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WEAPON SYSTEM COST ANALYSIS

David Novick

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The RAND Corporation
1700 MAIN ST. • SANTA MONICA • CALIFORNIA

WEAPON SYSTEM COST ANALYSIS

"Weapon system" has to a large extent been substituted for "weapon" over the last few years in the United States Air Force's approach to the introduction of new equipments into its inventory.* The expansion of the concept of a weapon to include all of the related equipment, installations, personnel, maintenance, supply, training, etc., has called for many changes to the previously held ideas on estimating the physical and financial requirements for new equipments. Development, procurement and logistics as well as planning and operations are also moving in this direction.

Since RAND was among the first to utilize the systems concept, it also has had a longer than average experience in the development of methodology and data necessary as inputs in weapon systems analysis. RAND's Cost Analysis Department has been actively participating in this work since 1950. This paper summarizes the concepts and methodology for computing Air Force weapon system costs used at RAND as of the winter of 1955. It is being made available at this time not because of any presumption that it is either the final or the best for preparing such estimates, but rather in response to an ever increasing demand for a statement of RAND's cost methodology from manufacturing and research organizations which serve the Air Force.

The methodology presented here has several characteristics that should be emphasized at the outset. First, it attempts to take into account all of the many factors that enter into a weapon system as it will be used by the

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* See, for example, Air Force Regulation 20-10, Air Force Regulation 80-27A, etc.

Air Force. Many of these factors are neglected or omitted in some of the other methods used to estimate weapon system costs. Second, it provides measurements of the demands for economic resources - men, material, capital, etc. - which will occur if the proposed new equipment is introduced in given quantities over specified periods of time. Although dollars are used as a device for accumulating and summarizing the data, the primary objective is economic rather than dollar cost. Third, it identifies the additional or incremental expenditures which will result from the use of a proposed new equipment so that the extra or new capabilities can be evaluated in terms of the incremental costs incurred. Fourth, it makes a clear-cut distinction between the one-time or investment outlays and the recurring or annual operating expenses to permit a better measurement of both the economic impact in terms of time and the total cost of the equipment over its expected useful life. The considerations enumerated are not always included or developed as completely in other approaches to weapon system cost analysis.

Since the emphasis of this paper is on methodology rather than on the specific dollar values which are the result of the calculations it was decided not to include actual or real numbers which would have imposed two limitations on circulation of the study: (1) security classification, and (2) AFR 170-17, Section 3, which sets forth the need-to-know even in the case of approximate measures of the cost of the items described.

We believe that the objectives aimed at in the release of RAND's methodology will best be served if it circulates freely as a working or reference document. In view of the limitations on distribution and use which real numbers would have imposed and the belief that the use of

fictitious numbers that were not even proximate values might result in confusion, it was decided to omit numbers from the sample table and worksheet. Standard USAF data sources are listed at the end of the paper and those who wish to apply real numbers can have access to these sources if they can meet the requirements of Air Force Regulations governing security and "need-to-know."*

Although this is the first outside presentation, it is but one of many steps in the development of the technique described here. It will be changed as new information and new ideas indicate the errors and omissions made in this projection. Another reason for issuing this document is to ask for criticism and comment by those who will study and/or use the methodology and procedures described here. It is essential to the effective use of the weapon systems concept that its basic tools be continuously refashioned and sharpened. Cost is one of the most important of these tools.

The material contained herein is not the work of any single person nor even of the Cost Analysis Department alone. Many individuals in the Air Force, in private industry, and in other parts of RAND have contributed generously. Furthermore, it is hoped that those who have worked with us in the past will continue to work along with us in the future, and that by the publication of this document the list of constructive sources will be greatly expanded for inclusion in the future versions of this document.

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* For those who can meet the eligibility requirements, specific applications of RAND's cost methodology are available in: Cost Analysis Department, The Cost of Decreasing Vulnerability of Air Bases by Dispersal, The RAND Corporation, Report R-235, June 1, 1952, (Secret); Cost Analysis Department, Air Defense Study: Cost Methodology (Radar Network, Aircraft, and Missile Systems), The RAND Corporation, Research Memorandum RM-1170, September 2, 1954, (Secret-RD); etc. A more complete statement of the methodology outlined here is available in: Weapon System Cost Methodology, Novick, David, The RAND Corporation, Report R-287, February 1, 1956.

COST ANALYSIS IN WEAPON SYSTEMS ANALYSIS

In the weapons systems method of analysis the mission equipment proposal is placed in a simulated operational context and is compared with alternative proposals and existing instruments. The comparison of weapons systems is done, for the most part, in one of two basic ways:

1. In terms of a specified degree of weapon effectiveness, usually expressed in number or value of targets destroyed, the various weapon systems are compared on the basis of economic cost. The system which accomplishes the stipulated level of effectiveness at lowest cost is selected as a preferred one.

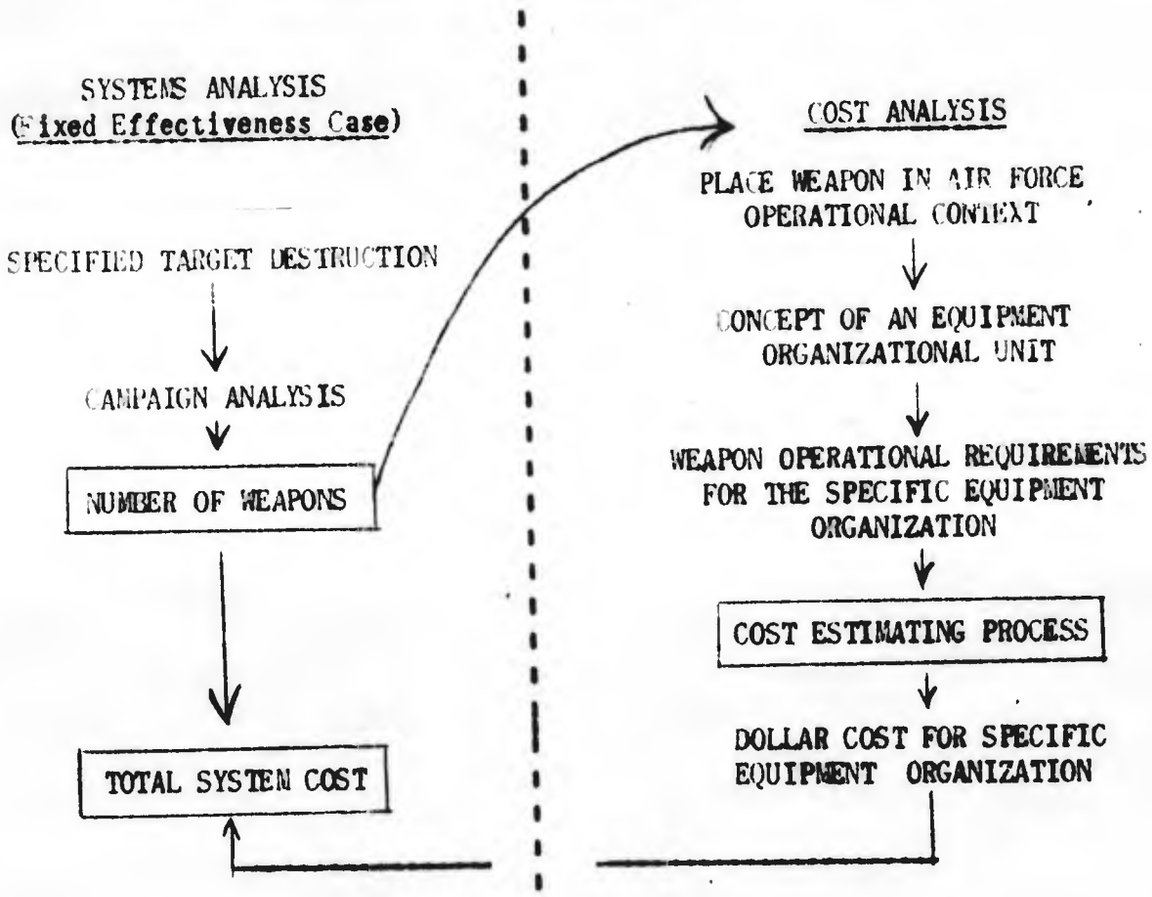
2. For a specified military budget, the various systems are compared on the basis of weapon effectiveness, again usually measured in terms of targets destroyed. The system which gives the highest target destruction possibility for a fixed budget is said to be a preferred one.

Cost is an essential element in the comparison, no matter which method is used. In the first instance, cost is the criterion of choice; in the second, cost must be calculated because of the fixed-budget specification. Broadly speaking, economic cost is taken to mean total amount of resources, i.e., labor, materials, capital, etc., required to introduce, operate, and support a weapon system.

Many considerations other than cost enter into weapons systems analysis, but they are not discussed in this paper. Chart I, graphically illustrates the place of cost analysis in the over-all treatment. Only the economic cost (as measured in dollars) of the personnel, equipment, supplies, and other logistic factors entering into each of the alternative or possible weapon systems is considered here.

Chart I

THE PLACE OF COST ANALYSIS IN WEAPON SYSTEMS ANALYSIS



RAND TECHNIQUES FOR COMPUTING AIR FORCE WEAPON SYSTEM COSTS

Although a part of the cost analysis task is simply to price out weapon systems in order to determine the dollar measure of the cost of producing and using them, the more important aspect of the work is to establish the costs in a way which will permit judgment regarding the significant economic requirements of one system compared with another. This has led to the development of a method of measuring the resources required for the introduction of the new weapon whether in the form of added bases, training, equipping, etc., or the supplementation required to reorganize existing assets for the new weapon. Since weapon systems do not "run themselves" these one-time investment requirements are then distinguished from the annual recurring expenditures involved in the operation of the various equipments. In addition to distinguishing between the one-time and recurring features of these costs, the methodology also attempts to identify the points of impact in terms of specific Air Force weapon organizations and methods of employing the equipment.

RAND's interest is usually in the selection of weapons to be developed. The time horizon, therefore, is at least five years, and more often ten years, in the future. It is obvious that these future weapons will be subject to many changes after their emergence from research and development and before their introduction in quantity for operational use. RAND's system of cost analysis does not aim at an accuracy of detail such as would be required for specific procurement of things or recruitment and training of personnel. Instead, it seeks comparisons, recognizing that in the long-range projections only outstanding or obviously dominant differences can be used to distinguish one equipment proposal from another. Consequently,

the RAND cost methodology is oriented toward a relatively high degree of aggregation and only attempts to establish values for significant factors which are reasonably proximate. Since the data are used in gross comparisons, it has not seemed appropriate for RAND's purposes to expend the man-years necessary to work out the information in greater detail or to provide for the continuing large-scale effort that would be necessary to maintain the data in that degree of refinement. The RAND procedure does, however, permit quick calculation. Furthermore, it is accurate enough to provide first approximations of economic resource requirements (as measured by dollars) for alternative programs. If the expenditure is warranted, accuracy of detail can be obtained by applying the man-hours and using the same method of accumulating the cost estimates.

OBJECTIVES

In its cost analysis work, RAND has three major objectives:

1. To identify separately each of the major elements of activity that enter into a weapon system so as to be able to determine the items of resource costs which change upward or downward as weapon characteristics are changed.

2. To identify all costs to the Air Force incurred by the operation of a weapon for its assigned mission. This means that not only the price of the major equipment items or costs incurred at the tactical squadron or wing level are taken into account, but also an estimate of the wing's or squadron's pro rata share of all support and administrative costs outside the tactical unit.

3. To distinguish the investment or one-time costs, such as bases, aircraft, initial stocks, primary training, etc., from the annual or recurring operating costs, such as pay and allowances, replacement equipment

gas, oil and fuel, and utilities, which must be met each year if the Air Force is to continue in operation. This permits identification of both the short-run and long-range costs which should be considered in making weapon-choice decisions.

Identifying System Cost Elements

The first step in the development of RAND's cost methodology was to identify the separate elements of activity which enter into the operation of a weapon system in order to determine the extent to which each was responsive to changes in weapon characteristics. The cost of any selected primary equipment can vary substantially from other possible choices, even when all weapons are designed to perform the same mission. Recognizing that the primary equipment outlay is only one element in a long chain of costs incurred in the accomplishment of a specific Air Force mission, the method was designed to determine the extent to which upward or downward changes in the price of the equipment are followed by changes in any or all of the other elements of cost.

A simple illustration of this is a bomber which costs 5 million dollars and requires a crew of 5 men compared with one which costs 5 million dollars and requires a crew of 10. If the comparison were limited to differences in crew size, it would seem that the bomber requiring the larger number of men would be the more expensive. However, analysis might, in fact, show the bomber with the larger crew to be the cheaper one. For example, the higher skills required for the smaller number of men might call for both substantially higher costs of training and higher rates of pay than the lesser skills for the larger number of men.

This type of illustration can be found throughout the chain of interrelated

costs. For example, if both bombers cost the same and if the total crew costs for each are the same, the total costs of each of the airplane systems may still be substantially different. If one airplane requires mechanical equipment now generally in use and little or no advanced equipment, and if the other utilizes large quantities of electronics equipment of an advanced kind with which the using units have had little or no experience, the first will cost less in terms of maintenance machinery and personnel than the one with the advanced electronics equipment requiring highly specialized training of maintenance technicians and new and expensive machinery for test and repair.

With such considerations in mind, each of the activities which enter into the operation of a weapon system has been analyzed. An attempt has been made not only to identify each activity separately but to establish the quantities of resources required at each point of action and the dollar costs incurred to obtain these resources. These have been developed into a classification of cost categories as shown in Table 1. Obviously all of these items are not equally important in each weapon system study.

Accumulating Total Cost

The next step in the development of the cost methodology was to extend this identification of the separate activities in a way which would permit their accumulation into significant totals for specific weapon types, and which would also ensure that all costs attributable to the weapon which were incurred throughout the Air Force were allocated to the weapon and the mission. This evolved naturally from the first effort when it became apparent that activities at the wing and squadron level might require varying rates of support from Air Force organizations outside of the wing. For example, if the new bomber is in a state of the art closely related to that of bombers

Table 1

MAJOR COST ELEMENTS USED IN SYSTEM COST ESTIMATES

Organization: (specify wing, squadron, etc.)
Equipment: (designate type of aircraft, radar, missile, etc.)
Operating Rate: (indicate hours per month, etc.)
Location: (indicate ZI, overseas, etc.)

Cost Elements	Investment	Annual Operating
Installations		
Equipment facilities	xxx	-
Personnel facilities	xxx	-
Maintenance	-	xxx
Equipment		
Primary mission equipment	xxx	xxx
Unit support aircraft	xxx	xxx
Organizational equipment	xxx	xxx
Specialized equipment	xxx	xxx
Stocks		
Initial stock level	xxx	-
Readiness reserve	xxx	-
Initial spares	xxx	-
Transportation	xxx	xxx
Personnel		
Training	xxx	xxx
Pay and allowances	-	xxx
Travel	xxx	xxx
Maintenance		
Mission aircraft	-	xxx
Unit support aircraft	-	xxx
POL		
Mission aircraft	-	xxx
Unit support aircraft	-	xxx
Miscellaneous (motor pool, heating, cooking, etc.)	-	xxx
Services and miscellaneous	-	xxx
Command Administration	xxx*	xxx
Support major command administration	xxx*	xxx
TOTAL	xxx	xxx

* There may not always be a significant amount of investment to be taken into account at the intermediate command and support major command levels. In the case of a markedly expanding Air Force, however, there is sure to be investment occurring at these levels.

now in use, the Air Training Command can generally utilize its existing equipment and teaching skills. If, in contrast, the bomber represents a substantial change in the state of the art, it will require the hiring of new instructors and the supplemental training of others, as well as the procurement of substantial quantities of new training aids and training equipment. This will extend beyond just the bomber itself, i.e., into all of the related equipment required for its operation and into the numerous types and kinds of shop equipment necessary to test and repair it.

Depot maintenance facilities of the Air Materiel Command will be affected in much the same way; if the equipment is of an advanced type, many or most of the maintenance workers within the depot system will have to be given additional training to bring them up to the requirements of the new equipment. These types of changes will extend further throughout the support activities, depending on the way in which the equipment must be operated. For example, if the component parts of the bomber are rugged, they can probably be stored and transported in the conventional manner. If, on the other hand, they are delicate, it may be necessary to build special dust-proof or air-conditioned storage facilities and to transport them from storage to the operating unit by air.

The illustrations just given relate to the way in which weapon choices may affect costs incurred in contributions to the weapon system at the support major commands whose activities are essential to the tactical operation. Actually, the weapon choice may result in higher or lower costs within the tactical major command itself. If the new weapon requires a substantial amount of autonomy and built-in direction at the squadron or wing level, this probably will result in lower costs at the air division, numbered air force, and tactical major command headquarters. On the other hand, a reverse pattern is introduced by a weapon choice that reduces the requirements for such

functions at the wing level but calls for substantial increases and higher costs for these activities throughout the levels above the squadron in the chain of command. This means that a comparison which is limited to the squadron itself and which does not extend through the various command and support organizations within the tactical major command necessary for its operation will present a misleading picture of the cost of the weapon system at the tactical major command level.

In the same way, costs at the higher levels of administration (outside the tactical major command) might vary substantially. The RAND procedure is designed to take care of such changes as a substantially new procurement activity, occasioned by a weapon which requires additional buyers or buyers of high skills, or other administrative changes which affect the costs of new weapon systems.

The Distinction Between Investment and Annual Operating Expenditures

Since both the build-up of a new Air Force and its operation occur over relatively long periods of time, it was felt important to distinguish between the way in which costs are incurred for new one-time investments and the requirement for continuing regular annual operating expenses. Answers to these questions were sought not only to determine the extent to which there are differences in the total amounts of money or resources required, but also for the purpose of providing a basis for judgment so that one can clearly identify those elements of cost which have to be met each year just for the purpose of operation, as distinguished from the costs incurred because of changes in the type and size of equipment.

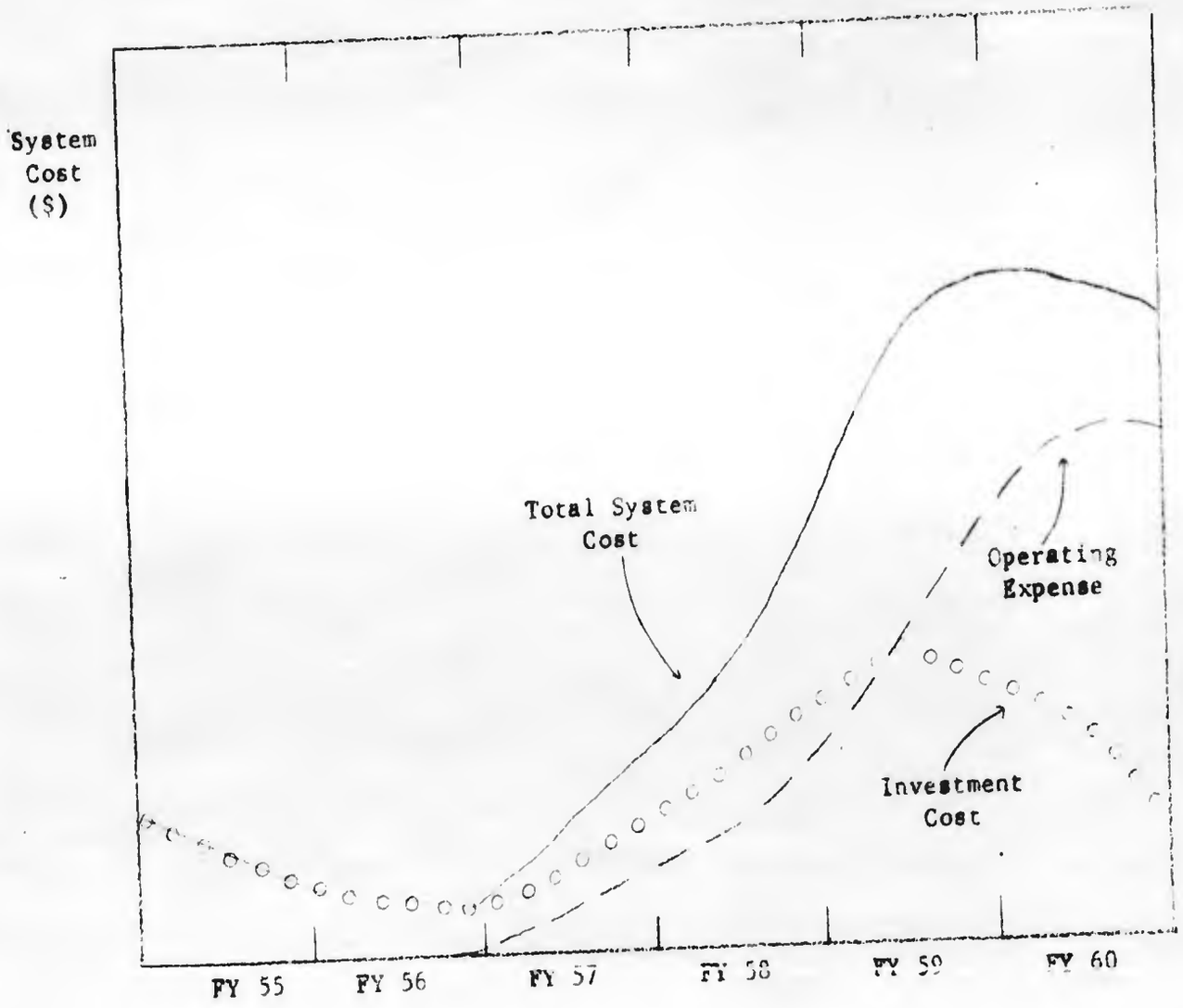
Since different elements are dominant in investment cost (chiefly major equipment and installations) than in annual operating cost (pay and

allowances, maintenance and Air Force administration), there is a significant difference in the resource demands of the two kinds of costs. The timing of these two kinds of costs in the introduction of a new weapon system is illustrated graphically in Chart II.

Referring to the example on page 8, if the price of the bomber was 5 million dollars in both cases, there would be no difference in the investment in mission equipment. However, if the equipment represented a new generation of bombers and a major advance in the state of the art, it might call for large-scale investments for changes or expansions in real property in both industry and the Air Force, as well as retooling and retraining at such places as the industrial suppliers, the Air Materiel Command and the Air Training Command. Perhaps more important, the wear-out or annual use-up rate of the two equipments might vary substantially. Thus, although the investment in both might be the same, the annual replacement of complete new units and major spares might vary with a resultant significant change in the annual recurring cost necessary to maintain the force at its assigned capability. Again, as the type of weapon is changed (e.g., from manned aircraft to pilotless vehicles), there may be a substantial difference between the requirements for original procurement and annual replacements. To maintain the training and proficiency of the operating personnel, it may be possible in the case of the unmanned vehicles to simulate operation so that very few articles are worn out or used up in the training process. In contrast, manned aircraft wear out in training and some of the units are lost in crashes and accidents.

Chart II

TIMING OF ECONOMIC IMPACT OF INVESTMENT AND
ANNUAL OPERATING COSTS IN TOTAL WEAPON SYSTEM COST



PRESENT APPLICATION

The methodology just described uses quantitative measurements derived from existing data. The data now available, in general, do not relate expenditures to activities in the way contemplated in this report. This has meant taking the information which is available and analyzing and interpreting it to yield weapon systems costs of the type described.

The Cost Analysis Department of RAND has sought to develop cost estimates which are consistent and reasonable for all weapon systems under comparison, rather than estimates which are accurate enough for use in actual procurement or in operations. The emphasis has been, therefore, on the development of a conceptual framework of costing procedures. Because of the nature of existing Air Force historical cost data, it has been necessary to use statistical methods of cost estimating to a considerable degree. The essence of this approach is the determination from historical data of useful relationships (factors) between items of cost which are relatively easy to estimate and items of cost which are very difficult (or laborious) to compute in a straightforward manner. Cost estimates for items of the latter type are then obtained by applying factors to estimates of cost for items of the former type. For example, cost estimates of aircraft spares and spare parts may be computed by applying a factor to the initial cost of the aircraft.*

This method of calculation yields costs for the wing or squadron unit which are not only consistent as between various elements of cost, but which are also reasonably accurate for estimating expenditures generated at the tactical unit level. In extending the costs beyond the squadron or wing level, fairly good data are available for determining the costs incurred

* A detailed illustration of the application of statistical methods to one cost element - airframes, a major item in the mission equipment cost category - is Cost-Quantity Relationship in the Airframe Industry, Asher, Harold, The RAND Corporation, (to be published).

within the major command. However, when the procedure is extended to cover the activities of the major support commands - although it has been possible to develop a conceptual framework - the available data do not permit determination of an entirely satisfactory basis of allocation of support major command costs to tactical units. Thus, such cost allocations made on the basis of existing data must of necessity be rather crude.

Estimating costs for future weapon systems is not an easy task. However, if future alternative weapons are to be analyzed in meaningful fashion before decisions are made to either develop them or procure them for the Air Force inventory, then cost estimates must be prepared so that adequate attention can be given to this important consideration. In this context, consistency in the scope and method of preparing the estimates so that the comparison will not be biased in favor of one system is more important than minute accuracy in the calculations.

RAND has found that reasonable estimates are based on three basic principles:

A. Learn as much as possible about the development, procurement and operation of present weapon systems. This involves much more than collecting numerical data and reports in a mechanical way. It requires "getting behind" the numbers and finding out how the basic processes work in fact, how the data were collected on primary forms of entry as well as the summary reports, and establishing a basis for determining whether or not the data or reports provide a reasonable picture of the process which they attempt to describe.

B. Avoid mechanical extrapolation. To be sure, we must extrapolate - particularly for weapons five or ten years in the future; but the method of

projection must be field-tested to insure its reasonableness and critically reviewed by at least two other analysts to insure its appropriateness in a specific application.

C. Be consistent but not mechanical. Since one of the key features of weapon system analysis is the comparison of alternative weapon proposals, freedom from bias in the methodology applied to the various weapon systems is a prime requisite. However, as in the case of extrapolation this does not permit the mechanical application of a single method to all weapons. Consistency when applied to a range of equipments means taking account of the special or peculiar features of each one and treating all of them in a consistent way. It does not mean mechanical or uniform application of a single method to all cases.

Adapting these three principles will not in themselves guarantee a good job of cost estimating in a weapon system analysis. Following them, however, will go a long way toward meeting the objective of good weapon systems cost analysis.

DESCRIPTION OF RAND METHODOLOGY

The method for computing the costs for each category shown in Table 1 is detailed in RAND's R-287, Weapon System Cost Methodology. Only an illustration is included here. Worksheet No. 2 which follows is the first of a set of eight pages used in summarizing the calculations for the installations element of cost. The set which makes up Worksheet No. 2 is one of 19 sets of worksheets used to summarize the calculations for the cost elements shown in Table 1.

THE INVESTMENT SIDE OF INSTALLATIONS

When new Air Force tactical organizations are established, or when new equipment is introduced into existing ones, a substantial investment in air-base facilities is usually required. This is particularly true if additional bases have to be constructed. But even when a new weapon is introduced on an existing base, some investment in installations facilities are usually necessary. For example, the runways may have to be extended in order to accomodate the new aircraft, more maintenance facilities may be required, or the new aircraft may call for more personnel than the old one, so that additional personnel facilities may be needed. In any event, whether new bases are constructed or new weapons are introduced on the existing bases, the estimated investment outlays for new or additional base facilities are summarized in the "installations" cost category.

For convenience of presentation and analysis, the total installations cost category has been broken down into two subcategories: equipment facilities and personnel facilities. In some instances this distinction is rather artificial, since certain base facilities are related to both

Appendix A

WORKSHEET NO. 2 - INSTALLATIONS

Facility	Unit of Measure	Unit Cost	Total Cost	Remarks
Category A - Airfield Requirements:				
1. Runways: Gross Wt. of A/C (Pavement Design)	LB			
Primary: Length & Width	LF			
Area	SY			
Crosswind:				
Area (80% of Primary/ Runway)	SY			
2. Taxiway: Length & Width	LF			
Area	SY			
3. Taxiway, Alert	SY			
4. Aprons:				
Operational	SY			
Hangar Access (Mtce.)	SY			
Transient & Base Flight	SY			
Total				
5. Pad, Warmup, Holding	SY			
6. Hardstand - Calibration	SY			
7. Washrack: Type				
Requirement	EA			
8. Washrack Treatment Plant	EA			
9. Firing-in-butt	EA			
Category B - Liquid Fuel Storage, Dispensing & Supplying:				
1. Bulk Storage				
Avgas	Gal.			
Jet Fuel	"			
Avlube	"			
2. Diesel Bulk Storage	"			
3. Mogas Bulk Storage	"			
4. Heating Fuel	"			
5. Hydrant Refueling				
No of Hydrants	No.			
Operating Storage	Gal.			
Category C - Communications, Navaids & Airfield Lighting:				
1. Communications Facilities				
Communications Base Transmitter	SF			
Communications Base Receiver	SF			
Communications & Telegraph Bldg.	SF			
2. Navaids				

the mission aircraft and the personnel in the combat unit (wing or squadron) located on the base. Broadly speaking, however, the two subcategories may be considered as being made up of the following elements:

Equipment Facilities

1. Airfield requirements
2. Liquid fuel storage and dispensing facilities
3. Communication, navaids, and airfield lighting
4. Operational facilities
5. Aircraft maintenance facilities
6. Training facilities
7. Storage facilities
8. Shops

Personnel Facilities

1. Troop housing facilities
2. Family housing
3. Administrative and community facilities
4. Utilities
5. Medical facilities

Physical requirements and specifications for the elements listed above are found in Air Force facilities requirements manuals. For various standard types of Air Force combat organizations (heavy bomber wing, medium bomber wing, fighter-bomber wing, fighter-interceptor squadron, etc.), the facilities requirements manuals give so-called minimum physical installations requirements needed to carry out the weapon's basic peacetime mission. Cost factors for construction in the Zone of Interior and relative factors for overseas areas are obtained from documents published by the U.S. Army Corps of Engineers and the USAF Directorate of Construction.

In computing the installations investment cost for a particular type of Air Force organization (e.g., a B-47 wing), the first step is to obtain a complete list of physical specifications for that type of organization from the Air Force facilities requirements manuals. Then these physical requirements are priced on the basis of the estimates of unit construction costs. Finally, the numerous individual items are aggregated into the two main subcategories: equipment facilities cost and personnel facilities cost. (For an example of the type of worksheet used to compute installations cost, see Worksheet No. 2 which obviously covers only items 1, 2, and 3, under equipment facilities.) Finally, if construction of the facilities is to be outside the Zone of Interior or in a specific area inside the Zone of Interior, the appropriate relative cost factor is applied.

If the particular type of organization being priced varies considerably from standard Air Force organizations, or if a standard type of organization is used but the installations requirements for it call for something other than the minimum facilities needed to carry out the basic mission during peacetime, then physical specifications given in the installations requirements manuals must be adjusted. In making these adjustments, such factors as the following may be taken into account: number and characteristics of the primary weapon (mission aircraft), number of personnel, unusual operating conditions or locations, etc.

ANNUAL OPERATING COST

Annual and recurring charges for installations represent an estimate of the cost of materials and contractual services required for maintenance of facilities for an Air Force unit's equipment and personnel facilities. Pay

of military personnel associated with installations maintenance is not included here, since payroll cost is accumulated in the personnel "pay and allowances" cost category.

Installations maintenance cost is computed by applying a specified percentage to the total investment cost for installations facilities. The percentage now applied was derived from an analysis of Air Force cost reports.

STANDARD DATA SOURCES

As indicated at the outset, a wide range and variety of Air Force manuals, documents, and reports are used as the source of the data to be processed in the RAND methodology. For those who may be interested in the application of this methodology, a list of these sources is attached; also included are references to both USAF and RAND material which may be helpful in further work.

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