Abstract—This paper describes research conducted by the Software Engineering Laboratory (SEL) on the use of dynamic variables as a tool to monitor software development. The intent of the project is to identify project independent measures which may be used in a management tool for monitoring software development. This study examines several Fortran projects with similar profiles. The staff was experienced in developing these types of projects. The projects developed serve similar functions. Because these projects are similar we believe some underlying relationships exist that are invariant between the projects. These relationships, once well defined, may be used to compare the development of different projects to determine whether they are evolving the same way previous projects in this environment evolved.

Index Terms—Database, management tool, measurement, monitoring software development.

Overview

The Software Engineering Laboratory (SEL) is a joint effort between the National Aeronautics and Space Administration (NASA), the Computer Sciences Corporation (CSC), and the University of Maryland established to study the software development process. To this end, data have been collected for the last six years. The data were from attitude determination and control software developed by CSC, in Fortran, for NASA. Additional information on the SEL, the data collection effort, and some of the studies that have been made may be found in papers from the Software Engineering Laboratory Series published by the SEL [1]-[3].

The interest in the software development process is motivated by a desire to predict costs and quality of projects being planned and developed. For several years, studies have examined the relationships between variables such as effort, size, lines of code, and documentation [4], [5]. These studies, for the most part, used data collected at the end of past projects to predict the behavior of similar projects in the future. In 1981 the SEL concluded that many of these factors were too dependent on the environment to be useful for the models that had been developed [6]. Any model which attempts to trace these relationships should therefore be calibrated to the environment being examined. The meta-model proposed by the SEL is designed for such flexibility [6].

Another way to isolate out the environment dependent factors is by comparing two internal factors of a project, thus ignoring all outside influences. One approach that is used to monitor software development examines the time gap between the initial report of software problems and the complete resolution of the problem [7]. Comparing two variables is useful because it also accentuates problem areas as they develop, providing relative information rather than absolute information. Relative information is useful to the project manager because it accentuates trends as the project develops. If project environments are similar, then similar values should be expected. Because the project environments in the SEL are similar, it was felt that this approach could be further extended to provide managers with information about how a set of variables over the course of a project differed from the same set of variables on other projects (baselines). The managers could be alerted to potential problems and use other variable data and project knowledge to determine whether the project was in trouble.

This methodology is flexible enough to respond to changing needs. Every time a project is completed the measures collected during its development may be added in to calculate a new baseline. In this way, the methodology can incorporate changes in the environment, as they occur.

Baselines might also be developed to reflect different attributes. For instance, several projects which had good productivity might be grouped to form a productivity baseline. Once baselines are established, projects in progress may be compared against them. All measures falling outside the predetermined tolerance range are interpreted by the manager.

Methodology

The implementation of this methodology is dependent on two factors. The first factor is the availability of measures that are project independent and can also be collected throughout a project's development. Variables like programmer hours and number of computer runs are project dependent. By comparing these variables against each other a set of relative measures may be generated which is project independent. For instance, the number of software changes may vary from project to project. The project dependent features shared by each variable will cancel out when the ratio of software changes per computer run is taken. The resulting relative measure is project independent.

The second factor is the need for fixed time intervals common to all projects. To normalize for time, project milestones

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C. W. Doerflinger was with the Department of Computer Science, University of Maryland, College Park, MD 20742. He is now with Texas Instruments Incorporated, Lewisville, TX 75067.

V. R. Basili is with the Department of Computer Science, University of Maryland, College Park, MD 20742.

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were used. The time into a project might be 20 percent into coding instead of 10 weeks into the project, for instance.

When computing the baselines one other factor was considered. At any given interval during development a variable may measure either the total number of events that have occurred from the beginning of development (cumulative) or the number of of events that have occurred since the last measured interval (discrete). Since these approaches may convey different information it was felt that they both should be used.

For simplicity, the baseline for each relative measure was defined as the average and standard deviation computed for the measure at predetermined intervals. A project's progress may now be charted by the software manager. At each interval in a project's development the relative measures are compared to their respective baseline. Any measures outside a standard deviation are flagged. These measures are then interpreted by the project manager to determine how the project is progressing. A flagged measure may indicate that a project is developing exceptionally well or it may indicate that a problem has been encountered.

The interpretation of a set of flagged measures is a three step process. First, the manager must determine the possible interpretations for each flagged relative measure using lists of possible interpretations developed and verified based on past projects.

Second, the union of the lists of possible interpretations of each flagged measure must be taken. The list formed by this union contains all the possible interpretations ordered using the number of times each interpretation is repeated in the different lists. The larger the number of overlaps a possible interpretation has, the greater the probability it is the correct interpretation.

Third, the manager must analyze the combined list and determine if a problem exists. Interpretations with an equal number of overlaps all have an equal probability of being the correct interpretation. If none of the possible interpretations for a given relative measure overlap then the relative measure should be considered separately.

When analyzing the interpretations, three pieces of information must be considered: the measurements, the point in development, and the managers knowledge of the project. A relative measure may indicate different things depending on the stage of development. For instance, a large amount of computer time per computer run early in the project may indicate not enough unit testing is being done. Personal knowledge may also give valuable insight.

A fundamental assumption for using this methodology is that similar type projects evolve similarly. If a different type of project were compared to this database, the manager would have to decide whether the baselines were applicable. Depending on the type of differences, the established baselines may or may not be of any value.

Example 1

Forty percent into coding a software manager finds that the lines of source code per software change is higher than normal. A list previously developed is examined to determine what the relative measure might indicate. The possible interpretations for a large number of lines of source code per software change might be:

1) good code,
2) easily developed code,
3) influx of transported code,
4) near build or milestone date,
5) computer problems,
6) poor testing approach.

If this were the only flagged measure the manager would then investigate each of the possibilities. If the value for the measure is close to the norm, less concern is needed than if the value is further away.

If in addition to lines of source code per software change the number of computer runs per software change was higher than normal, the manager would also examine this measure. The possible interpretations for a large number of computer runs per software change might be:

1) good code,
2) lots of testing,
3) change backlog,
4) poor testing approach.

The union of the possible interpretations of these two measures indicates that the strongest possible interpretations are 1) good code and 2) a poor testing approach. The number of possibilities to investigate is smaller because these are the only measures which overlap. The manager must now examine the testing plan and decide whether either of these interpretations reflect what is actually occurring in the project. If these two possible interpretations do not reflect what is happening on the project, the manager would then examine the other interpretations.

Baseline Development

To develop a baseline one must first have variables whose measurements were taken weekly for several projects. Five variables in the SEL database were used. The lines of source code, number of software changes, and number of computer runs were collected on the growth history form. The amount of computer time and programmer hours were collected on the resource summary form. Measurement of these variables started near the beginning of coding. In this study, nine separate projects were examined whose development was documented, with sufficient data, in the SEL database. The projects ranged in size from 51 to 112K lines of source code with an average of 75K. No examination was done for the requirements or design phases.

Once the variables were chosen the average and standard deviation was computed for each baseline. Some baselines suffered from limited data points during the beginning of the coding phase. A couple of the projects, in which problems were known to have existed, were flagged as soon as data on these projects appeared, but this was 50 percent of the way into coding. It is not known how much earlier they would have appeared if data existed at the early intervals.

Interpretation of Relative Measures

Once a set of baselines are established, new projects may be compared to them and potential problems flagged. To interpret these flagged relative measures a list should be developed
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Fig. 1. Computer runs per line of source code.

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Fig. 2. Computer time per line of source code.

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Fig. 3. Software changes per line of source code.

with each measure's possible interpretations. Each list must consider the possible interpretations of the relative measure when it is either above normal or below normal. What each component actually measures should also be considered when the different lists are developed.

A list was developed with possible interpretations for each relative measure being examined in the context of the SEL environment (Figs. 1-9). In another environment the interpre-
tation of these measures might be different. These lists are subdivided into two categories; above and below normal. The above normal category contains possible interpretations for the relative measure when it is outside one standard deviation from the average in the positive direction. The below normal category refers to interpretations when the measure is outside one standard deviation from the mean in the negative direction.

One of the reasons this methodology works is because of the implicit interdependencies between different relative measures. To show these interdependencies more explicitly a cross reference chart has also been provided (Fig. 10) for each interpretation to indicate other relative measures that can have the same interpretation. A number in the cross reference section indicates the list number of a relative measure that can have the same interpretation. The position of the list number in the four-quadrant cross reference section indicates whether both interpretations are found with above normal values, both with below normal values, or one with above and the other with below normal values.

With these lists a set of flagged relative measures may be evaluated. When a relative measure is flagged, its associated list is examined for possible interpretations. Overlaps of this list with the lists of other flagged relative measures form the new list of what these relative measures together might indicate. The more overlaps a particular interpretation has, the greater the chance it is the correct interpretation. Interpretations with the same number of overlaps must be considered equally. The more relative measures flagged the more serious the problem may be. It is up to the manager to determine whether the deviation is good or bad.

**Monitoring a Software Project's Development**

Once the baselines have been developed and the lists of possible interpretations have been put together a software manager...
may monitor the actual development of a project. Example 1 demonstrated how a single interval may be interpreted. The following discussion will trace the development of an actual project. During the actual use of this methodology, influence would be exerted to correct problems as soon as they are identified. With this study, we must be content to study a projects evolution, without hindrance, and see at what points problems could of been detected.

Project twenty\(^1\) was chosen for this examination because data existed throughout the projects development. In most respects project twenty was an average project. The project did have a lower than normal productivity rate. The lower rate may be partially explained by the fact that the management was less experienced when compared to other projects. The project also suffered from some delayed staffing. Changes in staffing will be noted when the different time intervals are discussed.

Table I (a) and (b) on the following page shows which relative measures were flagged when project twenty was compared to the baselines for each stage of development. The numerical values represent how many standard deviations each flagged relative measure was from the baseline. The baseline for each relative measure was calculated using all nine projects.

**Start of Coding**

At the start of coding only one relative measure is flagged. The smaller than normal number of software changes per line of source code using the discrete approach reflects work done during the design phase. The lists designed in the previous section were directed towards code production and testing and do not apply to this time interval when using the discrete approach. This measure may indicate good specifications or lots of PDL being generated. The manager might want to examine this measure later if it constantly repeated. Since it is the only measure flagged at this time it will be ignored.

**20 Percent Coding**

The flagged relative measures found using the discrete approach at this point represent the work done from the start of coding until 20 percent of the way through coding. The list of possible interpretations for the flagged relative measures, generated from the lists made previously for the individual relative measure, would look as follows.

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<th>#Overlaps</th>
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<td>Bad specifications</td>
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<td>3</td>
<td>Code removed</td>
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<td>2</td>
<td>Low productivity</td>
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<td>2</td>
<td>High complexity</td>
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<td>2</td>
<td>Error prone code</td>
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<tr>
<td>1</td>
<td>Lots of testing</td>
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<tr>
<td>1</td>
<td>Good testing</td>
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<td>1</td>
<td>Changes hard to isolate</td>
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<tr>
<td>1</td>
<td>Changes hard to make</td>
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<tr>
<td>1</td>
<td>Unit testing being done</td>
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<tr>
<td>1</td>
<td>Easy errors being found</td>
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The strongest interpretations are bad specifications and code being removed. If the actual history is examined one finds that during this period there were a lot of specifications being changed. This resulted in code which was to be modified being discarded and new code being written. During the early period a lot of PDL was being produced but very little new executable

\(^{\text{1The numbering convention used is an extension of the one first used by Bailey and Basil}}\)
The list of possible interpretations does show that low productivity is also a strong possibility.

### 40 Percent Coding

The flagged relative measures which appear using the cumulative approach, from this time period on, are stronger indicators than the ones used in the first couple of intervals because the average is computed using more data points. The use of the discrete approach for the interval of 20-40 percent is still dependent on three data points. The list of possible interpretations for this time period is as follows.

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The number of possibilities is larger with this set of possible interpretations. Five interpretations are slightly stronger than the others. During the actual development, the first release of the project was made. The amount of code actually written was also lower than normal during this period. The use of the discrete approach gives a stronger feeling that code is not being written. Transported code tends to be installed in large blocks which can be isolated using the discrete approach.

### 50 Percent Coding

The relative measures flagged during this period are the same as the ones flagged at the 20 percent coding interval. The deviation from the norm for this interval is larger. The larger deviation may indicate a more serious problem. The problem may have been just as serious earlier, but without the extra data points that are now available, it could not be determined. The possible interpretations may be taken from the list developed earlier. Bad specifications and code removal were not factors during this period. The next three highest priority interpretations were high complexity, error prone code, and low productivity. In addition to this, the manager should be concerned with the continued appearance of the relative measure and programmer hours per computer run, as seen using the cumulative approach. This may indicate a lot of testing going on. This in conjunction with error prone code as a possible interpretation may indicate trouble. During actual development this period was spent developing code for the second release. The project manager felt that code was still not being developed quickly enough during this period.

### 80 Percent Coding

The 80 percent coding interval does not show any measures outside the normal bounds. The addition of two staff members during the 60 percent coding phase, as well as the addition of a senior staff member during this phase, appears to have adjusted the project back along the lines of normal development. To fully compensate for the earlier problems one might expect some of the measures to swing in the other direction away from the average. The fact that this over correction did not occur might explain the problems encountered in the next section.

### Start of System and Integration Testing

The flagged relative measures at this time period reflect the build up of effort for the third and final release. The list of possible interpretations for the collective set of flagged measures looks as follows.

<table>
<thead>
<tr>
<th>#Overlaps</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>High complexity</td>
</tr>
<tr>
<td>3</td>
<td>Bad specifications</td>
</tr>
<tr>
<td>3</td>
<td>Code being removed</td>
</tr>
<tr>
<td>2</td>
<td>Error prone code</td>
</tr>
<tr>
<td>2</td>
<td>Low productivity</td>
</tr>
<tr>
<td>2</td>
<td>Lots of testing</td>
</tr>
<tr>
<td>1</td>
<td>Changes hard to isolate</td>
</tr>
<tr>
<td>1</td>
<td>Unit testing being done</td>
</tr>
<tr>
<td>1</td>
<td>Good code</td>
</tr>
<tr>
<td>1</td>
<td>Poor testing</td>
</tr>
<tr>
<td>1</td>
<td>Changes hard to make</td>
</tr>
<tr>
<td>1</td>
<td>Good testing</td>
</tr>
<tr>
<td>1</td>
<td>Compute bound algorithms being run</td>
</tr>
<tr>
<td>1</td>
<td>Easy errors being fixed</td>
</tr>
</tbody>
</table>

Since the code did have a past history of poor testing, an unusually large build-up of testing should be expected. The two interpretations that apply most to this situation are lots of testing and error prone code.

### 50 Percent System and Integration Testing

Only one relative measure is flagged at this interval. This measure was flagged using the cumulative approach. An exam-
Flagged relative measures might also be interpreted using a decision support system. The data for the various relative measures would be stored in a knowledge base along with a set of production rules. To evaluate a project the values for each relative measure would be entered into the system. The knowledge base would compare the relative measures to their respective baselines, determine which relative measures were outside the norm, and interpret those relative measures using the production rules. A list of possible interpretations ordered by probability would be generated as a result.

The difference between a decision support system and the approach presented in this paper is the method of interpreting the flagged relative measures. Each production rule in the decision support system is the logical disjunction of several flagged measures which yields a given interpretation. Each production rule is assigned a confidence rating which is then used to rate the possible interpretations. The lists for the relative measures provided earlier in the paper may be easily converted to production rules using the cross reference section. To develop the production rules for an interpretation one must generate the various combinations of relative measures which might reasonably imply the interpretation. Some relative measures may not imply a particular interpretation unless they are found in conjunction with another relative measure. Once the production rules are known and a knowledge base constructed a decision support system may be built. For an example of a domain independent decision support system see Reggia and Perricone [8].

**Summary**

The methodology presented in this paper showed that invariant relationships exist for similar projects. New projects may be compared to the baselines of these invariant relationships to determine when projects are getting off track.

The ability of the manager to interpret the measures that fall outside the norm is dependent on the amount of information the underlying variables convey. The manager must decide what attributes are to be measured (e.g., productivity) and pick variables that are closely related to them and are also measurable throughout the project. An example, a variable like lines of code may be too general when measuring productivity. Measuring the newly developed code, either source code or executable code, would be more informative since these variables are more directly related to effort. How applicable an interpretation is for the period currently being examined should also be considered when ordering the list. The variables the manager finally decides on are then combined to form relative measures.

One method of interpreting a relative measure is by associating lists of possible interpretations with it. When a relative measure appears outside the norm, the list of possible interpretations is considered. If more than one relative measure is outside the norm the lists are combined. The more times a possible interpretation is repeated in the lists, the greater the probability it is the cause. How applicable an interpretation is for the
period being examined should also be considered when ordering
the list. The manager must investigate the suggested causes to
determine the real one.

CONCLUSION
The ability to monitor a projects development and detect
problems as they develop may be feasible. The methodology
proposed showed favorable results when examining a past case.
The use of baselines and lists of interpretations for comparing
projects provides an easy method for monitoring software de-
velopment. Both the baselines and the lists of interpretations
may be updated as new projects are developed. As more knowl-
edge is gleaned the accuracy of this system should improve and
provide a valuable tool for the manager.

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Carl W. Doerflinger (S'82-M'83) was born in
Fort Sill, OK, on March 17, 1956. He received
the B.S. degree from the University of North
Carolina, and the M.S. degree from the Univer-
sity of Maryland, College Park.
He is now with Texas Instruments, Lewisville,
TX. His current interests include system man-
agement and performance issues.
Mr. Doerflinger is a member of the Associa-
tion for Computing Machinery.

Victor R. Basili (M'83-SM'84) is Professor and
Chairman of the Department of Computer Sci-
ence at the University of Maryland, College Park.
He was involved in the design and development of
several software projects, including the SIMPL
family of programming languages. He is cur-
cently measuring and evaluating software de-
velopment in industrial settings and has consulted
with many agencies and organizations, including
IBM, GE, CSC, GTE, MCC, NRL, NSWC, and
NASA. He has authored over 60 published
papers on the methodology, the quantitative analysis, and the evalua-
tion of the software development process and product.
In 1982, Dr. Basili received the Outstanding Paper Award from theIEEE
TRANSACTIONS ON SOFTWARE ENGINEERING. He was Program Chairman for the
Sixth International Conference on Software Engineering, and the First ACM
SIGSOFT Software Engineering Symposium on Tools and Methodology Eval-
uation. He serves on the editorial boards of the Journal of Systems and Soft-
ware and the IEEE TRANSACTIONS ON SOFTWARE ENGINEERING. He is a mem-
ber of the Association for Computing Machinery and the Executive Committee
of the Technical Committee on Software Engineering, and is a Senior Mem-
ber of the IEEE Computer Society.