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1

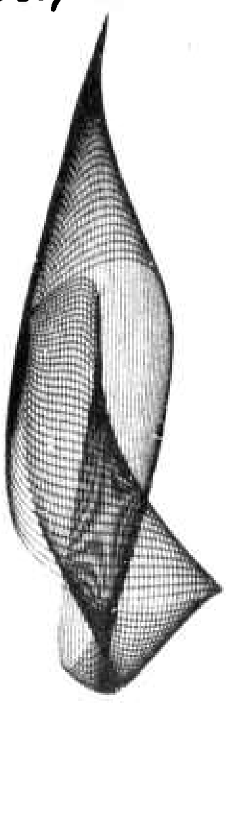
FINAL TECHNICAL REPORT

THE FEASIBILITY OF QUANTITATIVELY ANALYZING INVESTMENTS IN LOSS PREVENTION ACTIVITIES

By
M. J. Miller, L. M. Krasner and S. A. Wiener

Prepared For:
The Naval Facilities Engineering Command
Washington, D. C.

July 1971



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13 ABSTRACT

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2) Fire protection competes directly with operations activities for funding.

The methodology developed does not ask for more fire protection money. It does, however, provide a mechanism for optimal spending of the money available. The application of such a system, over the long term, could demonstrate that "Fire Protection" can keep its own house in order and is worthy of dominant interest funding. In addition, it would provide a funding rationale (self-defense) to explain why some sites incurring fire loss were purposely not funded or funded only to a limited level of protection.

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J. B. Smith, Vice President

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The intent of this study effort was to determine the feasibility of designing a fire risk management system. The available information was determined to be far less than optimal but adequate to formulate a first generation methodology of fire risk management. The existing boundary conditions were defined to be:

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FOREWORD

The enthusiastic support and cooperation of Messrs. S. M. Hurley, NavFac R&D; H. Anderson, NavFac Fire Protection; L. Duhrkoop and R. Darwin, NavMat; C. Burtner, NavShips; and D. Skar, E. Poole, J. Barnes of NavFac, Washington; as well as D. Wells of NCEL, and others at various levels of Navy Management from base level to the office of the ASN is gratefully acknowledged. The persons involved made the task of research and analysis personally enjoyable as well as technically satisfying.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

I

INTRODUCTION AND SUMMARY

The need for systematic analysis of investments in Fire Protection has been recognized by Navy Management. At the request of the Commander, Naval Facilities Engineering Command, a program was undertaken to develop a methodology for analyzing and optimizing these investments. The dual objectives of this program are the optimization of risk management activities and the establishment of funding priorities.

The emphasis is on the development of a method to assign limited fire protection funds to the most worthy fire protection recommendations. The approach is to construct a decision tree starting with the basic elements of the decision process. After discussions of the relative importance of each item with NavFac, NavMat, NavShips, and SecNav personnel, the following order of consideration was chosen.

Strategic Importance → Probable Life Loss → Probable $ Loss → Frequency Severity

Rules were then developed to assign rating values at each level of consideration. Various combinations of statistical data and subjective estimates are used in the present analytical system to make these assignments.

Items presently included in the analysis are outlined in Table I.

The values obtained from the analysis of each protection recommendation determine the path taken in the decision tree. This then provides the go - no go sort to determine which recommendations are to be considered for funding.

The format of the decision tree is shown in Figure I.

A finer sort of projects reaching yes in the decision tree is then made by incorporating consideration of both the costs and benefits of the project. The method presently recommended is to sum $(S^2 + L^3 + 2D^2 + 10P)$ for initially ranking projects which reach "Yes" and then calculate $(\text{Points} - 2D^2 - 50)^2 10^{-6}$ (Probable loss/project cost) to give a benefit/cost ratio.

The preceding system represents a feasible methodology for analyzing and optimizing fire protection investments. This system could be implemented in its present form as verified by three case studies. It is recommended, however, that the relative merits of refining the system with the use of more inclusive and sophisticated data be evaluated. This data currently does not exist and would cost in the neighborhood of $100,000 to $200,000 to obtain. The differential labor cost of applying the system, whether the present one or a refined one, cannot be determined without reliable comparative data.

The logical direction in which to continue this program is to evaluate the ease and cost of system application in conjunction with determining the extent to which methodology refinement via additional data is justified. A study program of this nature would cost $50,000 to $75,000.

Use of this type of methodology, by the Navy, should produce a number of benefits. Improved management techniques should result in smooth uniform decision-making for which a logic system defense exists. Optimization of funding should result in greatly reduced risk of serious large loss (strategic plus human plus dollar). Although it is possible that overall losses can be reduced, the real objective is a more quantitative understanding of the risks being assumed by the Navy. It is also possible that paperwork cost savings in the result due to the weeding out of unworthy fire protection recommendations during the go-no go sort. The determination of the cost of savings in the paperwork area would depend greatly on how and at what level(s) the Navy decide to implement the methodology as well as he results of the suggested comparative testing program.

In addition, it should at least be recognized, as far as overall Navy cost savings are concerned, that this basic approach with relatively minor

TABLE I

Strategic Importance (S) - Rating 0-10

1) Importance of supplies or facilities 0-4

2) Relative quantity 0-3

3) Ability to replace 0-3

Probable Life Loss (L) - Rating 1-5

1) Number exposed 1-5

2) Adjustment based on degree of protection

Probable Dollar Loss (D) - Rating 1-5

1) Potential Loss 1-5

2) Adjustment based on protection

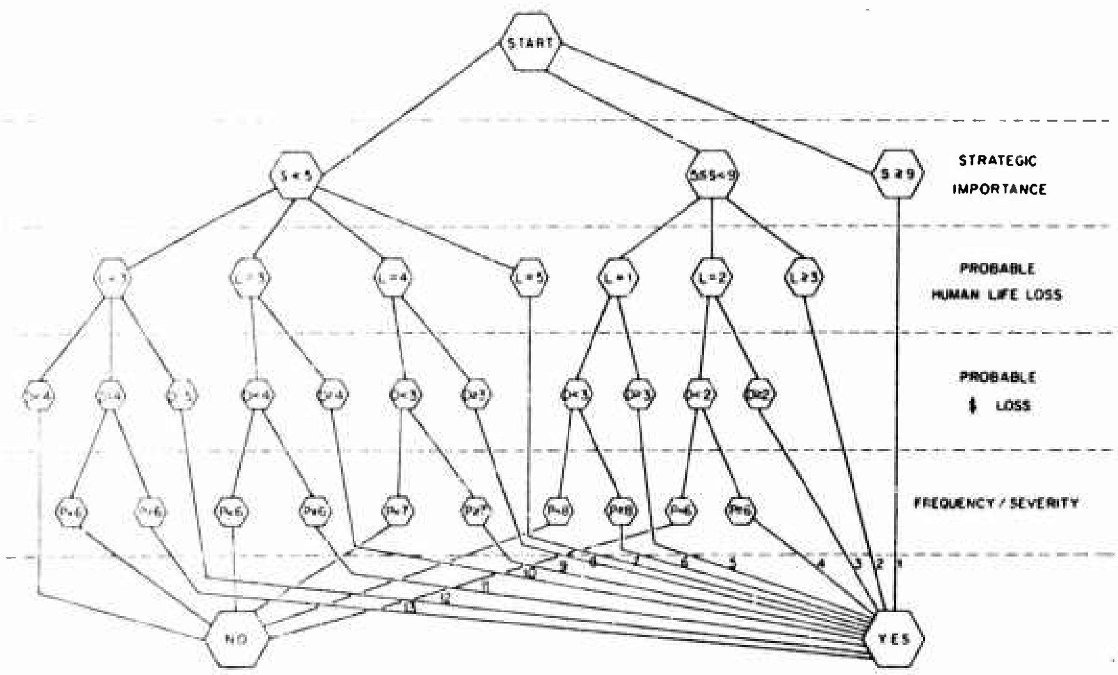
Relative Frequency/Severity of Fires (P) - Rating 3-9

1) Use Class 1-3

2) Construction 1-3

3) Fire Loading 1-3

FIGURE 1 - DECISION TREE FORMAT



change is applicable not only to fire protection but to protection against other perils and management of other pure risks as well, including windstorm, flood, riot and sabotage.

The following recommendations are made for future work:

1) Conduct extensive testing of the methodology on outstanding recommendations to evaluate ease of application, application time and implementation costs.

2) Determine to what extent added data accumulation for methodology refinement is justified.

3) Refine the methodology if testing proves advisable.

4) Conduct data analysis to provide rating values more specific to Navy activities.

5) Modify the fire protection survey to provide information more pertinent to the methodology.

6) Modify loss investigation techniques to provide the data required for an extended analysis.

II
SCOPE OF WORK

The objectives of this feasibility study were to:

1) Establish the availability of data and its source; determine such items as:

a) The value of building contents, including inventories, and the value of the shore facilities;

b) Information on the Navy's physical plant, its fire protection features, fire loss experience, and other factors essential to fire loss prevention.

2) Determine the adequacy of available information as a basis for a fire risk management system.

3) Determine the direct cost and feasibility of retrieving necessary information and data.

4) Develop a methodology for practical application of loss prevention to the Navy Department with cost estimates for possible Navy-wide application of the plan.

5) Prepare examples of the application of the loss prevention plan.

III
AVAILABILITY AND ADEQUACY OF DATA

Navy data is available but not in the format or quantity necessary to present an accurate cross reference of Navy real property statistics and Navy loss experience as needed for methodology input. The lack of this data, however, did not make it impossible to formulate the methodology. Where needed, industrial data was used satisfactorily, because the system deals with a relative rather than an absolute ranking. The assumption made was that relativity did not vary significantly between Navy and industrial experience. This assumption may not be entirely accurate, but it enables use of the only presently available data. If existing data were put in the proper format and if additional data were accumulated and fed into the system, the methodology would be even more pertinent to Navy operations. The sensitivity of the methodology to these changes should be determined.

For specific building types, data on numbers, ages, physical sizes and values are being generated from computerized property management files at Facilities System Office (FACSO). A simplified sample tabulation from the DOD summary is shown in Table II. A primary use of this real property data ("population" data) is to adjust or normalize loss statistics. Annual dollar losses must in due course be adjusted to compensate for the changing value of the dollar. The loss statistics must also be interpreted with full recognition of the changing size, value and nature of the shore establishment. For example, Figure 2 indicates the growth trend in buildings and personnel.

The following comments by FACSO concern the feasibility and cost of generating specific data in addition to that already requested.

1) Warehouse category data grouped by stacking height can most likely be provided at the original request cost depending on further clarification.

2) Additional detailed or summary reports of the type originally requested can be provided at costs of $200 to $400 per report. This will also cover minor programming modifications such as including construction type (permanent, semipermanent and temporary), etc.

TABLE II

A Partial NavFac Profile as of 30 June 1968*

	Total # Bldgs.	Total Area (K ft^2)	Total Acquisition Cost (K$)	Average Cost/ft^2 ($)	Average Bldg. Area (ft^2)	Average Cost/Bldg (K$)
Maint. Facil.	4,771	79,600	1,047,663	13.1	16.700	220.0
Family Housing	33,939	87,382	732,162	8.4	2,570	21.6
Troop Housing	21,222	64,230	613,926	9.6	15,200	145
Stge - Covered	9,774	133,327	574,045	4.3	13,600	58.7
R&D Facil.	2,288	18,559	517,938	27.9	8,100	226
Utilities (Elect.)	1,281	1,836	468,802	255.0	1,430	365
Training Fac.	2,415	34,337	340,943	10.0	14,200	14.5

*Ref. NavFac P-319, 1969 ed

To be updated and expanded upon receipt of additional population data

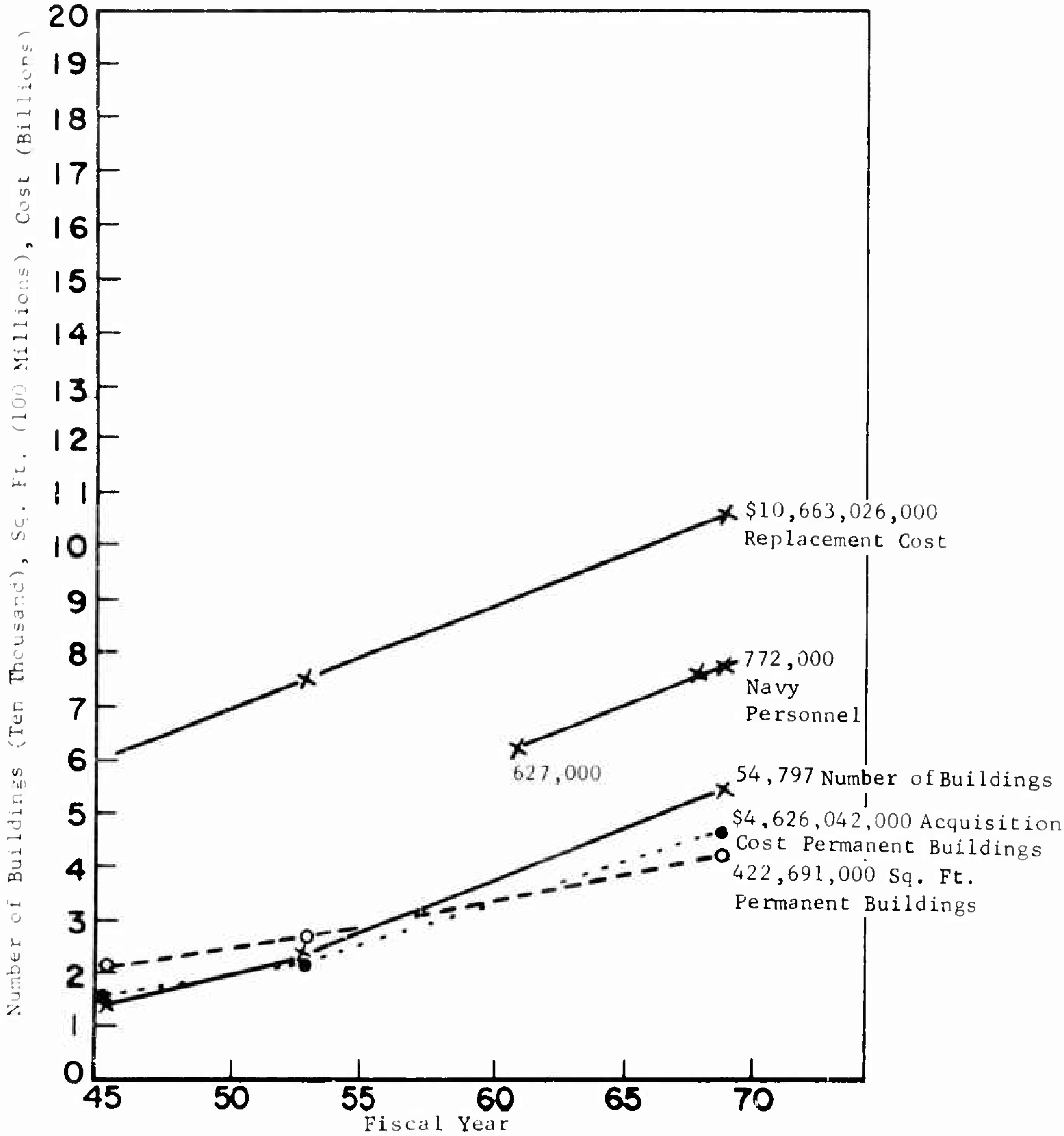


FIGURE 2 - GROWTH OF THE NAVY SHORE ESTABLISHMENT
(Permanent Buildings only, no contents)

3) Data related to other type facilities such as piers, wharves, etc., will require only minor programming changes and should also cost \$200 to \$400 per report.

4) Information regarding degree of protection requires changes to the real property inventory (RPI) code. Such changes are subject to approval of NavFac Code 07. However, a rough estimate of the cost of adding data elements to the data base would be in the neighborhood of \$80,000, including:

a) Automatic data processing changes (analysis, design and implementation - \$5,000 to \$10,000;

b) If property records are to be reprinted - paper - \$4,000, computer costs - \$8,000, bursting - \$2,000 and mailing - \$2,000;

c) Change and redistribution of Acquisition Data Forms (ADF) and NAVFAC P-78 - \$2,000 to \$10,000;

d) Field loading of new data elements - \$40,000 to \$70,000.

It should be noted that adding several data elements (within reason) would cost little more than adding one. Coordination and consolidation of system modifications would greatly reduce the cost attributed to any one additional system requirement.

5) Data covering total value of buildings and contents also require changes to the RPI code and are subject to the same comments as above.

6) Additional data such as that obtained from risk analysis and fire protection surveys could be used in parallel with the RPI data base to develop meaningful reports. To pursue this course of action initial development costs of up to \$50K should be expected prior to obtaining any meaningful results.

Since detailed "population" data has not as yet been analyzed, no attempt has been made to normalize loss data for evaluation. The use by the Navy of at lease two data coding systems presents a major obstacle. Property codes as used by FACSO in their computerized records represent a much finer sort than those used on the Fire Loss Report (NavFac Mat 11320.313, 1 January 1968) and in some cases no direct correlation may be possible.

Methodology refinement through the accumulation of more inclusive and detailed data is discussed in Section 5.2.

IV

RISK MANAGEMENT METHODOLOGY

4.1 DEVELOPMENT

Following visits to Naval bases and many Washington commands, it became evident that knowledgeable Navy personnel were generally agreed that a methodology of risk management, to be applicable, must be simple in method, straightforward in format and must include only the significant variables so as not to encumber its use.

Since the methodology deals with risk management and risk pertains to potential loss, it was first necessary to evaluate the fundamental nature of Navy loss. Loss incorporates property and people; property and people both possess strategic as well as dollar value. Further, for each environment there exists a probability of ignition and spread to the potential loss limit. These, then, are the parameters which govern differences between specific risks: potential loss (strategic, human and dollar) and their associated probabilities.

It was on this fundamental evaluation that the risk management methodology was based. The next step was to design a methodology which was both simple to apply and incorporated the governing parameters. At this point it became apparent that the lack of raw data would limit the ability to assign objective probabilities to the methodology. After careful consideration, the following system was evolved based upon relative probabilities. The system performs exactly as intended: defines a system of relative priorities in which each entry is compared with all others.

4.1.1 Strategic Importance (S)

Each project will have a rating from 0-10.

Factors to be included in the determination of a rating for strategic importance follow:

1. Importance of the particular supplies or facilities to the overall Navy mission.

   Rating 0-4

	Major weapons or cummunica- tions system tie in.	Minor weapons or communica- tions system tie in.	No weapons or communications system tie in.
Direct support	4	3	0
Indirect support	2	1	0
No support	0	0	0

2. Relative quantity of supplies or facilities involved compared to the available supplies or facilities of the same type.

Rating 0-3

Q_t is total quantity available.

Q is quantity under consideration.

Q_c is critical quantity to sustain desired level of activity and must be determined for supply or facility under consideration.

0 $(Q_t - Q) > (100+x)\% \; Q_c$

1 $(100+x)\% \; Q_c \geq (Q_t - Q) > (100+y)\% \; Q_c$

2 $(100+y)\% \; Q_c \geq (Q_t - Q) > Q_c$

3 $(Q_t - Q) \leq Q_c$

3. The ability to replace supplies and facilities, including consideration of replacement time and trained personnel.

Rating 0-3

Critical downtime (T_c) before other available supplies or facilities cannot sustain related operations must be determined.

0 Downtime $< T_c$

1 $T_c \leq$ Downtime $< (100+v)\% \; T_c$

2 $(100+V)\% \; T_c \leq$ Downtime $< (100+2v)\% \; T_c$

3 Downtime $\geq (100+2v)\% \; T_c$

Note: x, y and v represent values that must be assigned by the Navy

4.1.2 Probable Human Life Loss (L)

Each project will have a rating from 1-5.

Potential Life Loss

Rating	Description
1	Potential Loss $\leq$ 5 Lives
2	5 Lives < Potential Loss $\leq$ 25 Lives
3	25 Lives < Potential Loss $\leq$ 50 Lives
4	50 Lives < Potential Loss $\leq$ 100 Lives
5	Potential Loss > 100 Lives

Adjustment based on Protection and Personnel Safety Standards.

1. *Adequate fixed protection and meeting personnel safety standards.
2. Inadequate fixed protection but meeting personnel safety standards.
3. Personnel safety standards not met.

If 1, take 10% of potential life loss and assign points accordingly.

If 2, take 25% of potential life loss and assign points accordingly.

If 3, take 75% of potential life loss and assign points accordingly.

Minimum rating = 1

4.1.3 Probable Dollar Loss (D)

Maximum Possible \$ Loss (D_1) (with Fixed Protection Impaired)

Each project will have a rating from 1-5.

Potential Dollar Loss**

Rating	Definition
1	Potential \$ Loss $\leq$ 5 $\overline{M}$
2	5 $\overline{M}$ < Potential \$ Loss $\leq$ 20 $\overline{M}$
3	20 $\overline{M}$ < Potential \$ Loss $\leq$ 50 $\overline{M}$
4	50 $\overline{M}$ < Potential \$ Loss $\leq$ 100 $\overline{M}$
5	Potential \$ Loss > 100 $\overline{M}$

* Adequate protection is defined as meeting current Industrial Fire Protection Standards as a **minimum**.

**Demolition and cleanup costs can be included in this value if desired as long as it is done consistently.

If no fire department is available, properties in proximity to the object property must be included in the evaluation of Maximum Possible \$ Loss (D_1).

Adjustment based on protection:

1. Adequate fixed protection.
2. Below standard fixed protection.
3. No fixed protection.

If 1, take 10% of potential dollar loss and assign points accordingly.

If 2, take 40% (60% if no fire department is available) of potential dollar loss and assign points accordingly.

If 3, take 80% (100% if no fire department is available) of potential dollar loss and assign points accordingly.

4.1.4 Relative Frequency/Severity of Fires (P)

Consists of three parts

1) Occupancy
2) Construction
3) Fire Loading

Each part will have a rating of 1-3. These are to be summed. Relative Probability of Fire Occurrence will therefore range from 3 to 9.

1) Occupancy

Rating	Definition	
1	Low Frequency	$F \leq 1$ Fire/$\overline{M}ft^2$/yr
2	Medium Frequency	$1 < F \leq 3$Fires/$\overline{M}ft^2$/yr
3	High Frequency	$F > 3$Fires/$\overline{M}ft^2$/yr

Note 1: A guide sheet (4.1.5) lists explosion frequency and fire frequency ratings for principal occupancies. The higher of the two ratings will be used in the determinations of the Relative Probability of Fire Occurrence.

Note 2: If a building contains several types of occupancies, use the frequency rating of the predominating floor space.

2) Construction

Rating	Definition
1	Fire resistive
2	Plank on timber
3	Boards and joist, wood frame, nonprotected - noncombustible

3) Fire Loading

1 Light Hazard	-	Small quantities of combustibles such as metal-goods warehouses or metalworking with no cutting oils; hospitals, offices, auditoriums, schools, theaters, and barracks.
2 Moderate Hazard	-	Manufacture and/or processing of textiles, paper, hardware, and food; metalworking using cutting oils; other occupancies not classed as light or severe hazard, multiunit dwellings, offices, institutions, stores, and garages.
3 Severe Hazard	-	Concentration of combustible storage such as lumber; furniture; textile; paper or rubber products; and crated hardware, particularly when in high piles or tiered racks; congested mercantile occupancies; processing or storage of flammable liquids or hazardous chemicals.

4.1.5 OCCUPANCY RATING GUIDE

Occupancy	Fire Rating	Explosion Rating
Flammable Liquids		
Painting, spray	3	1
Painting, dip	3	2
Storage	2	3
Food		
Storage, raw stock & products	1	1
Warehouse, cold storage	2	1
Metal		
Assembly	1	1
Buffing & grinding	1	1
Core oven	2	2
Degreasing & cleaning	2	1
Die casting	2	2
Electrical test racks & room	2	1
Electrical winding	1	1
Engine testing	3	3
Forge furnace	1	2
Forging, excl. furnace	1	1
Foundry, ferrous	2	3
Foundry, nonferrous	2	3
Galvanizing	1	1
Heat-treat bath (oil quench)	3	2
Heat-treat furnace	2	3
Inspection, metal parts	2	3
Machine shop	1	1
Metal working	1	1
Plating, pickling, etching	2	2
Ship building	1	1
Storage, finished goods	1	1
Storage, metal	1	1
Storage, patterns	1	1
Welding	2	2
Nonmanufacturing		
Apartment	3	1
Club & recreation	3	1
Department store (bldg. only)	2	1
Dwelling, single family	3	2
Hospital	1	1
Library	1	1
Office	1	1
School & College	1	1
Shopping center	2	1

OCCUPANCY RATING GUIDE (continued)

Occupancy	Fire Rating	Explosion Rating
Nonmanufacturing (continued)		
Theatre, Auditorium & Musuem	2	1
Wholesale hardware	1	1
Paper		
Printing	3	1
Storage, cartons & containers	2	1
Rubber		
Foamed, storage	2	1
Vulcanizing	2	2
Service & Supervision		
Air compressor, receivers, piping	3	3
Air conditioning & ventilation systems	3	2
Automobile, parking garage	1	1
Automobile, sales & service garage	2	2
Boiler room	2	3
Cafeteria, plant (incl. kitchen)	2	1
Conveyors	2	1
Cooling towers	3	1
Drafting room	1	1
Electrical generation station (incl. hydro-steam-gas-diesel-powered)	1	1
Laboratory	3	3
Locker & washroom	2	1
Maintenance shop	1	1
Maintenance supply storage	1	1
Pump house, electric	1	1
Receiving, packing, shipping	1	1
Record storage	1	1
Refrigeration plant	2	1
Textile		
Laundry, commercial	2	1
Storage, garments	1	1
Wood		
Finished products storage	1	1
Lumber storage (incl. yard)	1	1
Woodworking	2	1

4.1.6 Ranking Systems for Projects Reaching Yes
(using Decision Tree, Figure 3)

Yes means the project will be considered for funding.

Any system must have boundary conditions and this one is no exception.

There will be limited funds available. Therefore, projects reaching YES must be ranked for priority of funding.

Following are nine sets of ranking rules by which all projects reaching Yes acquired final ranking. Also, a sample set of projects is attached along with the respective final ranking of those projects under the various sets of ranking rules.

Ranking Rules

A. Sum ($S^2+L^3+2D^2+10P$). Start with highest value. If tied, rank by highest S then L, D and P.

B. Sum ($10S+L^3+4D^2+9P$). Start with highest value. If tied, rank by highest S, then L, D and P.

C. Sum ($2S+L^2+3D+2P$). Start with highest value. If tied, rank by highest S, then L, D and P.

D. Sum ($2S+L^2+3D+3P$). Start with highest value. If tied, rank by highest S, then L, D and P.

E. Sum (S+L). Start with highest value. If tied, rank by highest D then P, S and L.

F. Sum (S+L+D+P). Rank by highest value. If tied, rank by highest S, then L, D and P.

G. Sum (S+L+D). Start with highest value. If tied, rank by highest P, then S, L and D.

H. Sum (S+L). Start with highest value. If tied, rank by highest L, then D, P and S.

I. Sum (S+L). Start with highest value. If tied, rank by highest S, then L, D and P.

It is not suggested that all the above sets of rules might be acceptable. Some are included to show the resultant effect of changes.

It is the writer's opinion that set A is the best of those presented.

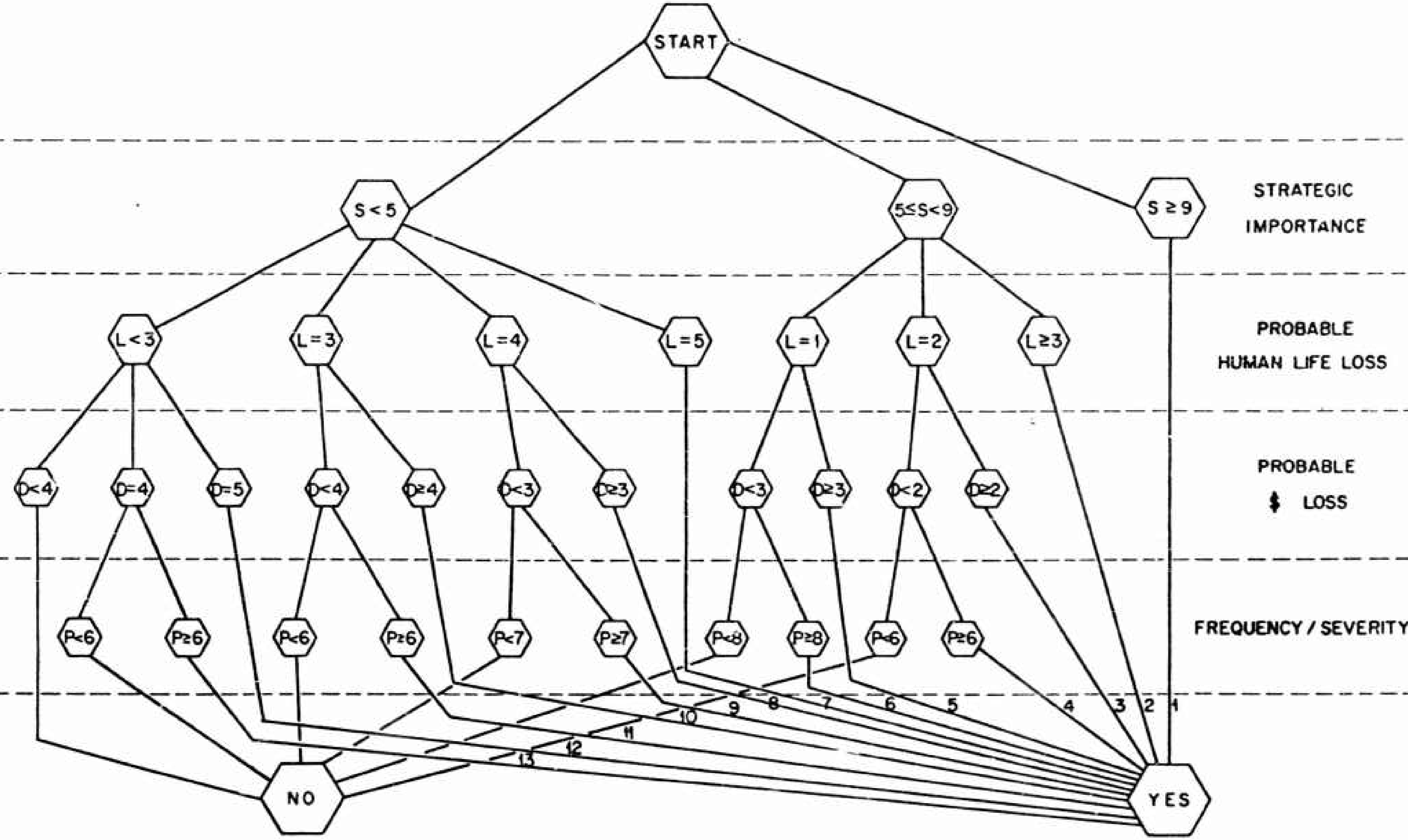


FIGURE 3 DECISION TREE

19257

Sample Project Ratings

Project Nos.	S	L	D	P
1	10	2	2	5
2	9	4	3	6
3	9	1	2	3
4	5	4	2	6
5	6	5	3	7
6	7	3	2	6
7	5	2	5	8
8	4	1	5	6
9	2	2	4	6
10	1	4	3	6
11	0	5	2	8
12	6	2	1	7
13	8	1	2	8
14	4	4	2	7
15	1	3	4	5
16	2	3	2	7
17	0	5	1	4

Final Project Ranking
(Determined by Different Sets of Ranking Rules)

Project Ranking \ Ranking Rules	A	B	C	D	E	F	G	H	I
	Project Numbers								
1	5	5	5	5	2	2	2	2	2
2	2	2	2	2	1	5	5	1	1
3	11	7	11	11	5	7	1	5	5
4	17	11	7	7	6	1	7	6	3
5	1	8	4	14	3	13	6	3	6
6	7	4	14	4	13	6	3	4	13
7	14	14	6	13	4	4	13	13	4
8	4	*1	*1	6	14	14	4	14	12
9	13	13	13	*1	12	12	8	12	14
10	6	6	10	10	*7	8	14	*7	*7
11	10	*17	8	8	8	3	12	*11	8
12	8	10	*17	12	10	*11	9	*17	16
13	3	7	12	16	*11	16	10	10	10
14	12	15	16	*17	16	9	15	16	*11
15	15	12	9	9	*17	10	*11	8	*17
16	16	3	3	15	9	15	16	15	9
17	9	16	10	3	15	*17	*17	9	15

* Possible misplaced rank under governing system

4.1.7 Application of Cost-Benefit Factor to Ranking Scheme

The cost of doing a project should be considered in deciding which projects receive priority for funding. Ideally, some method is required for relating the cost of the project to the improvement in protection that the project delivers to that facility, and to the relative importance of that facility. Assuming that the relative improvement in protection is equal we can develop various mechanisms using cost, point value, and dollar value to alter the final rankings of projects from that given by the original ranking formula (rule A here). The assumption may not be valid realistically but it is useful in allowing the presentation of examples.

From tables of random numbers dollar amounts were obtained to provide project cost (with the range $20K to $350K) and probable dollar loss (within the range $250K to $60M) figures for the point totals given for seventeen projects by ranking rule A.

Project Name	Pts.	Probable $ Loss(000)	Cost (000)
a	249	15,828	335
b	223	8,907	173
c	213	1,067	131
d	167	17,033	44
e	166	660	157
f	163	50,156	331
g	158	26,546	258
h	157	579	51
i	153	9,521	64
j	144	5,936	74
k	143	6,032	91
l	127	3,899	52
m	120	3,368	148
n	116	1,408	79
o	110	5,082	190
p	109	487	24
q	104	28,393	107

Various mechanisms were applied to each project's point value. Two of the mechanisms found more agreeable to our own judgments are (1) $(\text{points}-50)^2 \div \text{cost}$, (2) $(\text{points}-2D^2-50)^2(10^{-6})\left[\frac{\text{probable \$ loss}}{\text{cost}}\right]$. Cost and probable dollar loss are given in thousands. The results are as follows:

$(\text{Points}-50)^2 \div \text{Cost}$		$(\text{Points}-2D^2-50)^2(10^{-6})\left[\frac{\text{Probable \$ Loss}}{\text{Cost}}\right]$	
d	311.1	d	4.599
h	224.5	a	1.724
c	202.8	b	1.402
b	173.0	i	1.343
i	165.8	f	0.994
p	145.0	g	0.833
j	119.4	j	0.593
a	118.2	k	0.479
l	114.0	l	0.422
k	95.0	q	0.344
e	85.7	c	0.211
n	55.1	h	0.125
g	45.2	m	0.105
f	38.5	n	0.073
m	33.1	o	0.072
q	27.3	p	0.066
o	18.9	e	0.055

Deciding which mechanisms are "more agreeable" is subjective to a great extent. The two examples so judged were developed in an evolutionary manner. The first mechanism tried, points ÷ cost, gave so much impact to the cost factor that it was felt to flood the point factor. It could give relatively low point projects unrealistic priority when the cost of the project was low. In our random projects the lowest costing six placed one thru six by lowest cost although several had very low point rankings. The highest costing projects found their way to very low priority rankings despite the fact that three of the lowest four had high point ranking (first, sixth and seventh).

To reduce the impact of cost alone and to give more weight to point values two approaches were used. One was to weight high point valued projects more than low valued projects by squaring point value. Another was to bring the probable dollar loss of the facility into the mechanism as a ratio with cost of project and remove it as a factor in determining the point value. This gives a partial ranking rule A, points = S^2+L^3+10P which must be used in conjunction with probable dollar loss and cost figures. The ratio of probable \$ loss to cost recognizes that a larger, more valuable facility costs more to protect and doesn't handicap a high cost project in a high value facility as using cost alone would. However, it does give advantage to high probable dollar loss facilities with lower cost projects. This is as it should be given a reasonably high point ranking for the project originaly.

Our aim was to develop a sample mechanism that would preserve the basic ranking philosophy (i.e., maintain points as the major factor and allow cost or cost and value to influence the final ordering rather than to dominate it entirely). The two mechanisms for which results are given do this. One uses cost alone. The other uses a probable dollar loss to cost ratio. Dividing the seventeen sample projects by point ranking into top six, middle six and bottom five, $(\text{point}-50)^2 \div \text{cost}$ leaves nine projects within their original divisions. Of eight crossing divisonal lines, four shift down an average of 6 3/4 places while four shift up an average of 5 1/2 places. In the same manner, $(\text{point}-2D^2-50)^2(10^{-6})\left(\frac{\text{probable \$ loss}}{\text{cost}}\right)$ leaves twelve within their divisions. Of six crossing divisional lines, three shift up an average of 4 1/3 places and two shift down an average of ten places.

4.2 TESTING

In order to determine the applicability of the methodology to real situations, three case studies were conducted. These cases were selected so as to represent diverse examples of fire protection recommendations incorporating different conceptual considerations.

It is important to note that in certain instances it will be necessary to make rating decisions based on logical assumptions. This is especially true when dealing with strategic importance. The rationale for such decisions is discussed.

CASE I

Function: Training Facility

Recommendation: Sprinkler 1st, 2nd and 3rd floors of training building

Project Cost: $30,000

Description: The training building is part of a three-building complex. Construction dates back to late 1800's. It has three stories, basement and attic totaling 40,000 usable square feet. The two adjoining buildings total 75,000 usable square feet and are not adequately separated from the object building from a conflagration standpoint.

This facility is not unique other than from a traditional point of view. Any location physically large enough could act as a substitute. The value of this facility is derived from the personnel (instructors and attendees) present at any time and their present as well as future leadership and innovative potential. Therefore, supplies and facilities must include personnel.

Strategic Importance(s) (Final Rating 5)

1. Importance of the particular supplies or facilities to the overall Navy mission.

   Rating 2 (Indirect support to Major Weapons Systems)

2. Relative quantity of supplies or facilities involved compared to the available supplies or facilities of the same type.

   Rating 3 (Only Naval Facility of this type. Conceptually, critical quantity is at least one)

3. The ability to replace supplies and facilities, including consideration of replacement time and trained personnel.

   Rating 0 (The buildings could be substituted for quickly. The loss of qualified instructors would cause some delay in reopening the facility elsewhere but not enough to consider it greater than the critical downtime, since the facility could be inoperative for at least one year without any permanent effect.

Probable Human Life Loss (L) (Final Rating 5)

Potential Life Loss is 500 lives, Rating 5.

Adjustment 3, personnel safety standards not met take 75%.

(.75) (500) = 375 lives > 100 lives, rating 5

Probable Dollar Loss (D)   (Final Rating 1)

Potential Dollar Loss:

Replacement cost of Building	\$6 million		
Contents value	2 million		
Total	8 million	=	Rating 2

Adjustment 2, below standard fixed protection. Take 40%.

(.40) (\$8$\overline{M}$) = \$3.2M < \$5$\overline{M}$ = Rating 1

Relative Frequency/Severity (P)   (Final Rating 4)

A. Occupancy

Library = 1

Office = 1

School = 1 ∴ Rating 1

B. Construction

Plank on timber   Rating 2

C. Fire Loading

Light hazard   Rating 1

Project Ranking

Project goes to yes via path No. 7

Points

Ranking rule A, $S^2 + L^3 + 2D^2 + 10P$ yields 183 points

Cost Benefit

$(\text{Points} - 2D^2 - 50)^2\ 10^{-6}$ (probable dollar loss/project cost) =

$(183 - 2 - 50)^2\ 10^{-6}\ (3.2 \times 10^6/3 \times 10^4) = 1.836$

CASE II

Function: Fueling Operation

Recommendation: Installation of foam fire protection distribution systems on two fuel piers.

Project Cost: $53,000

Description: The piers are of timber construction with a concrete deck. They are kept in almost continual operation. This facility's ability to function normally is extremely important to the mission of the Depot.

Strategic Importance (S) (Final Rating 6)

1. Importance of the particular supplies or facilities to the overall Navy Mission

   Rating 4 (Direct support to Major Weapons Systems)

2. Relative quantity of supplies or facilities involved compared to the available supplies or facilities of the same type.

   Rating 1

3. The ability to replace supplies and facilities including consideration of replacement time and trained personnel.

   Rating 1

Probable Human Life Loss (L) (Final Rating 1)

Potential Life Loss is less than five-Rating 1.

This is the minimum rating for this item. No adjustment is possible.

Probable Dollar Loss (D) (Final Rating 1)

Potential Dollar Loss:

Replacement cost of piers $3 million - Rating 1

Adjustment 3. No fixed protection. Take 80%.

$(.80)\ (3\ \overset{1}{\overline{m}}) = \$2.4\ \overline{m}\quad \$5\ \overline{m}$ Rating 1

Relative Frequency/Severity (P) (Final Rating 8)

A. Occupancy

   Fuel storage Rating 3

B. Construction

   Plank or timber Rating 2

C. Fire Loading

   Process and storage of flammable liquids Rating 3

Project Ranking

Project goes to yes via path No. 6

Points

Ranking rule A, $S^2 + L^3 + 2D^2 + 10P$ yields 119 points

Cost Benefit

$(\text{Points} - 20^2 - 50)^2\ 10^{-6}$ (probable dollar loss/project cost) =
$(119-2-50)^2\ 10^{-6}\ (2.4 \times 10^6)/\ (5.3 \times 10^4) = 0.203$

CASE III

Function: Warehouse

Recommendation: Sprinklers

Project Cost: $32,000

Description: The warehouse was constructed in 1942 and has a floor area of 30,000 square feet. The building was constructed without fire walls and is currently storing clothing of different types.

Strategic Importance (S) (Final Rating 1)

1. Importance of the particular supplies or facilities to the overall Navy Mission.

   Rating 0 (No weapon or communications system tie-in)

2. Relative quantity of supplies or facilities involved compared to the available supplies or facilities of the same type.

   Rating 1

3. The ability to replace supplies and facilities including consideration of replacement time and trained personnel.

   Rating 0

Probable Human Life Loss (L) (Final Rating 1)

Potential Life Loss is less than five. Rating 1.

This is the minimum rating for this item. No adjustment is possible.

Probable Dollar Loss (Final Rating 1)

Potential Dollar Loss:

Replacement cost of building	$128,000
Contents Value	936,000
Total	$1,064,000

Adjustment 3, no fixed protection. Take 80%.

(.80) ($1,064 $\bar{m}$) = $851,000 $5 $\bar{m}$ Rating 1.

Relative Frequency/Severity (P) (Final Rating 6)

A. Occupancy
   - Garment storage — Rating 1

B. Construction
   - Plank or timber — Rating 2

C. Fire Loading
   - Severe hazard — Rating 3

Project Ranking

Project goes to no. It is not worthy of further consideration.

CASE STUDY SUMMARIES

	S	L	D	P	Yes/No	Points	Cost Benefit Factor
I Training Facility	5	5	1	4	Yes	183	1.836
II Fueling Operation	6	1	1	8	Yes	119	0.203
III Warehouse	1	1	1	6	No	--	--

V

FEASIBILITY AND COST OF RISK MANAGEMENT METHODOLOGY

5.1 PRESENT APPLICABILITY

In its first generation format, this simple technique is easily and quickly usable as the case studies indicate. Parts two and three of the strategic importance rating offer the only mechanical roadblocks to immediate application. The percentages in these sections, currently depicted by variables, must first be defined. FMRC is in no position to do this, having neither the necessary data nor the background required. It is believed, however, that the Navy has the competence and experience to assign workable subjective values.

It should be realized that this risk management methodology represents a sound and, as discussed in Section IV, workable concept. It is important that this be understood. What has been developed is a conceptual tool. It is not suggested that this first generation methodology should be applied as is, although it could be. Changes based upon better and more inclusive data should be implemented first. These changes would not, however, affect the conceptual approach but rather would refine it.

5.2 FEASIBILITY AND COST OF ADDITIONAL DATA

At present there is no way of predicting where the law of diminishing returns takes over and refinement should cease. It is possible, but not likely, that a refined methodology (discussed in Section 5.5) will not yield a better priority ranking than the first generation model. The optimum degree of refinement probably exists somewhere between the present model and the ideal model.

It is safe to assume that additional real property physical and dollar size distribution and corresponding detailed fire loss data, possibly obtained by sample survey, would result in meaningful and productive refinement of the system. This refinement would cost an estimated $100,000 to $200,000 and some usable input data would be at least 5 years in coming. The extent to which these expenditures are justified must be determined. This could be reasonably defined by a statistical and field sensitivity study in which input parameters in question were intentionally and dramatically changed as resulting priority rankings were monitored.

5.3 FEASIBILITY AND COST OF APPLICATION

From a feasibility point of view, the present methodology or a refined version of it can be mechanically instituted to do the job intended in a relatively short period of time. The obstacles to smooth functioning would be of a political nature. These problems would include obtaining Navy acceptance and defining the proper level of implementation. Decision makers would have to be educated to the value of the system, since fire protection would still compete with operational line items. These problems are, and will remain, those of the Navy and must be resolved internally.

Any incremental labor cost or cost savings resulting from the implementation of the current version or a refined version of the methodology cannot be determined at this time. In order to define this differential cost, a field testing program must be initiated similar to a comparative fire study analysis. This analysis would follow the complete path of fire protection funding recommendations and calculate the average associated times and costs for the present Navy way of doing business and that of the proposed methodology (given the Navy-defined level of implementation).

5.4 DISCUSSION OF IDEAL REFINEMENT

The ideal refinement of this system depends primarily on an optimum collection of historical data (or at least a representative sampling where no data exists).

In order to assign accurate relative ratings to the various segments of the methodology, comparative frequency/severity data is needed for different boundary conditions. Ideally, the system would consist of strategic, life and dollar ratings having probabilistic severity levels built in and an additional probability of fire occurrence defining the expected boundary conditions.

Probable Life Loss would be determined based upon two sets of frequency severity curves, one set for protected environments and one set for unprotected.

For each set, each type of occupancy would then have one or more curves associated with it. These curves (Figure 4) vary for different square foot exposure ranges. Probable Dollar Loss would be determined in the same manner (Figure 5).

At first glance it might be imagined that these sets of curves would add complexity beyond a desirable limit. In practice, the system user would merely turn to the proper table for Life Loss and Dollar Loss (generated from the distribution curves) and pick off an appropriate rating. Dollar Loss rating assignment would be similar.

Probable Strategic Loss is a much more difficult variable to which to assign values. It is unlikely that an assignment as ideal as the two above could ever be accomplished. A more arbitrary system such as the current one would be employed.

An overall probability frequency of fire occurrence for each occupancy would then be found in the same manner and all of the rating pieces would be ready for ranking the project. The ranking rule used could also be refined with the aid of a computer to yield rankings in line with predetermined conceptual guidelines.

The proper application of cost-benefit analysis omits the assumption that all projects result in equal improvement of protection. Rather, the effect the project would have on each component of the ranking system should be evaluated. To do this, the capability to do more than assess the difference between no protection and full protection is required. Each project's improvement upon existing protection would have to be measurable from historical data or at least subject to reliable estimation. It is not a simple task to determine the probable savings in dollars for various improvements, although data might be retrievable for particular types of facilities. Accurately estimating the change in probable strategic impairment and probable loss of life is even more difficult.

The problem with strategic impairment might be approached by working with the probability of a fire of a certain severity or greater occurring with

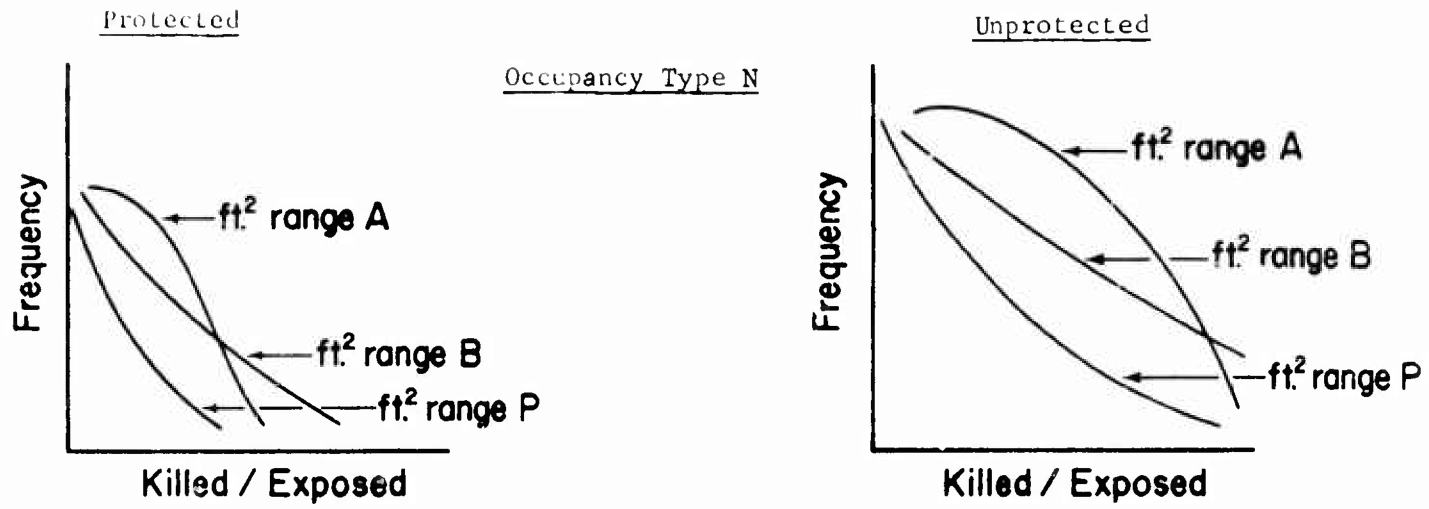


FIGURE 4 - PROBABLE LIFE LOSS/FREQUENCY SEVERITY CURVES

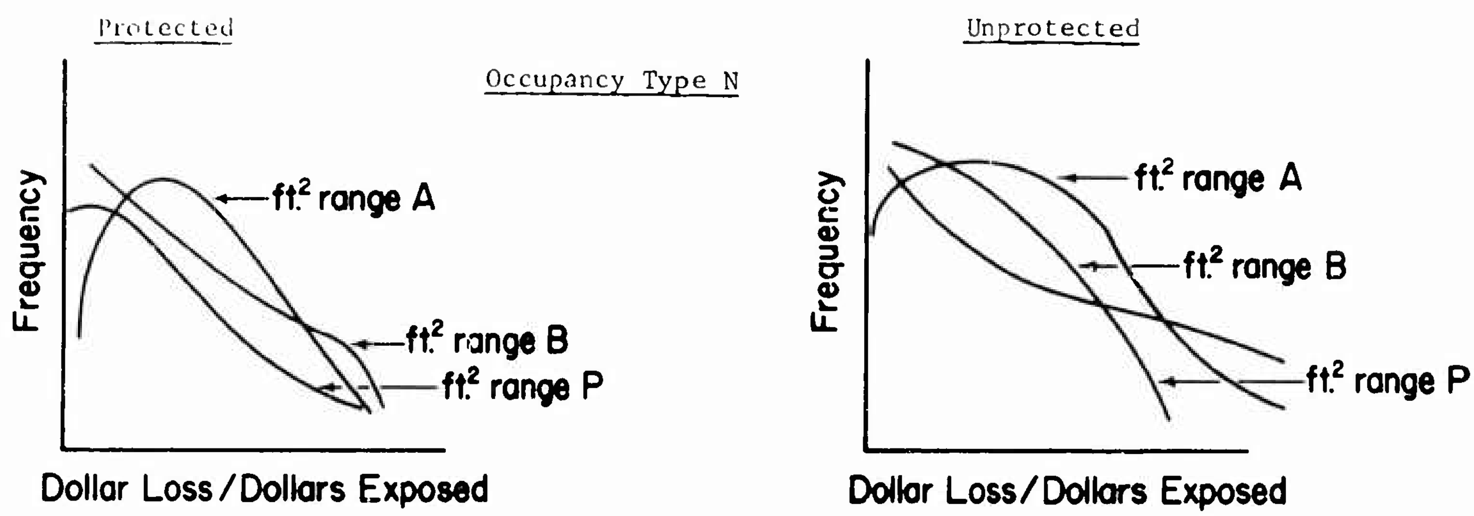


FIGURE 5 - PROBABLE DOLLAR LOSS/FREQUENCY SEVERITY CURVES

existing protection and a different probability if the project were completed. A fire at or above some critical level of severity would be considered to completely destroy strategic capability. Ranges of severity below this could be set up and fires in these ranges judged to reduce strategic capability by various percentages or not at all. The change in the probability of reaching the various levels resulting from improved protection must also be found. This change in probability could be combined with some dollar evaluation for strategic point value, the cost associated with the downtime incurred by the facility, and the cost of shifting the burden normally taken by that facility to other facilities either temporarily or permanently. Replacement of the facility would not be considered under strategic impact except as it affected downtime.

In the area of loss of life, the effect of the proposed project would also have to be figured. This would include the reduced likelihood of a fire severe enough to endanger life and the increased probability of escape. The value of lives in the facility would have to be approximated using the cost to the government, of insurance, paper work, recruiting and training of replacements.* An average value would have to be determined. Using the probability of life loss with and without the project, savings per year could be figured in "life" dollars, compatible with normal dollars.

Ideally, then, the complete cost-effectiveness figure for each project would look like this:

$$\sum_{i = S,\, L,\, D} \frac{(\text{exp loss/yr})_i \text{ w/o project} - (\text{exp loss/yr})_i \text{ w/project}}{\text{cost/yr}^{**}}$$

This summation would give an ordering by cost-effectiveness for projects being considered for funding which could then be used as the final priority of ranking.

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*The effect of publicity and investigations would also have to be considered.

**Cost per year includes the original investment amortized over the estimated life of the project plus any increased or decreased maintenance costs incurred by the change in protection.

The above discussion relative to refinement presents an ideal. In some areas, the level of refinement is not feasible or justified from a value added viewpoint. The breakeven point would be determined in a subsequent effort.

VI
CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

The simple methodology proposed can aid in assigning priorities in funding fire protection improvements. Further refinement can improve the sorting process. The optimization of funding to reduce risk should result in a reduction in the potential for serious large loss. The analytical process itself will provide a quantitative basis for understanding the residual risk being assumed by the Navy.

6.2 RECOMMENDATIONS

The following recommendations are made for future work:

1) Conduct extensive testing of the methodology on outstanding recommendations to evaluate ease of application, application time and implementation costs.

2) Determine to what extent added data accumulation for methodology refinement is justified.

3) Refine the methodology if testing proves advisable.

4) Conduct data analysis to provide rating values more specific to Navy activities.

5) Modify the fire protection survey to provide information more pertinent to the methodology.

6) Modify loss investigation techniques to provide the data required for an extended analysis.

APPENDIX A

SUMMARY OF RISK MANAGEMENT AND PRIORITY SYSTEMS

A Program for the Fire Research and Safety Act (1) by Drs. Rockett and Robinson and Mr. J. F. Christion of the Fire Research and Safety Center at the National Bureau of Standards contains, in Section 3.4.1, comments regarding the development of a building fire-design methodology and the need for a broad logical framework within which the components can be synthesized into a successful entity. It is our purpose, in the present project, to provide this framework in the context of Naval Operations.

Studies in the past have concentrated on specific component problems in analysis and measurement. Carroll Burtner's thesis dated June 1961[2] presents a very good analysis of several components. Burtner concludes that insurance rating systems are not pertinent to the Navy and that the Navy data base is not sufficiently large to rely on the "law of large numbers". His conclusion is that 2 - 2½% of value at risk is an allowable protection cost since this has been shown to be economical in industry. He also indicates that more Navy data are needed. For instance he suggested that fire protection systems in all cases should be given a different category code so that an accounting can be made of protection costs and areas protected. He also suggested concentration on large loss potentials (over $250K) as is done by the Army. He noted the basic elements of the loss potential estimate as being construction, occupancy, exposure, protection and the elements of place and time. He ended the dissertation by pointing out that life safety features or situations in which the mission of important activities are involved were beyond the scope of the study.

Professor M. E. Hickey of U. Md. presented in March 1970 a prototype cost benefit analysis system[3] for application to Fire Safety Problems. One of his concluding statements is that current methods of collecting fire loss data do not provide valid estimates of ignition occurrence probability. He further concludes, however, that refinement of the proposed management system for fire safety can lead to new techniques for performance budgeting systems and that the technique could be extended to reflect the potential for life loss. He envisions the application of modern management tools, such as computer simulation and gaming using mathematical models to aid in the implementation of fire safety philosophies.

These two papers cover a span of about ten years. During this period some advances have been made in the development of mathematical models to reflect fire behavior. Most of these have been oriented toward specific problem areas such as fire initiation and spread following nuclear weapon bursts[4,5,6] and general treatment of the economics of Fire Protection [7]. Only recently have more fundamental models of fire behavior been proposed[8,9].

Priority and financial analysis systems have been designed to aid in the allocation of funds within various DOD Departments but as yet these have not been applied extensively to fire protection projects. One example is the priority system developed by NavFac Code 06. (Military Construction Priority Model Description, 16 December 68).

Systematic Risk Management is receiving more and more attention as techniques in the fields of Systems Analysis and Decision Making become more refined. A Symposium promoting the Systems Approach to Fire Protection was presented by the Federal Fire Council in 1966[10]. The currency of formal, systematic decision making is evidenced in engineering by relatively new System Analysis courses at MIT, UCLA and elsewhere and in business by new short courses in management decision making being offered by the AMA.[11] The recent (July 13, 14, 1970) Symposium "Systems Analysis in Relation to the Fire Problem" sponsored by the NFPA and held at the University of Maryland reemphasized the need for a systematic approach to risk management and the design of loss prevention systems.

A summary of the current status of Risk Management is offered by James Christy in the opening and closing paragraphs of an article ("Qualified Methodology is the Key to Risk Managements Value")[12] in the May 1970 issue of the journal Risk Management. He opens, "In the next decade risk management will become broader in scope, more precise in its practice and better appreciated by top management."

Christy then concludes, "If and when we understand the nature of risk management, we shall find answers to questions which stop us today, and we can convey the message to understanding managers. A qualified methodology will provide specifics to replace vagueness. Realistic standards of performance will evolve in due course and the risk manager who meets them will find his place in the sun."

Refined techniques for analyzing risks and losses are now being developed (such as relating frequency-severity data to the size spectrum of values at risk) and preliminary efforts have shown they can be applied to the Navy if data is presented in the proper format. A DOD-wide base would be even more informative if differences in data coding practices can be resolved. A sample presentation and discussion of state and national loss data (albeit with many necessary assumptions and simplifications) was presented in the Program for the Fire Research and Safety Act.[1]

Various efforts are underway to quantify components of the problem. For example, "Systems Safety Engineering" has been used by the Air Force several years (Mil-5-38130 (USAF) - 30 September 1963[13] to identify failure trains and relative probabilities. More recently, R. L. Browning of Monsanto Company presented a series[14,15,16,17] of articles in Chemical Engineering entitled "Analyzing Industrial Risks", "Calculating Loss Exposures", Estimating Loss Probabilities", and "Finding the Critical Path to Loss" in which real applications of "Fault Tree" techniques are discussed. Another article in Chemical Engineering, "Plot Safer Shipping Course"[18] presents an analysis based upon the formulation of a Logic Diagram defining the role of each transportation element.

Future expansion of these analytical systems should provide for more refinement in areas such as loss probability (fire spread models) and protection system performance. A formalized approach can result in more systematic application and understanding of present fire protection standards (DM-8)[19] and perhaps form a logical basis for revised engineering guidelines.

The statement is made in the Program of The Fire Research and Safety Center[1] (par. 2.5.3.3) that "fire protection engineering follows a pragmatic approach with a tendency toward 'cookbook' solutions". The purpose of the methods proposed in "An Engineering Study of Fire Protection"[20] and in this study is to rectify this situation by providing a logical, integrated approach to both the engineering and management aspects of fire protection, loss prevention, risk management and safety.

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