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CONTINGENCY APPROXIMATION IN MILESTONE SETTING FOR NAVY R AND D ACTIVITIES

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Report analyzes impact of contingencies upon different categories of projects and tests a new method for determining milestone progression.

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Contingency Approximation in Milestone Setting
For Navy R and D Activities

Introduction

The results of the study reported here are concerned with the planning and control aspects of the contingency approach to management which encompass milestone setting and the problems related to estimating completion dates for projects.[1] This investigation was empirical even though it did not have a specific theory or algorithm to test. Rather, it was guided by the hypothesis that in the work situations for a specific research and development project, it is possible to calculate how much time will be lost from the schedule because of job related breakdowns, disruptions, unforeseen events and all other problems which are classified as contingencies. Although the proponents of a contingency theory of management have primarily concentrated on proving through experimental and field data that there is no single best way to organize for effective results, the preceding hypothesis is suggested by the literature in that several studies have focused on understanding the factors which some organizations can control or manipulate to produce more effective results than others are able to accomplish.[2] The findings of this study add a dimension to the concepts of previous studies in that once the parameters causing slippages in the schedule are identified, it

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[1] The development of a contingency theory of organization is discussed in Paul R. Lawrence and Jay W. Lorsch, Organization and Environment (Boston: Harvard Business School, Division of Research, 1967), 185-210.

[2] See generally, Joan Woodward, Industrial Organizations: Theory and Practice (London: Oxford University Press, 1965); James Thompson, Organizations in Action (New York: McGraw-Hill, 1967); Jay W. Lorsch and John G. Morse, Organizations and Their Members: A Contingency Approach (New York: Harper and Row, 1974).

appears that it will be possible to roughly compute an average percentage of individual job and overall project time lost because of the contingencies which occur within a certain interval.

The foundation for this hypothesis was developed in the summer of 1976 during research conducted at the Dahlgren Laboratory of the Naval Surface Weapons Center.[3] That research looked at how management by objectives is implemented at the division and section levels in a Navy R and D laboratory, and it was learned that the most frequently recurring detriment to the success of MBO was an inability to set precise milestones for completing the objectives involved in a project. Moreover, there was a noticeable absence of any scientifically reliable approach to establishing target dates.

As a result of the scheduling deficiency uncovered by the first Dahlgren survey an effort was undertaken to derive tools of a quantitative nature which could serve as a realistic and practical guide for a manager faced with the problem of ascertaining time posts for the completion of an objective or with the related and nearly equivalent problem of estimating how long it will take to complete a project. The development of more valid tools would, of course, be relevant to management philosophies such as MBO wherein any meaningful objective must have a time milestone, and the milestone in turn must be as accurate as possible.[4] A realistic milestone for each objective not only provides the basis for correctly setting final due dates but it also furnishes the means for computing project costs and for

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[3] See Philip L. Martin, Lee W. Johnson, Richard P. McNitt and Warren L. Stutzman, Management by Objectives in a Navy R and D Laboratory (Technical Report No. 1: Office of Naval Research, 1976).

[4] Paul Mali, Managing by Objectives (New York: John Wiley and Sons, 1972), 15.

allocating resources. The best understood and most widely used computational method for establishing milestones is the program evaluation and reporting technique (PERT) developed by the Office of Naval Research in the 1950's for the Polaris program.[5] It, therefore, constituted the beginning for conducting research.

Research Design

In order to describe the planned line of investigation it is first necessary to refer briefly to the algorithm used by PERT in estimating the time of completion for a single task or activity; that is, the time assigned to an edge in a PERT network. Most of the PERT networks encountered at the Dahlgren Laboratory are calculated by using some variant of the formula

$$t_e = \frac{a + 4m + b}{6}$$

where a represents the shortest time for completion of the task, m represents the most likely time, and b is an estimate of the longest time. By its very nature the mean time t_e is biased by the inaccuracies inherent in the quantities m and b. To be more specific, the time a is probably the best piece of data since most competent and experienced managers can approximate the completion time of a task fairly accurately under the assumption that everything goes smoothly (in a sense a given task has a minimum completion time that most managers can agree on). On the other hand, there is no upper bound on the number of things that can go wrong, so the

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[5] See Harvey M. Sapolsky, The Polaris System Development: Bureaucratic and Programmatic Success in Government (Cambridge: Harvard University Press, 1972). Chap. 4.

estimate b of the worst time is the result of subjective reasoning. Finally, if a manager is to estimate the most likely time m, he will frequently calculate the optimistic time a and then add a contingency factor. This contingency factor will vary from manager to manager, but a particular manager will use a factor that appears reasonable to him on the basis of past experience.

This study focused on the contingency factor in an attempt to derive a milestone setting procedure that somewhat models the manager's method of ascertaining the time m. To determine, in part, whether there is a rather constant contingency factor associated with a given group,[6] case histories and project records have been used. If, on the basis of a large number of samples, a most-likely contingency factor can be determined, then an expected time, t_e, for an activity can be calculated from

$$t_e = (1 + k)\, a$$

where k is an historical contingency factor for the group and where a is the most reliable piece of data available, the minimal time for the activity.

Rather than an aim at developing a comprehensive and general theory that would apply in any situation, this study was narrowly defined in order to search for a theory that is applicable to the Navy laboratory system. Hopefully, the insights gained in this environment will also provide a foundation for more widely-ranging generalizations and applications in other research agencies. On this basis then the investigation began with a data gathering phase in R and D units. The first task was to

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[6] One theorist believes that over time a manager develops the ability to predict fairly accurate outcomes. See Howard M. Carlisle, Management: Concepts and Situations (Chicago; Science Research Associates, 1976) 14.

identify the relevant parameters of a task that insure that the optimistic completion time, a, is in fact a fairly well-defined piece of data. Once the determining characteristics of such elemental activities were identified, past projects of a group were selected and broken down into their individual activities to derive a best possible time of completion for the project. The actual project completion times were then tabulated and analyzed to derive a best estimate of an historical contingency factor for the group responsible for the project.

These case histories, along with current projects that were monitored in a real-time environment, determined whether there are one or more contingency factors for groups and project classes that remain roughly constant over some useful time frame. Where there was an absence of any meaningful data, the only recourse was to speculate further on what form actual data might take or on what parameters might realistically affect the determination of elemental activities or contingency factors. Initially, the purpose of this investigation was to use a large sample to derive a numerical best-estimate contingency factor that gives the manager an alternative to guessing at a contingency factor on the basis of nonquantified experience. However, problems concerning national security along with the complexity of well-documented, highly technical projects limited the amount of research which could be done in the allotted time. Nevertheless, a representative sample of data was collected for strictly hardware, strictly software and for projects combining both hardware and software systems.

The Dahlgren Laboratory of the Naval Surface Weapons Center was selected as the research source since the Laboratory has a wealth of historical data. For example, groups at Dahlgren who work with the Strategic Systems Project Office have a number of milestone charts associated with past projects and, moreover, these groups are fairly stable and have a resident collective memory of past projects.[7] In addition, the investigators are familiar with DL, both from past studies and continuing association. The team was interdisciplinary, containing both managerial and mathematical expertise which was necessary for an efficient and meaningful data analysis.

Case History Examples

To illustrate the reality of the contingency time factor, two well-documented project histories are included at this point. The first case concerns the development of a software package for a strategic weapons system. Since it was cast in the same mold as several previous programs, there was some accumulated experience which provided relevant guidelines for the setting of milestones. However, the occurrence of a few unexpected problems could have caused the project to overrun its due date if an allowance had not been made for contingencies.

For the purpose of delineating contingencies, this case is divided into four stages which roughly correspond with the involvement of different work groups. To begin with, a schedule was prepared on the assumption that the General Services Administration would permit the acquisition of a necessary piece of equipment from a single source because in contrast with the alternatives its complexity best suited the needs of the weapon system being serviced. Despite the cogency of this argument, the GSA insisted upon publicly advertising the proposed purchase for competitive bids.

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[7] For an account of such a program, see Sapolsky, op. cit.

Preparing the required forms took two weeks, and the GSA studied the matter for 8 days before officially announcing that bidding was open to the public. According to federal government regulations, vendors must be afforded 30 calendar days in which to respond, and then it normally takes an agency two weeks to evaluate all proposals before a contract is awarded. As a result it was thought that the original schedule had slipped from 7 to 9 weeks, and this change was taken into account by adjusting completion dates for different interim phases.

In the meantime the initial events leading up to the installation of the new equipment proceeded ahead of plans until the first test revealed an error in coding and one in formulation. While their correction brought the project back in line with the revised timetable, it was given an unexpected push forward when only one bid was received (from the source producing the desired piece of equipment). Consequently, two weeks were regained on the original calendar, but the project at this point was still about 7 weeks behind the first negotiated milestone because a rule had been stringently enforced by an outside agency. As the project progressed into its second stage, delays were caused by an error discovered in one of the new sections of the computer program and by formulation errors. The project was also plagued during its early phases by problems related to bad data input, but gradually operating experience and increased familiarization with the new methods made it possible to complete certain events more quickly thereby recovering some of the slipped time.

As work continued in the second stage, more complications slowed the pace. In particular there were formulation errors that increased the iterative process of corrections, reassembly and checkout. Another compounding factor was the unreliability of an essential support system, and several assemblies contained errors that necessitated reassembly. Collectively, these difficulties were interpreted at first as meaning that the completion of three subsequent tasks would be postponed by 15 days with the further result that integrated testing of the weapon system was pushed 15 days downstream. Even so, the above modifications were made without jeopardizing development of the project since allowance had been made for such contingencies in the overall schedule.

By arranging for overtime work and adjusting manpower allocations certain test cases were finished on schedule thus making up time which permitted the integrated testing to begin only three days later than originally planned. Moreover, an extraordinary effort by one group plus extra work by other members of the project team regained about three weeks on the due date of the overall milestone.[8] The price of the personnel shifts was that some future events started behind schedule, but this delay was not too disadvantageous as they did not impact on the critical path of the project.

In the third phase a little time was lost as several tests which had initially taken 11 hours stretched out to 13 hours because of formulation changes that in the long run compensated for the additional time by improving the quality of the product. Other time consuming problems were errors in another new section of the computer program, and one important interface was prevented by a hardware complication which necessitated repair. As a consequence integrated testing was delayed, but this was not a

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[8] Extra work is overtime for which there is no additional payment of money.

serious setback because again the contingency factor which had been incorporated into the milestone provided extra time that brought the project closer to the benchmarks originally established.

Coming down the stretch, events were met as planned until the safety and quality assurance checks uncovered minor defects involving printouts and one programming error. There was an anticipated delay of two to four weeks, but this time was somewhat made up by overtime work and by arbitrarily moving the next SQA effort up 2 1/2 months. This change also took into consideration last minute breakdowns which would make attaining the final milestone an impossibility. However, Command commitments over which the unit had no control nor to which it made any input apparently put the schedule 30 days behind, but at this point a favorable learning curve and improved methodology along with new, more sophisticated equipment regained much of the lost time. One month later the project was back on the original timetable, and the product was delivered on the first agreed date.

On the other side of the coin the second case history illustrates what can go wrong when the time of a milestone is drastically shortened. This example, the same as the first one, also involves a software component for a strategic weapons system, and the second project was likewise for a new generation of an older system that had been in operation for some time.[9] Therefore, the log of previous experience indicated the kinds of contingencies to anticipate and how much time should be built into the schedule for unforeseen incidents. Accordingly, the original plan was prepared so

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[9] Unlike the first case the second project involved cooperating with outside agencies and several private contractors.

that the major events could be attained on time even though there would be the normal coding and formulation errors which are common in software development.

The first quarter of this project progressed smoothly as research and analysis concentrated on the range of alternatives which could be developed into equations. In the second phase alternatives were selected, and the effort to prepare equations was started. During the first half of the schedule, the professionals involved in this part of the project noted certain enhancements and refinements which could be made to provide greater accuracy and effectiveness in the weapon system, and they initiated a series of subprojects to add these features.

Shortly after passing the halfway point, some of the outside participants commenced pressuring the naval command responsible for the activities to move the milestones forward in order to begin testing at a date earlier than planned. The requested changes were made primarily because over a number of years the software products had been far better than expected, and those in charge were confident that the laboratory could complete its assignment equally as well in less time. Too little attention seems to have been given, however, to the fundamental fact that the successful operation of the weapon system depended upon the performance of the software component whose quality in any case is largely determined by the amount of time allotted to its development. In other words the general rule for such projects is first that the ratio between success and failure will increase or decrease in accordance with the length of the schedule and second that the sophistication of the product will be commensurate with the amount of time available for development.[10] Had these considerations been properly weighed it is doubtful that the software process would have been accelerated since this decision virtually mandated minimal standards of performance and quality while running the risk of negative consequences.

As a result of the revised schedule the Dahlgren group was left with barely enough time to finish the computer programs and to perform a few routine tests. The major tests, notably the simulations at a special berth, could not be conducted within the time frame established by the new deadline, and the conclusion was that without being able to completely "debug" the package, the system failed during its trial run much to the chagrin, disappointment and embarrassment of most everyone concerned. Moving the timepost up from its original mark was thus a costly mistake.

For software projects the mere reduction of several weeks in a schedule can make a difference on the outcome. At the same time no one can be legitimately blamed for the errors which caused the above failure because in research and development projects, especially in the software category, there are a minimal number of problems which will arise. For example, on the average any computer will be inoperative a certain number of days per month due to mechanical failure, power shortages or acts of nature such as lightning striking a facility. The kind of work being performed also demands

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[10] The reason this axiom applies more to software projects than to other kinds of research and development efforts is that within a minimum time a project such as the basic trajectory which gets a missile to its target can be developed. This means that the weapon system can function, but after this point, software schedules can be adjusted to fit various needs of a weapon system such as, for example, adding measures for evading the enemy's defense. By contrast the success of most hardware projects requires more than a minimal time for development in that satisfactory performance means there must be a completely finished product. For instance, a 5-inch gun for a warship must be fully functioning to be effective.

for minimal development absolute time frames which cannot be arbitrarily accelerated. A typical case is that if it takes a computer programmer 30 days to do one line, it does not hold conversely that 30 programmers can complete the task in one day because the functions are sequential meaning that they must be completed in logical order. In many instances software functions are almost inalterably tied to a fixed timetable presuming that nothing in the plan goes wrong. As mentioned earlier, though, there are a certain number of errors and breakdowns which will inevitably occur no matter how much care and caution is exercised. Therefore, a schedule will only be realistic if a contingency factor is added to the time of the best possible case. That is to say, an equation consisting of optimal time plus an allowance for contingencies will calculate a more valid milestone. The first case history demonstrates a successful accounting for contingency time. The second experience indicates that a milestone which contains no contingency time may be met on schedule, but the product may not only be inferior to what is possible, it may also be a failure.

The Characteristics of Contingencies

Regardless of whether the project histories concerned hardware, software or a combination of the two systems, the importance of a contingency factor was apparent in every instance. By a variety of personally designed methods, the experienced managers had derived a contingency factor which was appropriate for their particular situation. In each case the weight varied according to the inherent nature of the projects which can be denoted by a continuum ranging from programmed to nonprogrammed. At one end there are projects which occur regularly with the result that a rather standard measure of contingencies is developed not only for the overall milestone but also for specific tasks within the project. At the other end there are nonprogrammed projects which occur infrequently or are completely new ventures with the result that the computation of how much time will be lost because of unforeseen events becomes a problem of original estimation by whatever means with frequent adjustments of the milestones as a project progresses. For both types of work PERT or, at least the logic of this technique, was generally used to set milestones. However, the inputs were not always the same, and this difference was usually found to have an effect on the value of the contingency factor.

The distinction among the inputs can be broadly described as external and internal although this classification requires a sharper definition. First of all, internal inputs are determinants involving the immediate project groups such as the ability and expertise of personnel, availability of funds, space, other related facilities and so on. By comparison external inputs are factors involving the contribution or participation of outside groups which must be divided into interorganizational and intraorganizational in character. This categorization is significant because it identifies activities over which a manager may have some control in contradistinction to others over which he has very little, if any, control. For example, a manager has a better understanding of the internal inputs since they are matters that he works with on an almost everyday basis. Therefore, he not only has a solid foundation upon which to base a contingency factor, but he may be able to adjust the internal variables in such a way as to minimize their impact on a schedule.

With regard to the external environment a manager through administrative status or personal influence may be able to overcome factors that are intraorganizational inasmuch as they are part of the same agency, but it is seldom that more than persuasion can be used to deal with interorganizational factors because they are under the jurisdiction of other agencies. The data collected clearly indicate that a project leader can be frustrated in his efforts to maintain a schedule by the delays caused by any external relationship, but this problem may reach the acute stage more readily in the case of interorganizational commitments or constraints. The previously mentioned problem with the General Services Administration illustrates this point.[11] In contrast another software case history involved using a piece of inoperative equipment belonging to a sister division which was not interested in repairing it. As a consequence the project chief successfully appealed through the mutual chain of command to secure the necessary maintenance without losing more than a few days from the schedule. It is virtually impossible to get this kind of cooperation from an interorganizational participant by going through channels since the head of an outside unit will usually be protective of his subordinates' priorities for their own work. Along the same lines another dissimilarity between internal and external inputs is that in the case of milestone slippages inside the project unit can be made up by arranging overtime work, but a manager cannot rely upon outside counterparts using overtime to compensate for losses in a schedule.

Concerning the nature of contingencies there is also a difference in the degree of their impact, as noted in the second case history, between hardware and software projects.[12] In that episode it was pointed out how in software it is possible within a certain time frame to produce an output of

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[11] See p. 6, supra.

[12] See discussion accompanying note 10, supra.

minimal performance whereas in hardware it takes a maximum amount of time to turn out a fully functioning product. As a result the occurrence of problems for which no allowance has been made may only result in a software project not containing a great deal of sophistication when the milestone is reached; but for hardware, slippages in the schedule means that the project will not be completed on time. On the other hand the data also indicated that in software delays frequently cannot be offset by overtime or by employing extra personnel since it takes a definite amount of time to perform many tasks such as preparing a computer program. By comparison hardware projects can sometimes be brought up-to-date by extending the work day or by adding more employees.

On the basis of what has been discerned about the nature of contingencies in a Navy R and D laboratory it is apparent that a manager has more difficulty in making an allowance for the external nonprogrammed category. This kind of situation is both unfamiliar and outside the normal means of control. Not even the experienced project leader can make entirely accurate evaluations of such a contingency factor, and in order to avoid mistakes in the future a system for recording contingencies needs to be developed because current project histories and records are generally inadequate for this purpose.

Contingency Calculation

It has been previously noted that following the pattern of current methodology the most widely used system for setting milestones is PERT or some variant of this formula. Therefore, if the standard managerial practice of adding a factor for unforeseen events to the earliest estimated completion date is a good strategy for computing milestones and determining completion times, then a historically derived contingency factor will provide a manager with a statistically valid best estimate for target dates. To achieve this degree of accuracy, the next logical step is developing a contingency accounting scheme which breaks out the categories that make up the contingency factor. A start in this direction was made during the research for this study which learned that among the major causes of time losses are complications in processing paper work through channels, problems in the performance of work by external participants, slippages in the delivery of materials by outside suppliers and so on. Unquestionably, there are many other job related delays and interruptions that can be tracked over a period of time to ascertain their average impact on a project.

As far as contingency accounting is concerned, the basic approach itself is not new considering the standard deductions which one made from the work year of 2,080 manhours for illness, leaves, holidays and so forth. In other words all managers know that for very legitimate reasons they will not get 2,080 hours of work from their employees. What is different though about contingency accounting is its inclusion of job perturbations from the technical side of the house along with a variety of organizational disruptions. By merely being superficially cognizant of the contingencies which occur in projects over a period of time some experienced managers at the Dahlgren Laboratory have learned how by approximation to adjust their computations to produce more realistic milestones. If, for example, 10% of the historical contingency factor usually comes from unforeseen technical problems (or from personnel absences, transfers, etc.), a contingency factor for a new generation of a project can consequently be decreased or increased in accordance with a manager's assessment of the level of technical difficulty of the current project (or the likelihood of personnel difficulties, transfers, etc.).

Groups which have been continually involved for years in software development for strategic naval systems have especially become accurate in setting milestones which meet the demands imposed by a service command's program schedule while providing sufficient time to build enhancements in the product.

Aside from the aforementioned cases there are only a few other isolated situations at Dahlgren in which contingency accounting is attempted on a large scale. The most common method used to balance delays and disruptions in a project is allowing extra time for analysis and evaluation and for conducting tests. In most instances this planned slack in a schedule compensates for the losses occurring in other functions. An example of this practice was encountered in a hardware project which consisted of 57 events covering 40 weeks. It included three major test phases with six stages designated for analysis and evaluation, all of which were given more time than it was anticipated would be necessary. The remaining 49 target dates were scheduled in terms of the minimum time considered necessary to complete them.

The project lost time initially because of uncertainty over how its requirements would be finally defined by the sponsoring naval command. The schedule also slipped when several external problems arose. First, there were postponements in the performance of work by a sister laboratory to which some tasks had been assigned by a subcontract. Second, an on-base unit exceeded its deadlines in the fabrication process, and despite the intraorganizational nature of these breakdowns, they could not be overcome by activating the chain of command. After these losses were accounted for in the timetable, there was still enough slack in the system for the project to be completed one month ahead of the planned finishing point since the allotments for analysis, evaluation and testing were more than sufficient for these purposes.

Rather than rely upon rough approximations as in the case of the preceding method, a better approach, of course, would be to make allowances for slippages in the schedule based upon work measurement over a period of time. In order to establish a foundation for this analysis a history of various tasks must be compiled through a systematic bookkeeping of work stoppages. Once an accounting scheme has been devised, a contingency balance sheet can then be prepared with additional charges of time being debited to the various categories that constitute the total time for a project thereby providing in advance for the kinds of overruns which have occurred in the past. Thus, if the time t_o designates the optimistic duration of a project (derived from a critical path analysis of the earliest possible completion time for specific activities), and if t_c designates the actual completion time, then $t_c - t_o$ represents the total time overrun for a project. This time overrun can be broken down into its component categories and charges made to each category inasmuch as time is a quantifiable variable and the baseline optimistic completion time is a verifiable piece of data since it is derived from the reliable estimates of completion times for elemental activities. As a result such a balance sheet would present numerically valid information which would enable a manager to monitor changes in the historical contingency factor for any group, and he would also have the means for assessing any changes in the makeup of the contingency factor.

Milestone Progression

By determining the contingency factor for a project a number of other organizational benefits are derived. To begin with, it facilitates marking the progress of a project because a milestone that has been set with allowance for unforeseen events provides a more realistic basis for making time interval evaluations. In accordance with this concept the periodic progress or status reports that a supervisor receives from a project can be used in a variety of ways to estimate when the project will actually finish. An alternative tested by this study is a finishing-date estimation scheme which is based on the tracking equations for the α-β radar tracker. In essence, a range radar tracking system obtains periodic information on the range and speed of a moving object (typically, an airborne object), and this position and velocity data is then used in the tracking equations to predict future positions and velocities of the object. If a project is viewed as flowing through the edges of a PERT chart then, in principle, the same techniques can be used to estimate the future status of a project given that the current status and rate of progress is known. To further emphasize the parallels between radar tracking and project monitoring, it is observed that radar data is usually noisy data for which frequent updates are necessary to suppress the noise and to track an object which is changing both position and velocity in an erratic fashion.

The tracking equations for the α-β radar tracker are:

$$y_p(k) = y(k-1) + T\dot{y}(k-1) \qquad (1)$$

$$y(k) = y_p(k) + \alpha[U(k) - y_p(k)] \qquad (2)$$

$$\dot{y}(k) = \dot{y}(k-1) + \frac{\beta}{T}[U(k) - y_p(k)] \qquad (3)$$

These equations represent, mathematically, the radar system estimates of the range and velocity of a moving object, where:

T = time between transmission of the $(k-1)$-*st* and k-*th* radar pulses

$U(k)$ = estimate of the range of the object, based solely on the k-*th* pulse

$y(k)$ = smoothed estimate of the range of the object after the k-*th* pulse

$\dot{y}(k)$ = smoothed estimate of the velocity of the object after the k-*th* pulse

$y_p(k)$ = predicted range of the object at the k-*th* pulse, based on the smoothed range estimate at the $(k-1)$-*st* pulse.

The basic idea behind equations (1) - (3) is that the raw radar data provided by $U(k)$ is noise-contaminated and must be smoothed to provide an accurate range estimate. In particular, equation (1) gives the predicted range for an object moving at a velocity of $\dot{y}(k-1)$ after an elapsed time T, given that the object starts at a range of $y(k-1)$. In equation (2) this predicted range $y_p(k)$ (a range based on past history) is used to smooth the radar range estimate, $U(k)$, which was acquired at the k-*th* pulse. Equation (3) is similar to (2) and gives a smoothed velocity estimate, $\dot{y}(k)$, that combines both past history and a current (noisy) velocity estimate.

To use the philosophy of the tracking equations of the α-β radar tracker for monitoring projects, it is necessary only to define project state variables corresponding to range and velocity. In particular, it is feasible to equate "percentage of project completed" with range and to observe that velocity is then defined in a natural fashion as "percentage of project completed per days expended." Once the current position and velocity are known, it is patently an easy task to estimate the finishing date of the project. Of course, this estimation scheme is most accurate for projects that involve only a moderate amount of effort in terms of man-years. The interviews conducted by this study suggest that managers can provide the necessary data and can estimate the percentage of a project completed to within 5-10%. Clearly, periodic reports that quantify the percentage of a task that is completed will serve several purposes:

a) They will provide a historical record which can serve for planning similar projects.

b) They will serve to give an early warning of possible time overruns.

c) Points (a) and (b) in conjunction can be used to derive a contingency factor for similar projects.

As an example to illustrate the ideas above, an experiment was run using data derived from a completed project which was scheduled for 70 days or 14 work weeks. The column headed PROGRESS lists the days of actual progress made during week i where, of course, the plan anticipated 5 days of progress during each week. The column headed VELOCITY lists a smoothed estimate of the current rate of progress, where a velocity of 1. was assumed by the plan (i.e., 5 days of progress for 5 days of effort). Finally, the column headed FINISH DATE is the estimate provided at week i by the α-β tracker, derived from the input position at time i and equations (1) - (3). The duration of the project was 16 weeks, so the project actually finished on day 80.

WEEK	PROGRESS	VELOCITY	FINISH DATE
1	3.	.98	72.14
2	2.	.94	76.59
3	2.	.89	82.49
4	4.	.85	86.76
5	3.	.82	90.98
6	4.	.80	93.68
7	12.	.86	86.01
8	7	.93	79.81
9	6.	.99	75.72
10	5.	1.02	73.58
11	3.	1.02	73.62

WEEK	PROGRESS	VELOCITY	FINISH DATE
12	3.	1.00	74.77
13	3.	.96	76.45
14	4.	.94	77.82
15	4.	.91	78.92

Conclusion

The inclusion of contingency time in the setting of milestones for projects will be a significant development for navy research and development activities because currently it is seldom recognized as a legitimate variable thereby explaining why many target dates are miscalculated. In addition its computation by a contingency accounting scheme will improve administration since this research, even though its units are time, will give the manager some more hard data to supplement the traditional project dollar budget. Such a decision-making procedure is also pertinent to ascertaining what constitutes productivity in the R and D setting in that accurate time milestones are a necessary first step in formulating a productivity measure.