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A COMPUTERIZED MODEL FOR ESTIMATING SOFTWARE LIFE CYCLE COSTS (--ETC(U)

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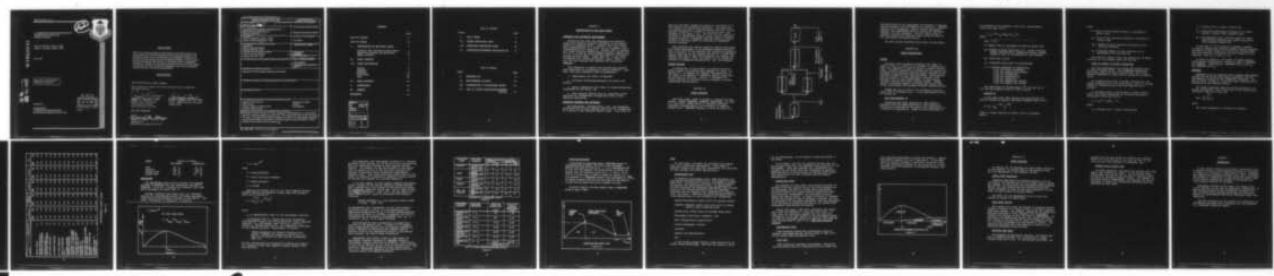
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A COMPUTERIZED MODEL FOR ESTIMATING
SOFTWARE LIFE CYCLE COSTS
(MODEL CONCEPT)

Gerard A. Bourdon, Captain, USAF
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April 1978

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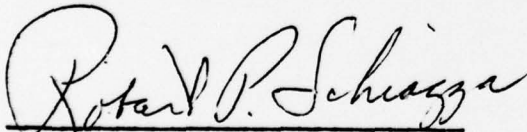
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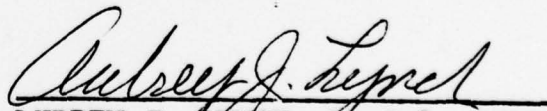
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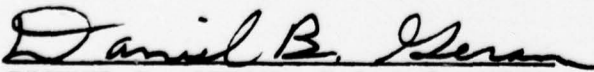


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SECTION I

INTRODUCTION TO THE BASIC MODEL

SOFTWARE COST ESTIMATING ENVIRONMENT

Estimating the costs for developing and operating large scale computer programs (software) is an endeavor subject to extensive error. Schwartz (Ref 8:56) notes that underestimation by a factor of 2.5 is common, while overestimations are unheard of. Devenny (Ref 3) presents data which indicates underestimation factors ranging from 1.1 to 2.6 at the Air Force Systems Command's Electronic Systems Division (ESD). Clapp (Ref 2:9), in her study of software cost estimating methods, notes, "There is only one real problem with software cost estimation: overruns."

The literature is replete with reasons why software cost estimating has historically been so difficult. However, four major obstacles seem to predominate:

1. Requirements are often ill-defined,
2. Available models/methodologies are overly simplistic,
3. Large, homogeneous data bases for model/methodology development do not exist, and
4. Past research efforts have not committed enough resources for successfully accomplishing their often ambitious objectives.

REPORTING SEQUENCE AND RATIONALE

The development, implementation, test, and subsequent modification(s) of this computer model will be accomplished by a series of ESD Technical Reports (TRs). This first TR

lays out the model concept and serves to introduce it to the software cost estimating community. The second TR will depict the model's detailed design, and will include program flowcharts, a listing of the source code, and examples of the model's use. The third TR will report on the model's performance against actual costs on selected software projects. Subsequent TRs will report on modifications to the basic model as reflected in subsequent version releases.

The rationale for issuing technical reports concurrent with model development is to encourage maximum participation on the part of the software cost estimating community. Only by doing so can we overcome the lack of a large homogeneous data base at ESD (and elsewhere) for testing and refining the model. Thus, this model will be tested and refined via widespread dissemination, use, and feedback.

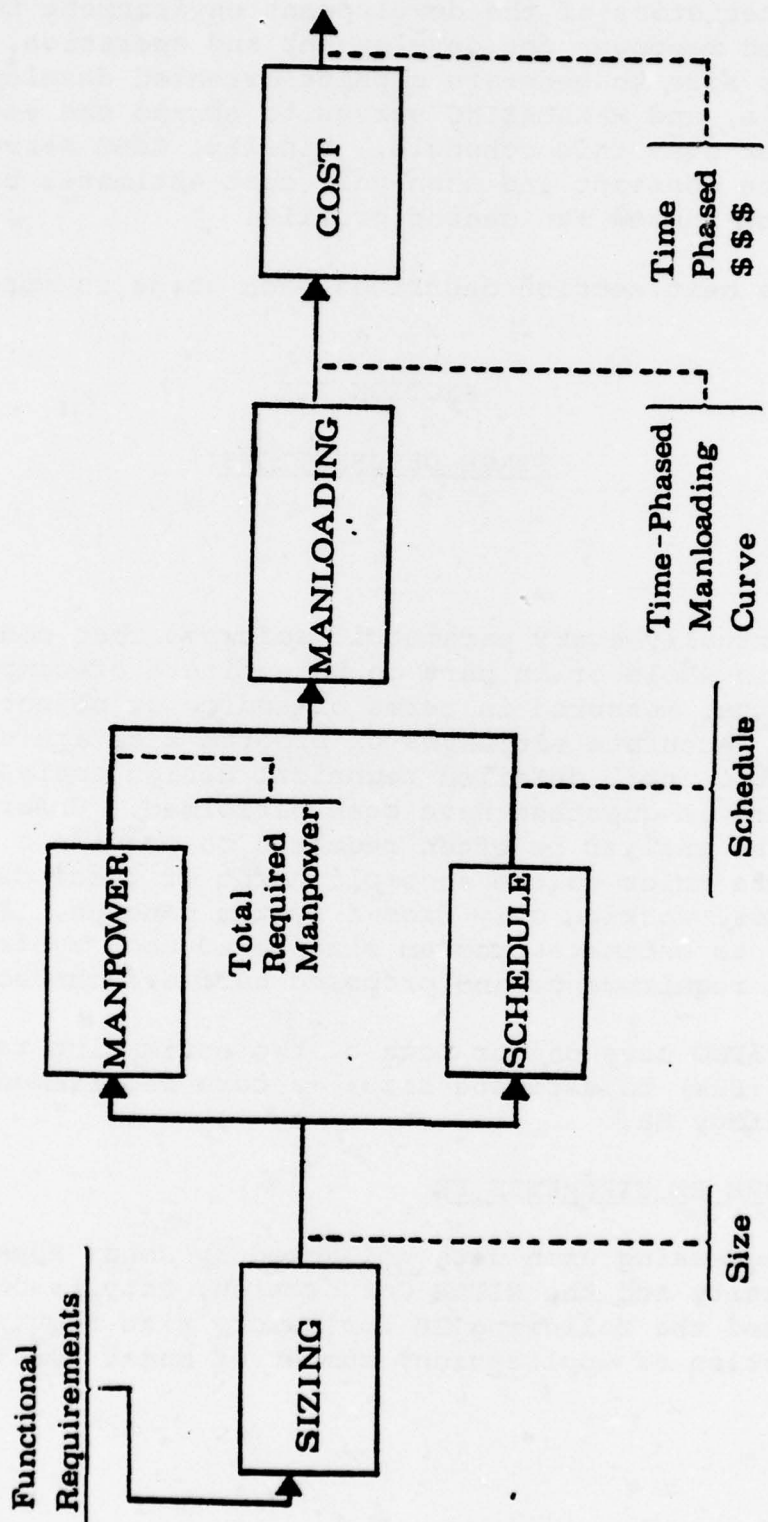
REPORT OUTLINE

In Section III of this report, we discuss the basic model concept, and discuss each submodel, or stage. In Section IV, we discuss the computer implementation of the model, with emphasis on operation options which will be available to the user. Section V discusses how future versions of the model will be modified to handle uncertainty statistically.

SECTION II

MODEL OVERVIEW

The basic model, shown in Figure I, consists of five stages: SIZING, MANPOWER, SCHEDULE, MANLOADING, and COST. At a top level, SIZING serves to transform software functional characteristics into estimates of computer program size. MANPOWER combines a sizing estimate with



BASIC MODEL

Figure - I

characteristics of the development environment to estimate required manpower for development and operation. SCHEDULE employs size to generate a phase-oriented development schedule, and MANLOADING serves to spread the estimated manpower over this schedule. Finally, COST serves to generate constant and then-year cost estimates based on the time-phased manloading profile.

The next section describes each stage in more detail.

SECTION III

STAGE DESCRIPTIONS

SIZING

Virtually every parametric software cost model is based in whole or in part on an estimate of computer program size, measured in terms of source or object instructions. Accurate estimates of program size are usually not available until detailed technical design analyses of the programs in question have been performed. Unfortunately, the cost analyst is often required to provide a cost estimate prior to the accomplishment of these design analyses, working only from a system concept. SIZING serves to estimate program size based upon system functional requirements and proposed hardware characteristics.

SIZING uses one or both of two estimating relationships (ERs) to estimate size: a core requirements ER and an analogy ER.

CORE REQUIREMENTS ER

Regressing upon data collected by Johns Hopkins University and the MITRE Corporation, Doty Associates obtained the following ER for memory size requirements as a function of application, number of major functions to

be performed by the software, word size, and processor cycle time (Ref 4:173):

$$M = e^{.177+k} (N_f^{.332} W_s^{.147} t_c^{-.770})$$

where

$$\exp = 2.718$$

M = Memory size in thousands of words of object code

N_f = Number of major functions (e.g., target tracking, target identification, system monitoring, display, steering, etc) to be performed by the software.

W_s = Word size in bits

t_c = Processor cycle time* in microseconds

k = A constant dependent on application

2.573 for signal processing

2.727 for missile fire control

2.781 for interfacing

3.412 for communication

3.565 for navigation

4.046 for command and control

4.451 for weapon fire control

The coefficient of determination (R^2) for this ER is .52, and the standard error is .086 ln units.

ANALOGY ER

In the same study, Doty derived the following ER for size by analogy to similar (existing) software (Ref 4:174):

$$M = M_a (N_{fa}^{-.678} N_f^{.678})$$

*Time to either retrieve or store a word in processor memory.

where

M = Size of the proposed program in thousands of object words

M_a = Size of the analogous programs in thousands of object words

N_{fa} = Number of major functions performed by the analogous software

N_f = Projected number of major functions to be performed by the new software.

Doty does not report either the coefficient of determination nor the standard error for this ER.

WORDS TO OBJECT TO SOURCE CONVERSIONS

The core requirements and analogy ERs estimate size in terms of object words. Since MANPOWER employs ERs based upon object and source instructions, the sizing estimate expressed in words must be converted to instructions.

To transform from words to object instructions, the analyst multiplies M by the blend factor (ratio of average number of instructions per core word required for a process).

To transform object instructions to source instructions, the analyst evaluates the following expression developed by Doty (Ref 5:D-5):

$$I_s = I_o / (1 + P_h (E_h - 1))$$

where

I_s = Program size in source instructions

I_o = Program size in object instructions

P_h = Fractional percentage of program to be implemented in Higher Order Language (HOL)

E_h = HOL expansion ratio (average number of object instructions generated per source instruction after program compilation).

If the code is to be written in Assembly language (a source language that includes symbolic machine language statements in which there is a one-to-one correspondence with the executable instruction and data formats of the computer), then $E_h = 0$ and $I_s = I_o$.

As shown in Figure I, the output of SIZING (Object and/or Source Instructions), serves as input to MANPOWER and SCHEDULE. (Specifically, MANPOWER uses I_o and I_s , and SCHEDULE uses I_o .)

MANPOWER

MANPOWER serves to estimate total manpower requirements through the use of ERs which employ estimated size and environmental factors as the independent variables. The ERs are shown in Table I, along with their coefficients of determination and standard errors.

For those situations where the sizing estimate is in source instructions, and is less than 10,000 instructions, the Table I ERs are of the form

14

$$MM = a I_s^b \prod_{i=1}^b f_i$$

where

MM = Total manmonths to develop the software

APPLICATION	SIZING UNITS	ESTIMATED SIZE	DOTY ESTIMATING RELATIONSHIP	COEFFICIENT OF DETERMINATION	STANDARD ERROR
S C I E N T I F I C	OBJECT	ALL	$MM = 4.495I^{1.068}$	.74	72.1
		$\geq 10K$	$MM = 7.054I^{1.019}$	.78	72.1
	SOURCE	< 10K	$MM = 2.011I^{1.019} \prod f_i$	.90	2.6
			$MM = 7.054I^{1.019}$	.78	72.1
C O M M A N D	OBJECT	ALL	$MM = 4.573I^{1.228}$	.78	41.1
		$\geq 10K$	$MM = 4.089I^{1.263}$	.80	41.1
	SOURCE	< 10K	$MM = .501I^{1.263} \prod f_i$	.89	1.9
			$MM = 4.089I^{1.263}$	.80	41.1
B U S I N E S S	OBJECT	ALL	$MM = 2.895I^{.784}$	.48	12.4
		$\geq 10K$	$MM = 4.495I^{.781}$	.61	10.7
	SOURCE	< 10K	$MM = 3.742I^{.781} \prod f_i$	.78	1.8
			$MM = 4.495I^{.781}$	.61	10.7
U T I L I T Y	OBJECT	ALL	$MM = 12.039I^{.719}$	.30	58.1
		$\geq 10K$	$MM = 10.078I^{.811}$	.45	51.7
	SOURCE	< 10K	$MM = 1.744I^{.811} \prod f_i$	.61	2.3
			$MM = 10.078I^{.811}$	.45	51.7

MANPOWER ERs

TABLE I

I_s = Number of source instructions

a,b = Constants (derived via regression analysis)

$\prod f_i$ = Product of environmental factors

In all other cases, $\prod_{i=1} f_i = 1.$

Table II shows the values assigned to the environmental factors if the appropriate environmental conditions are or are not present.

SCHEDULE

SCHEDULE serves to estimate the development schedule, and position it into phases

DEVELOPMENT SCHEDULE

Regressing upon data from 74 development programs, Doty derived an ER for development time given by

$$t_D = I_o / (99.25 + 2.33I_o^{.667})$$

where

t_D = "Reasonable" development time, in months

I_o = Number of delivered object instructions

Additionally, Doty's analyses yielded average distribution of schedule and expenditures as shown below

<u>Phase</u>	<u>Per Phase</u>	<u>Cumulative</u>
Analysis	.1 t_D	.1 t_D
Design	.33 t_D^D	.43 t_D^D

FACTOR	APPLICATION		SCIENTIFIC		COMMAND & CONTROL		BUSINESS		UTILITY		ALL	
	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
SPECIAL DISPLAY	1.11	1.00	1.11	1.00	1.43	1.00	1.00	1.00	1.00	1.00	1.11	1.00
DETAILED DEFINITION OF OPERATIONAL REQUIREMENTS	1.00	2.00	1.00	1.54	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.11
EXPECTED CHANGES TO OPERATIONAL REQUIREMENTS	1.05	1.00	1.05	1.00	1.05	1.00	1.00	1.00	1.05	1.00	1.05	1.00
REAL-TIME OPERATIONS	1.67	1.00	1.33	1.00	1.00	1.00	1.00	1.00	1.43	1.00	1.33	1.00
CPU MEMORY CONSTRAINT	1.25	1.00	1.25	1.00	1.00	1.00	1.00	1.00	1.18	1.00	1.43	1.00
CPU TIME CONSTRAINT	1.67	1.00	1.51	1.00	1.00	1.00	1.00	1.00	2.32	1.00	1.33	1.00
FIRST S/W DEVELOPED ON CPU	1.92	1.00	1.92	1.00	1.92	1.00	1.00	1.00	1.92	1.00	1.92	1.00
CONCURRENT COMPUTER HARDWARE DEVELOPMENT	2.22	1.00	1.67	1.00	1.33	1.00	1.00	1.00	1.25	1.00	1.82	1.00
TIME-SHARE, VIS-A-VIS BATCH PROCESSING, IN DEVELOPMENT	.83	1.00	.83	1.00	.83	1.00	1.00	1.00	.83	1.00	.83	1.00
DEVELOPER USING COMPUTER AT ANOTHER FACILITY	1.43	1.00	1.43	1.00	1.43	1.00	1.00	1.00	1.43	1.00	1.43	1.00
DEVELOPMENT AT OPERATIONAL SITE	1.39	1.00	1.39	1.00	1.39	1.00	1.00	1.00	1.39	1.00	1.39	1.00
DEVELOPMENT COMPUTER DIFFERENT FROM TARGET COMPUTER	1.11	1.00	2.22	1.00	1.00	1.00	1.00	1.00	1.43	1.00	1.25	1.00
DEVELOPMENT AT MORE THAN ONE SITE	1.75	1.00	1.25	1.00	1.25	1.00	1.00	1.00	1.21	1.00	1.25	1.00
PROGRAMMER ACCESS TO COMPUTER LIMITED	1.00	.67	1.00	1.00	1.00	1.00	.90	.90	1.00	.67	1.00	.90

ENVIRONMENTAL FACTOR VALUES

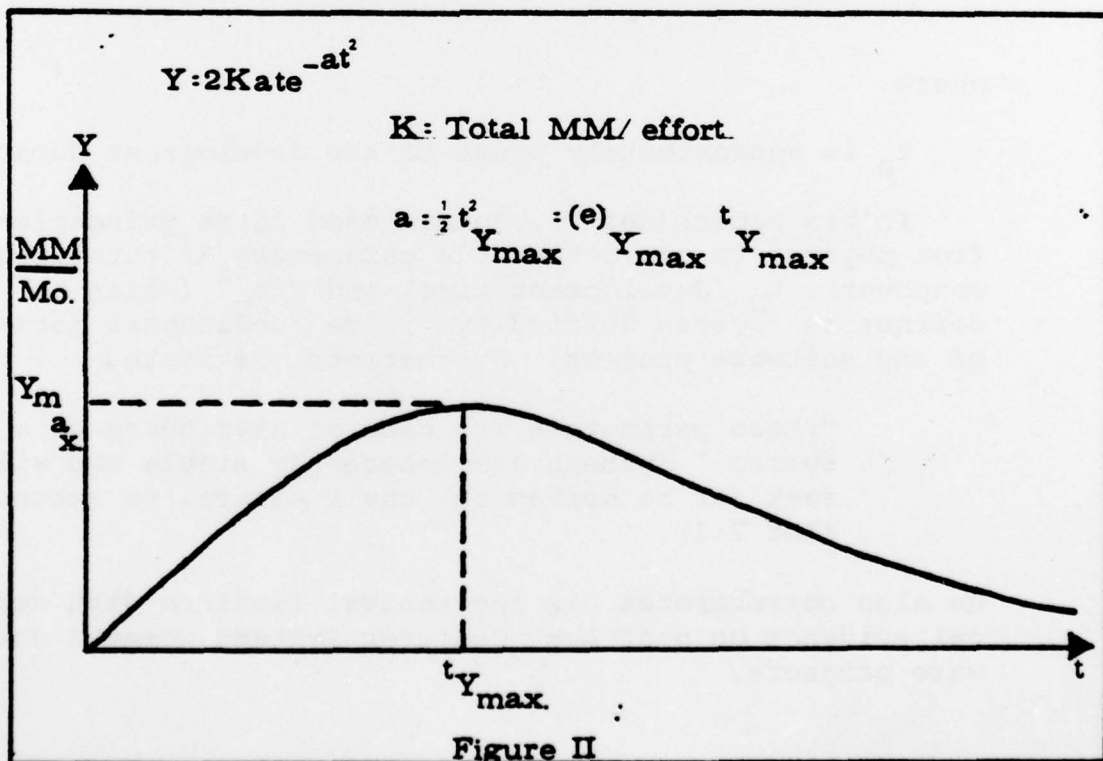
TABLE II

<u>Phase</u>	<u>Number of Months</u>	
	<u>Per Phase</u>	<u>Cumulative</u>
Code	.09 t_D	.52 t_D
Checkout	.085 t_D	.605 t_D
Package Test	.20 t_D	.805 t_D
System Test	.195 t_D	1.0 t_D

MANLOADING

The MANLOADING stage serves to spread the manpower provided by MANPOWER over the schedule(s) provided by SCHEDULE. To do so, it applies the software life cycle curve developed by Putnam (Ref 7).

Putnam's software life cycle curve is a tailored version of a generalized project life cycle manloading curve derived and observed by Norden of IBM (Ref 6). The curve, illustrated in Figure II, is given by



$$Y = 2 K a t e^{-at^2}$$

where

Y = manmonths/month

K = total life cycle manpower

a = shape parameter

e = 2.71828

Applying the Norden curve to U.S. Army Computer Systems Command software developments, Putnam shows that Norden's curve can be written as

$$Y = (k/t_D^2) t e^{-t^2/2t_D^2}$$

where

t_D is approximately equal to the development duration.

In his paper (Ref 7), Putnam uses first principles from physics to prove that the parameters K (total required manpower), t_D (development time) and K/t_D^2 (which he defines as "system difficulty"), are fundamental parameters of any software project. Furthermore, he states

"These parameters are natural attributes of a system. Systems are inherently stable and will seek (or be driven to) their natural parameters."
(Ref 7:2)

He also corroborates his theoretical findings with empirical evidence on past Army Computer Systems Command software projects.

The hypothesis that development schedule is a "natural" parameter which systems will be driven to also corroborates well with experience outside of Army Computer Systems Command. For example, at ESD the validity of the hypothesis is evident in view of the fact that virtually all software developments have historically experienced schedule slips. (One might argue that these slips are the result of optimism in planning a schedule, acting in place of realism with respect to a natural schedule.)

In further support of this natural schedule phenomenon, Brooks, manager of the IBM 360 Operating System development, observes that "the urgency of the patron may govern the scheduled completion of the task, but it cannot govern the actual completion." (Ref 1:47). He then goes on to state "Brook's Law", which is consistent with Putnam's findings:

"Adding manpower to a late software project makes it later." (Ref 1:48)

To demonstrate this consistency, we note that Putnam's difficulty factor $D = K/t_D^2$ is also hypothesized and demonstrated empirically to be a natural system parameter. Such being the case, an increase in manpower (K) must be accompanied by an increase in development time (t_D) if difficulty (K/t_D^2) is to remain constant.

Table III depicts Doty's observation of expenditure profiles in the general case. In Table IV, we compare Doty's expenditure profile with the manpower expenditure profile obtained by evaluating the integral form of Putnam's curve at the appropriate points in the development schedule, and note a close correlation.

MANLOADING uses Putnam's curve to time phase the development manpower generated by MANPOWER against a development schedule generated by SCHEDULE. Additionally, if the user so desires, he can enter an externally provided schedule (such as one imposed by higher headquarters). In this case, MANLOADING generates two manloading profiles (against natural and imposed schedules).

DEVELOPMENT PHASE	DEVELOPMENT MILESTONE	AVERAGE DISTRIBUTION OF EFFORT			
		SCHEDULE		EXPENDITURES	
		%	CUM%	%	CUM%
ANALYSIS	COMPLETE SYS. DESIGN (PDR)	10	10	3	3
DESIGN	COMPLETE PKG. DESIGN	25	35	17	20
	COMPLETE UNIT DESIGN	8	43	7.5	27.5
CODING	COMPLETE UNIT CODING	9	52	11	38.5
CHECKOUT	COMPLETE UNIT DEBUGGING	8.5	60.5	10	48.5
TEST AND INTEGRATE	COMPLETE PKG. TEST	20	80.5	27	75.5
	COMPLETE SYS. TEST	19.5	100	24.5	100

DISTRIBUTION OF DEVELOPMENT EFFORT
TABLE III

DEVELOPMENT MILESTONE	CUMULATIVE DEVELOPMENT	CUMULATIVE EXPENDITURES (DOTY)	CUMULATIVE MANPOWER EXPENDITURES (PUTNAM)
COMPLETE SYS. DESIGN	.1 t_d	3%	1.3%
COMPLETE PKG. DESIGN	.35 t_d	20%	15.1%
COMPLETE UNIT DESIGN	.43 t_d	27.5%	22.6%
COMPLETE UNIT CODING	.52 t_d	38.5%	32.3%
COMPLETE UNIT DEBUGGING	.605 t_d	48.5%	42.3%
COMPLETE PKG. TEST	.805 t_d	75.5%	71.0%
COMPLETE SYS. TEST	1.0 t_d	100.0%	100.0%
CORRELATION R=.998			

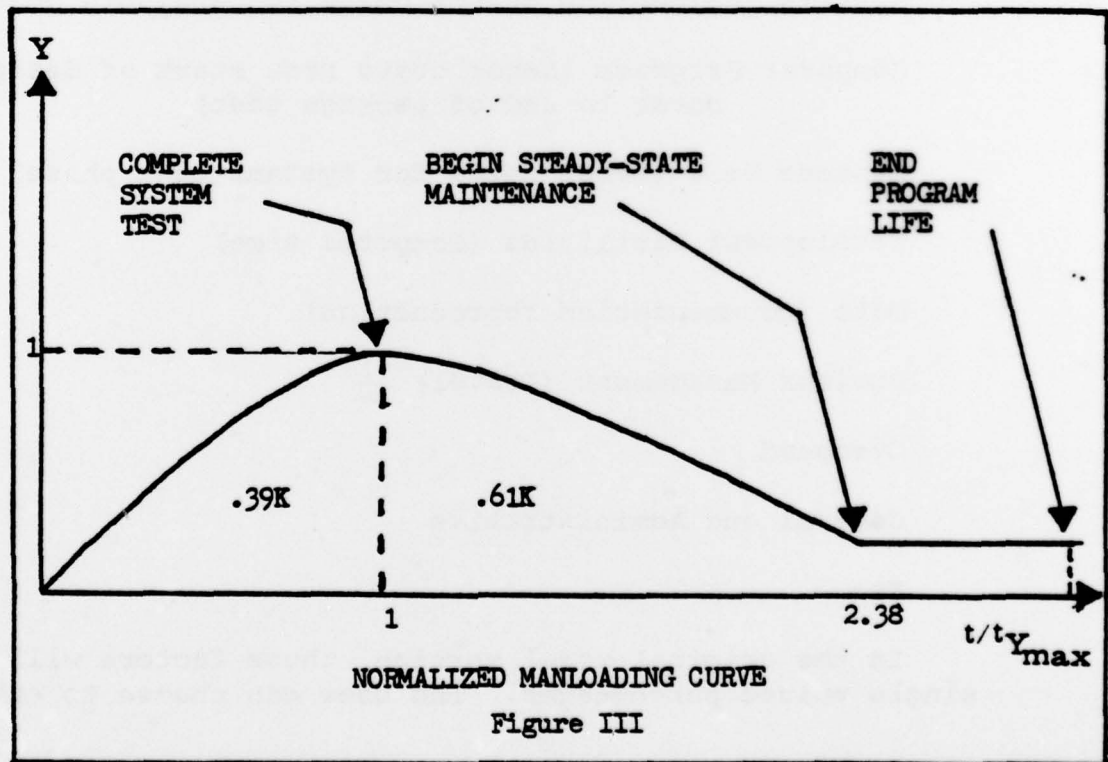
DOTY VS PUTNAM EXPENDITURE/MANPOWER PROFILE

TABLE IV

LIFE-CYCLE MANLOADING

In generating the manloading profile, MANLOADING employs two observations made by Putnam. The first is that development manpower (area under the curve up to $t = t_d$) is approximately 39% of total life cycle manpower. The second is that, in reality, the manpower level for maintenance levels off at $t = 2.38 t_d$, to its value of Y at that point. As shown in Figure III, where t_d and Y_{max} are normalized to 1, MANLOADING assumes a level manloading at $t = 2.38 t_d$ and simply increments time until the area under the curve equals K , at which time the system life cycle is assumed to be over.

As shown in Figure I, the dual schedule output of MANLOADING serves as input to COST.



COST

To this point, the model has generated time phased life cycle manloading requirements. COST serves to generate constant and then-year (escalated) cost estimates by cost category and budget appropriation.

DEVELOPMENT COST

To determine development costs, COST multiplies the time phased manloading profile by a user-supplied average labor rate, in dollars per manmonth (including overhead, and general and administrative costs, as appropriate). It then multiplies the estimated time-phased labor-related costs by cost factors derived by Doty for secondary resources such as computer time, documentation reproduction, and travel. COST then allocates estimated costs on a time phased basis to the following cost categories:

Systems Engineering (Labor costs for analysis phase)

Computer Programs (Labor costs from start of design phase to end of package test)

Systems Test (Labor costs for systems test phase)

Development Facilities (Computer time)

Data (Documentation reproduction)

Project Management (Travel)

Overhead

General and Administrative

Fee

In the original model version, these factors will be single valued percentages. The user can choose to enter

his own percentages, or use default values pre-loaded in the model.

As an option, the user can specify the base year for his average labor rate, and expected starting month for the development. COST then presents the time-phased cost estimate for the above nine cost categories by applying approved Office of the Secretary of Defense (OSD) escalation factors for the 3600 (research and development) appropriation.

TRANSITION COSTS

For purposes of this model, the transition period is defined to be that portion of the life cycle between end of development and start of steady state maintenance. Activities during this period involve operational test and evaluation, enhancement, and correction of major design and coding errors. As shown in Figure IV, manpower during this period of time is assumed to consist of a mix of contractor and government personnel, with the government level building up linearly from zero to the steady state maintenance level during this period.

During this phase, COST first calculates the government level and subtracts it from the total level. It then costs the contractor segment (for all nine cost categories) in the same fashion as the development phase. It costs the government portion by applying user-supplied cost factors found in AFM 173-10, USAF Cost Planning Factors.

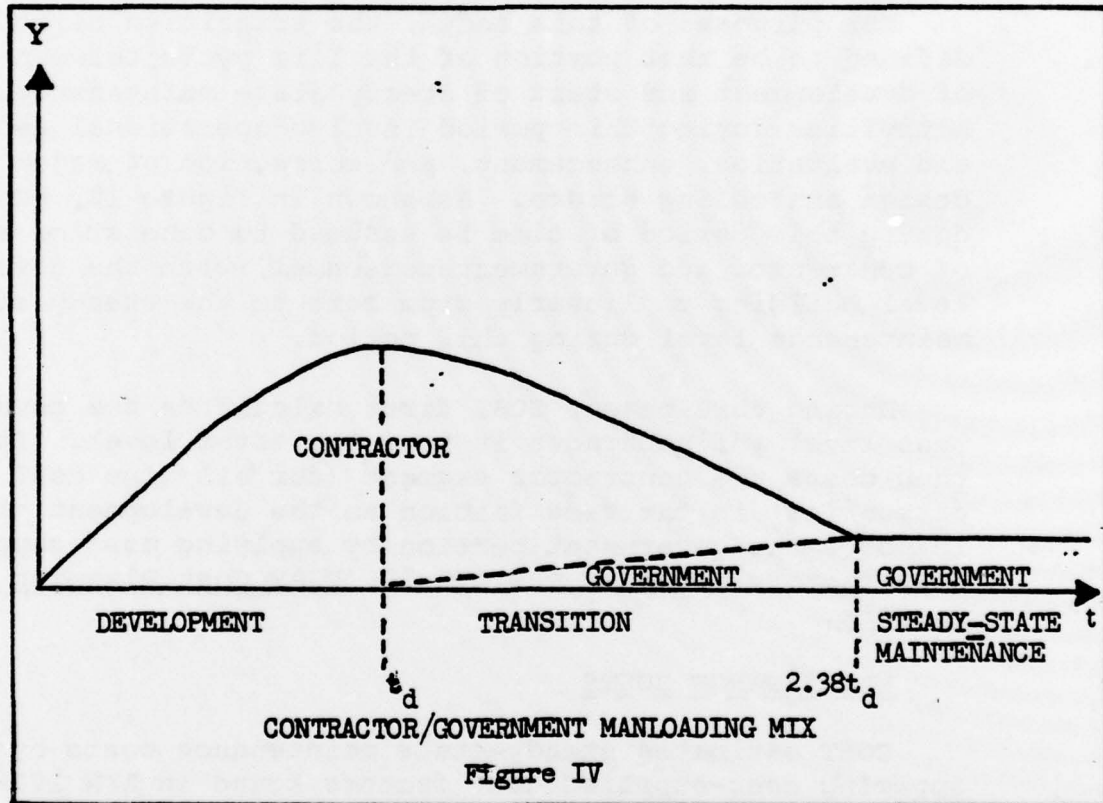
MAINTENANCE COSTS

COST estimates steady-state maintenance costs by applying user-supplied cost factors found in AFM 173-10 to the steady-state maintenance level.

COST RISK

COST calculates time-phase development, transition, and maintenance costs for manloading profiles based upon

both estimated development schedule and external, imposed development schedule (if one is provided). In the case where an external schedule is provided, the model takes the cost differences between the two profiles on a month-by-month basis and generates a time-phased schedule cost risk profile.



SECTION IV

MODEL FEATURES

In Section III, we discussed the basic model structure. In this section, we discuss some of the features which will be implemented in the computer version.

ENTRY POINT SELECTION

Depending upon where the software project is in its life cycle, the analyst may wish to by-pass certain stages. For example, if the project has progressed beyond detailed design, the cost analyst may have contractor provided sizing estimates in which he has high confidence; in that case, he would prefer to by-pass SIZING.

The model will be implemented so as to allow the analyst to select his entry point.

BACK_CHECK_OPTION

This option will allow the analyst to exercise certain stages in reverse, as a check on data he may have received from other sources. For example, suppose he has externally-provided estimates of size, manpower, and development schedule and chooses to enter the model at MANLOADING. By exercising the bench-check option, the analyst can solve the inverse of the Doty ERs to obtain an estimate of size as a function of manpower and environmental factors. The resulting estimated size then serves as a check on the externally-provided sizing estimate.

MULTIPLE_RUNS_MODE

For purposes of sensitivity analysis, the analyst may wish to perform multiple runs, varying only a single variable from run to run. In the Multiple Runs Mode, the

program will ask the analyst to declare that variable which will vary from run to run, and will ask for the value of only that variable on subsequent runs.

INTERIM STAGE OUTPUT MODE

In normal operation, the model will provide only time-phased cost profiles as output. In the Interim Stage Output Mode, the analyst will be able to declare stages for which he desires to receive output. For example, by declaring Stage 4 (MANLOADING), the analyst will direct the model to output the time-phased manloading profiles generated by that stage.

SECTION V

UNCERTAINTY

In the initial version of the model, uncertainty will be handled solely by user-conducted analysis of variations in output as a function of variations in input. Although such sensitivity analyses provide a first cut at analyzing the effects of uncertainty in specifying the system, they do not capture uncertainty inherent to parameters and relationships internal to the model.

Subsequent versions of the model will handle uncertainty inherent to the model by employing a combination of statistical analyses on the regressions underlying the ERs, and Monte Carlo sampling techniques on those parameters and relationships derived by techniques other than regression.

Detailed discussion of the handling of uncertainty via statistical and Monte Carlo techniques will be contained in a subsequent Technical Report.

SECTION VI

SUMMARY

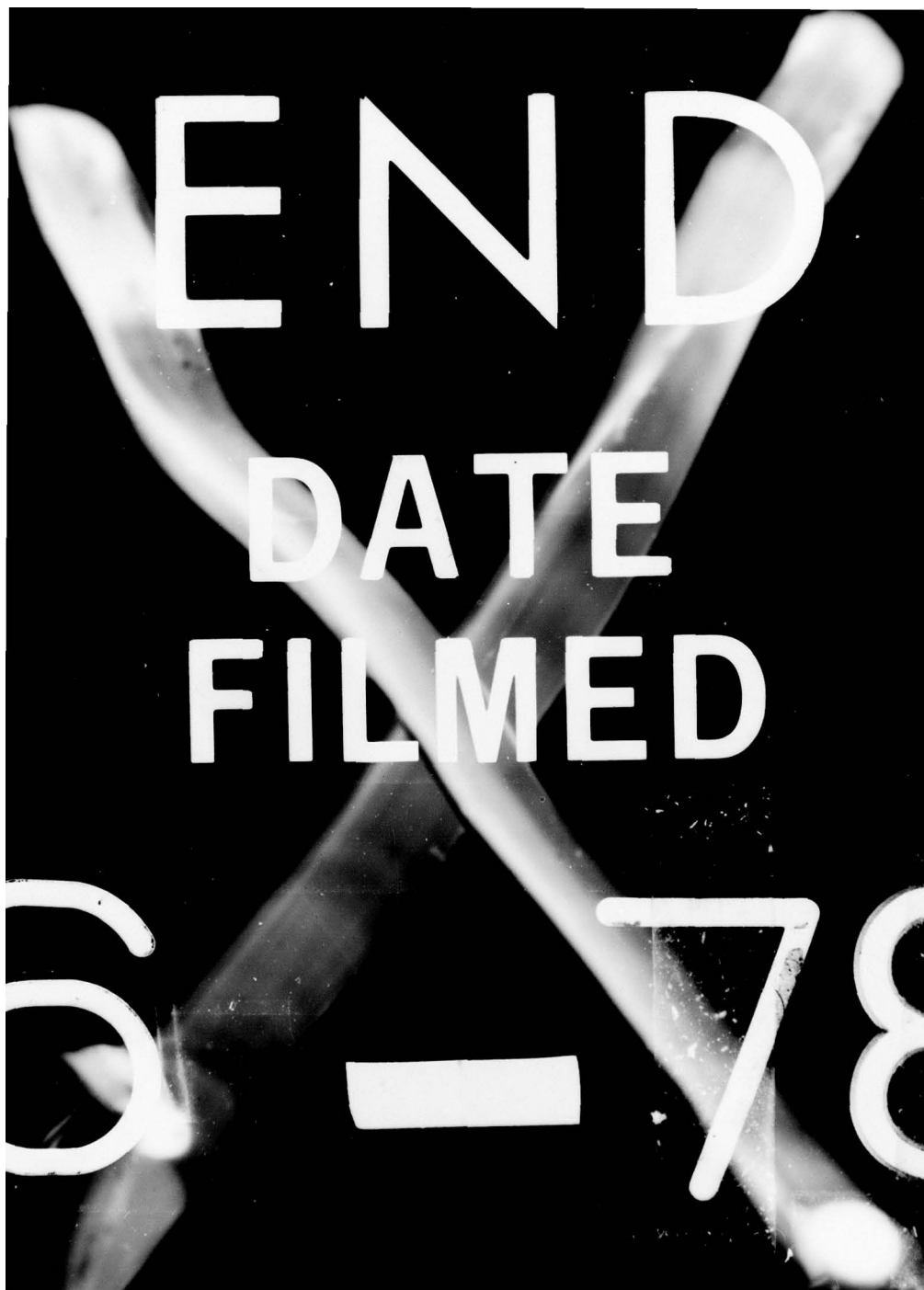
This report has outlined conceptually a software cost model incorporating and integrating recent and relevant research in various aspects of the software life cycle. The computer version of this model is currently (Winter 1978) being designed and implemented at ESD for use as a research and possible estimating tool.

The motivation for publicizing the model prior to its actual implementation is to motivate interest and discussion within the software cost estimating community. Hopefully, this interest and discussion will, in turn, result in widespread model usage and experimentation, with resulting successes and failures relayed back to ESD. Such feedback will be the primary means for testing and improving the model.

Individuals interested in discussing the model are encouraged to call Capt Joseph Duquette at (617)-861-2795, or AUTOVON 478-2795.

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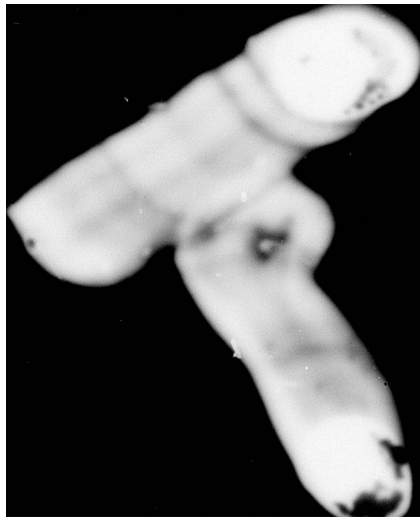
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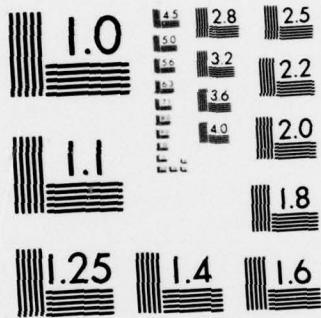
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SUPPLEMENTARY

INFORMATION

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