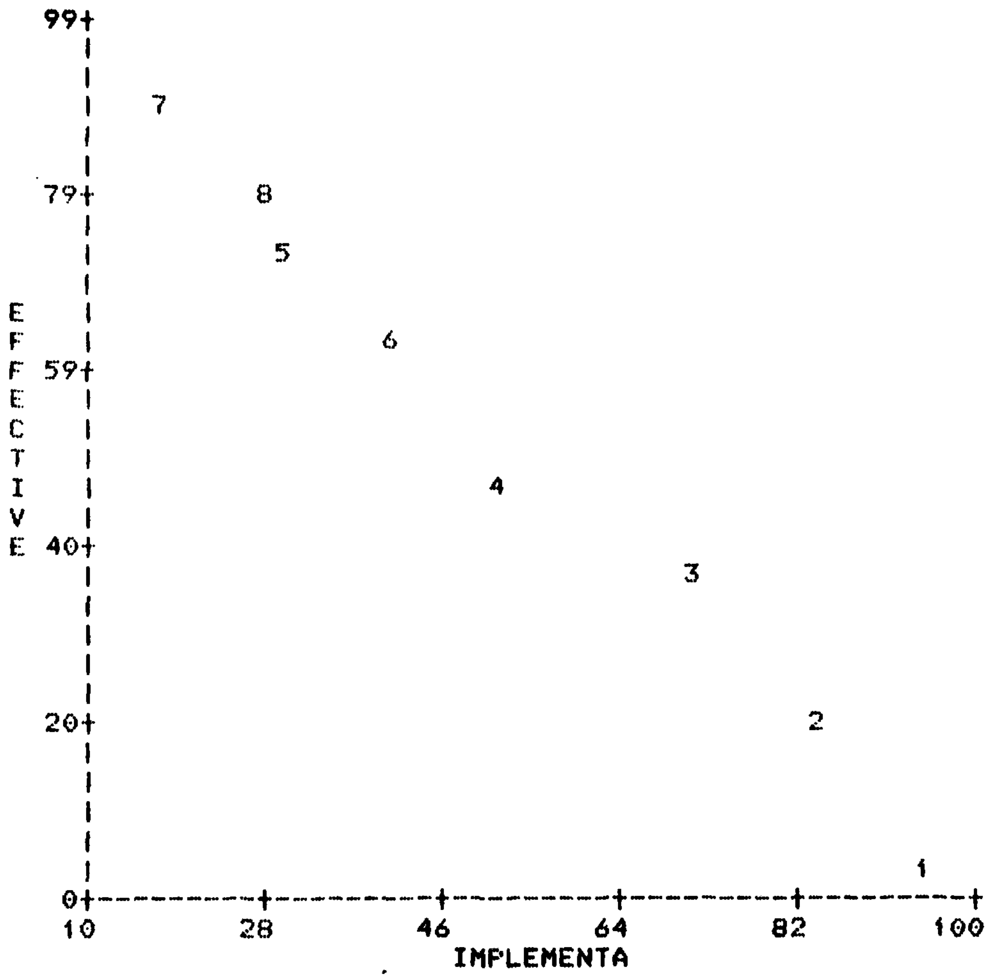


Figure 2-17b

WWDSA SENSITIVITY PLOT - THIRD SESSION

2.15 Utility Assessment Tutorial (Workshop 21)

On 11 December, a tutorial attended by three DCEC analysts addressed the following two subjects:

- Assessing Soft Variables - The Lawrence Livermore Laboratory/Nuclear Regulatory Commission (LLL/NRC) study on public values concerning the health hazards of nuclear waste was reviewed. Techniques for assessing "soft" or controversial variables such as life, death, and illness were examined in detail.

- Influence Modeling - This topic addressed how to formulate a problem and structure it initially in order to select an appropriate analytical approach. The problem addressed was developing a system for prioritizing military targets. After specifying the outcome dimensions of principal value, we listed some of the conditioning variables and roughed out the form that a working model might take. The participants' response was quite positive.

2.16 Cascaded Inference and Opinion Revision Tutorial (Workshop 22)

On 30 December, a tutorial was held on hierarchical/ cascaded inference. This tutorial included:

I. Mathematical Underpinnings
   A. Extension of Bayes' Rule
   B. The likelihood principle

II. Results from Empirical Studies

A. "Lying experimenter," bookbag and poker chip tasks--excessiveness

B. Evaluation of evidence from court trials--conservatism

C. Inappropriate opinion revision of subjects given conflicting, contradictory, or redundant data

III. Applications of Hierarchical Inference Methods

A. Indications and warning
   1. Korean warning problem
   2. Soviet posture model
B. Technical intelligence

IV. Issues for Future Application

A. Multi-valued versus binary intermediate variables
B. User responsiveness
C. Training

2.17 Automated Network Targeting Aid (Workshops 23-48)

During January-April 1981, a series of twenty-six meetings was held to develop design concepts for a new military targeting aid. The dates of the 26 meetings were: 4, 10, 11, 19, 25, and 26 February; 3, 4, 6, 12, 13, 17, 18, 19, 20, 24, 27, and 31 March; 2, 7, 8, 10, 14, 16, 20, and 21 April. The need for a new aid arose from urgent problems faced by the target coordination staff of the Rapid Deployment Joint Task Force (RDF). The RDF's target coordinator was the primary "user" conferring with CCTC and DDI in the meetings.

The decision problem faced by the RDF is to nominate targets to maximally delay a larger enemy's advance while it projects itself into operation. The targets are bridges, tunnels, and so forth, along a lines of communication (LOC) network.

The decision-analytic approach taken by DDI was to model the network mathematically as a graph and then devise operations research methods for maximizing the length (duration) of the minimum path between the enemy and his objectives. Both the graph structure and data were built to represent an expert target officer's judgments about targeting rather than a scientist's description of the problem. The model is then an aid that will help the target officer keep track of his judgments and integrate them to plan targets. It is not a scientific model, but a judgment model.

During the meetings, new branch and bound algorithms were developed for maximizing the minimum path through a network by selectively damaging targets. Based upon these algorithms, a concept for an automated network targeting aid was developed. The product of the meetings was a working report (Advanced Network-Targeting Aid: System Design Concepts. McLean, Virginia: Decisions and Designs, Inc., April 1981) that provides design concepts for a state-of-the-art targeting aid incorporating video disc technology. These concepts form a basis for additional research and for definition of functional requirements.

DATE
ILME