SOFTWARE METRICS

The Quantitative Impact of Four Factors on Work Rates Experienced During Software Development

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Abstract

This paper describes a model of the software development process which is being used at the IBM, Federal Systems Division. The model considers the software development process to consist of a sequence of activities, such as "program design" and "module development" (or coding). A manpower estimate is made by multiplying code size by the rates (man months per thousand lines of code) for each of the activities relevant to the particular case of interest and summing up the results. The effect of four objectively determinable factors (organization, software product type, computer type, and code type) on the productivity values for each of nine principal software development activities has been assessed. The analysis indicates that four factors can be identified which account for 39% of the observed productivity variation.

Software Cost Analysis By Work Components

Software development costs may be estimated by considering each of the activities or work components that constitute a particular software development process.[1] These components are the basis for a software engineering management model[2] used by the Federal Systems Division of IBM. Sixteen work components have been identified from which the software organization or the engineering organization involved in a software development project can structure its particular activities. Data on 9 of them served as the basis for the work reported upon here. This information was based on experience at the IBM, Manassas, Virginia facility. These work components are:

Software Requirements Definition - This work component includes the definition and/or analysis of functional, operational, and other software system requirements.

Software Development Planning - This work component includes all tasks necessary to generate the plans necessary for the implementation of the software system.

Functional Design - This work component covers the documentation of the functions the software must perform to meet the requirements imposed upon it.

Program Design - This work component covers the documentation of the software system from an internal viewpoint.

Module Development - This work component covers the tasks associated with the detailed design of the software modules and their coding and test.

Software Integration and Test (SWIT) - This work component covers the integration and testing of the software system and the analysis to determine if it meets the system requirements.

SWIT Problem Analysis and Error Correction - This work component covers the analysis and correction of software problems uncovered during SWIT.

System Test - This work component covers the hardware/software integration and test effort.

Acceptance Test - This work component covers the demonstration to the customer that the software system satisfies the requirements imposed upon it.

A cost estimate can be made by considering the nature of the particular software development job and the work components (such as program design, coding, etc.) that constitute it. Then, the labor (man months) for each component is estimated. The sum of these man month figures is the amount required for the given job. The labor for each work component is estimated as the product of the productivity rate (in man months per thousand source lines of code = MM/KSLOC) and the amount of source lines of code. Thus;

$$\text{Total labor (man months)} = \sum_{i=1}^{n} Pe_i \times S = SP_T$$

Where; n = number of work components

Pe_i = work rate #i

S = amount of source lines of code (=KSLOC).

The approach to considering the software development process as a sequence of activities with well-ordered time precedence relationships is a model long used by industrial engineers, and has been applied recently to modern electronic systems development.[3,4] Considering the development process in terms of its constituents enables the estimator to achieve a greater degree of intellectual control than if he were to evaluate the process overall. For example, it may not be clear how the availability of a new process that facilitates unit testing would impact overall development productivity. However, its effect on the work component that covers unit test would be much easier to discern. Then, the effect on overall productivity can be readily calculated by simply reviewing the appropriate rate (e.g. the proper "Pe_i" in the equation given above).

The Impact of Four Factors on Work Component Productivities

Earlier work has considered the effect on overall productivity of various factors relating to the complexity of the code to be developed, the skills of the software development work force, and other factors representative of the software development environment.[5, 6, 7, 8] This paper provides a quantitative assessment of the impact of several significant factors on the work rates of 9 specific work components.

A linear regression model was structured to relate the values of work rate in man months per KSLOC (MM/KSLOC), experienced in a reasonably large number of cases (typically more than 30 data samples), to variables representative of the factors; organization, software product type, computer type, and code type, involved in each case. The multiple correlation coefficient between the MM/KSLOC value and the encoded values of each of the variables was determined in each case. The square of this value times 100 is equal to the amount of variation in the given cost component 'explainable' by these four variables. Table 1 tallies their percentages, together with the sample size for each of the 9 work components that were evaluated.

Table 1 - Percentage of Variation in Work Rate Explainable by Four Factors(1)

Work Component	Percentage of Variation In Work Rate Explained By The Four Factors (1)	Number of Samples Used
Software Requirements	15.12	30
Software Development Plan	17.81	38
Functional Design	15.53	45
Program Design	38.43	66
Module Development	55.87	60
Software Integration and Test (SWIT)	46.90	51
SWIT-Problem Analysis and Error Correction	60.33	51
System Test	26.13	39
Acceptance Test	49.40	42
Average	36.17	47

(1); organization (2 alternatives); product types (2 alternatives); computer type (3 alternatives); code type (3 alternatives)

Table 1 shows that, on a work component basis, the percentage of variation explained by the four factors is 36.17%. However, on an overall project basis, this percentage increases to 39% value. This is because the percentage of variation explained is larger for those work components which represent a greater proportion of the overall software product development effort.

Conclusion

The methodology of 'bottom-up' or 'micro' software development cost estimation and analysis has been described. The definitions of the sixteen cost components used by the IBM Federal Systems Division were presented. The effects of knowledge of four factors in resolving the uncertainty of nine of these cost components were presented.

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THE VIEWGRAPH MATERIALS
for the
J. GAFFNEY/R. JUDGE PRESENTATION FOLLOW

THE QUANTITATIVE IMPACT OF FOUR FACTORS ON WORK RATES EXPERIENCED DURING SOFTWARE DEVELOPMENT

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WORK RATE

- WORK RATE IS AN INDICATOR OF PRODUCTIVITY WHICH USES SOURCE LINES OF CODE (SLOC) AS THE MEASURABLE

  LABOR (MAN MONTHS) = WORK RATE (MM/SLOC) • WORK (SLOC)

SOFTWARE WORK COMPONENTS

- o SOFTWARE REQUIREMENTS DEFINITION
- o SOFTWARE DEVELOPMENT PLANNING
- o FUNCTIONAL DESIGN
- o PROGRAM DESIGN
- o MODULE DEVELOPMENT
- o SOFTWARE INTEGRATION AND TEST
- o PROBLEM ANALYSIS AND ERROR CORRECTION
- o SYSTEM TEST
- o ACCEPTANCE TEST

ESTIMATION METHODOLOGY

$$\text{TOTAL LABOR (MAN MONTHS)} = \sum_{I=1}^{N} P_{E_I} \times S = M$$

WHERE:

M = MAN MONTHS

N = NUMBER OF WORK COMPONENTS

P_{E_I} = WORK RATE #I

S = NUMBER OF SOURCE LINES OF CODE

THE FOUR FACTORS

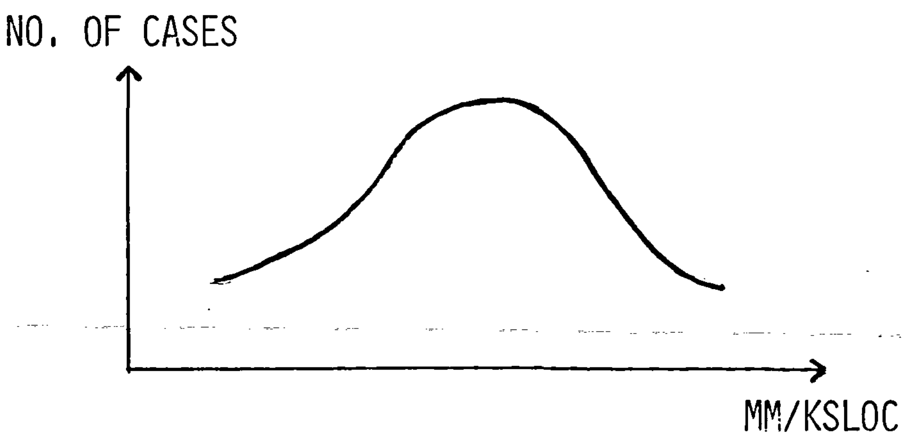
WHOSE EFFECT WAS ANALYZED

o	ORGANIZATION	(2 ALTERNATIVES)
o	PRODUCT TYPE	(2 ALTERNATIVES)
o	COMPUTER TYPE	(3 ALTERNATIVES)
o	CODE TYPE	(3 ALTERNATIVES)

OVERALL MAN MONTHS/KSLOC

DISTRIBUTION

(ONE PER WORK COMPONENT)



(SIMULATED)

PERCENTAGE OF VARIATION IN WORK RATE EXPLAINABLE BY FOUR FACTORS

WORK COMPONENT	PERCENTAGE OF VARIATION IN WORK RATE EXPLAINED BY THE FOUR FACTORS	NUMBER OF SAMPLES USED
SOFTWARE REQUIREMENTS	15.12	30
SOFTWARE DEV. PLAN	17.81	38
FUNCTIONAL DESIGN	15.53	45
PROGRAM DESIGN	38.43	66
MODULE DEVELOPMENT	55.87	60
SOFTWARE INTEGRATION AND TEST (SWIT)	46.90	51
SWIT-PROBLEM ANALYSIS AND ERROR CORRECTION	60.33	51
SYSTEM TEST	26.13	39
ACCEPTANCE TEST	49.40	42
AVERAGE	36.17	
WEIGHTED AVERAGE	39.00	

SUMMARY

- o DESCRIBED WORK COMPONENT APPROACH TO ESTIMATION
- o ASSESSED IMPACT OF FOUR FACTORS ON WORK RATE
- o DETERMINED THAT THESE FOUR FACTORS ACCOUNTED FOR 39% OF THE VARIABILITY IN THE OVERALL WORK RATE
- o EXPLAINED WHY THE RESULTS DEMONSTRATE THE POWER OF THE WORK COMPONENT APPROACH