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# Monitoring systems and their effectiveness for project cost control in construction

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**Abstract**

This paper reports on a research to investigate the effectiveness of some commonly used monitoring systems, in detecting deviations from the planned cost and performance. The monitoring systems used in this work are:

1. Leading parameter technique
2. Variances method
3. Activity based ratios technique

The paper describes these monitoring systems; their characteristics, the measures they use and their effectiveness for assessing performance. The systems are first evaluated on a theoretical basis and then on the basis of results from investigations carried using simulation approach. A project model has been developed which realistically simulates the progress of the project and which generates information relevant to these monitoring systems. Factors affecting the project cost and performance are represented by changes in the project plan and inflation rates. It has been found that some of the earlier monitoring systems have more response to changes than the others. The research has also shown that the Activity based ratio's technique gives a clearer and simpler indication of the overall progress of the project than the other two techniques.
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*Keywords:* Cost control; Monitoring systems; Construction; Progress; Simulation

## 1. Introduction

In a project, plans are usually drawn to ensure that work is carried out to the desired quality; in the allowed time; and according to budget. Divergences from the plan however occur and within construction such occurrences are common. Such divergences are nevertheless expected because of the nature of construction work and the uncertainties associated with it. In the case where the differences between the plan and the actual work performance are large, control action is normally required to try to bring the actual performance on course with the desired state of the plan.

Progress on the project is required to be monitored and compared as the work proceeds in order to be able to identify and measure these differences. The measurements made are usually limited in number because of cost related to data collection. There are a number of systems that are traditionally used in construction to monitor and report on the progress of the work. Some of them rely on information related to activities while others are based on work types. Although all of these systems are used to produce measures of project performance, financially or otherwise, the basis of measurement used and its interpretation of work performance is different in each of them. For this reason hence it is expected that, for particular real situation, some of these systems will produce measures that may call for control action while perhaps others may fail to do so.

This paper contains a review of a number of commonly used monitoring systems and their characteristics. A project model has been developed which realistically simulates the progress of the project and which generates information relevant to these monitoring systems. Factors affecting the project cost and performance

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are represented by changes in the project plan and inflation rates. The paper concludes with the results of the experimentations as to which monitoring systems are more effective in drawing management's attention to problem areas than others.

## 2. Monitoring and control

A project is highly unlikely to proceed in all respects entirely according to plan, particularly when the plan has been expressed in some detail. At one level a plan represents a model of the work method and divergences from the plan may be thought of as showing defects in the model. At another level a plan may represent a document of contract, an agreement between two parties concerning how a project will be carried out. Divergences from the plan in the latter case represent breaks in the agreement, which may or may not be of concern to the parties. Small deviations between plan and actual performance may be seen both as being within the limits of uncertainty of the model building process and as not sufficiently great to cast doubt on the achievement of the major objectives of the project. Larger differences however may require a revision of the model of future work to ensure that it is realistic. In the case where the plan represents an agreement, such revision may indicate that the major objectives of the project are no longer attainable and alterations in both the method and the objectives may be necessary.

The classical control cycle involves three stages:

1. Measuring the state of the system.
2. Comparing these measurements with the desired state of the system.
3. Taking corrective action to return the system to its desired state or to minimise some loss function [1].

Ideally such system should be stable, respond quickly to changes and be relatively insensitive to small amounts of noise and measurements inaccuracies. Time lags in such systems have been shown to degrade performance [1].

In a construction project context, the steps in the control cycle could be considered as:

1. Make a plan.
2. Implement the plan.
3. Monitor actual output and record it.
4. Report actual and planned parameters and their variations.
5. Take action.

The first four stages constitute the monitoring part of the process. Monitoring provides quantitative information on which control action may be based. It will always fall short of perfect accuracy and the possible size of errors should be borne in mind when control action is taken. Great accuracy can usually only be bought at the cost of delaying the information to an unacceptable degree. Control action will be demanded from management and, in the absence of formal information from monitoring, the management will take control action based on their use of informal information systems; hunches; beliefs and advice. Some managers are highly successful in their use of informal information systems but such success is by no means universal. There is no reason to believe that informal systems should be abandoned in favour of formal systems. Control action will be a product of the total information available to the manager.

## 3. Methods of monitoring projects

As indicated earlier, monitoring project performance involves making measurements as the project proceeds and comparing those measurements with the desired or expected values. The measurements made are limited in number because of the cost of data collection and also by company policy and precedent. Performance in a project is complex and a limited number of measurements will provide a less than complete picture of the performance. This partial picture may be adequate for the purposes of controlling the work or it may not.

Much of the available work on project performance measurement is embedded in the work on project control. Typically, the parameters used for assessing performance are financial. They are, at least in theory, easily calculated and easy to interpret. They are also very important to the people doing the collection and analysis—usually the contractors and clients. Three of the most commonly used monitoring techniques are involved here and are discussed later.

### 3.1. Leading parameter

Just like 'unit costing' Gobourne [2] and Pilcher [3], the leading parameter is a technique based on the idea of choosing one or more of the major types of work as measures of the performance of the whole project. For example, in a project where concreting forms a large portion of the work, the amount of concrete poured at any one time of the project can be used as a measure of the performance of the work. The actual cost per leading parameter as well as the total cost of the project is usually compared with the planned during the same period of time. This technique can also be used for a project which consists of many sections with different kinds of work in each of them. In this situation it is possible to use a different parameter as a measure of performance for each section.

A major problem with this technique as an effective tool for cost control is that projects often involve many important types of work and that the ' goodness' of the single parameter selected for assessing the project performance may well vary with time. In an attempt to overcome this, sometimes different parameters are used at different stages throughout the project. Whilst going some way to solving the problem, this introduces difficulties in the changeover period between one parameter and the next. Also although it is possible for this technique to show the deviations of the project performance from the plan, it does not show the reasons for these deviations.

### 3.2. Activity based ratios[4,5]

This is a financial control technique that employs the ratios between the earnings and expenditures of the project activities as measures of performance. The system can also be used to measure the performance of the whole project as well as that of the activities. The three ratios the system relies on for the calculation of performances are:

$$\text{Planned Performance} = \frac{\text{Planned Earning}}{\text{Planned Expenditure}}$$

$$\text{Actual Performance} = \frac{\text{Actual Earning}}{\text{Actual Expenditure}}$$

$$\text{Efficiency} = \frac{\text{Actual Performance}}{\text{Planned Performance}}$$

These ratios can be calculated at any time and over any duration for which a plan is available. Both planned and actual work must be evaluated using the same rates for earning and the same rates for expenditure. If the earning rates come from the original estimate, the performance measures calculated above give an evaluation of the performance against the estimate and the efficiency gives a measure of the project performance against the plan. All values should, in theory, be unity although since it is sensible to plan slightly optimistically, it is perhaps advisable to aim for 1.05 for planned performance and efficiency.

The measures used by this technique are both simple to calculate and simple to interpret. They require relatively little data and can be applied at a range of levels on a project. They can for example be prepared for a whole project or a section of it and can therefore be useful in measuring contributions of individual subcontractors to a project.

Based on the above, it can be concluded that the measures used in this method are excellent communication tools and particularly useful for short-term applications. The forecasts made are based solely on the plan and are not statistically reliable.

### 3.3. Variances and Earned Value Analysis (see Staffurth [6], Lockyer and Gordon [7]and Harrison [8]

In this context, variances are differences between two values. In project measurement and control they are usually differences between two expenditures—the planned and actual, although the incomes or any other values could be used.

The use of Variances to measure project performance is perhaps one of the oldest and most commonly used techniques. By considering the current and final state of the actual and the plan, it is possible to build a quite detailed picture of the project. Indeed, because it is possible to produce these figures for the whole project or for any section of the project, they are commonly used to assess the whole of a project, sections of it or, for example, the performance of single subcontractors.
Basically by plotting various expenditure curves such as those for the first project budget; the last estimated total cost; latest estimated expenditure; and budget value of work done, two main types of variances can then be determined. These are the 'Budget Revision Variance' and the 'Total Cost Review Variance'. They are the main project variances, which may indicate an increase in the cost of the project compared with its budgeted expenditure. They do not however identify the causes of this increase.

It is possible to break these two main variances down into more detailed sub-divisions in order to assist in recognising the reasons for the changes in cost. For example the 'Total Cost Review Variance' can be broken down into the 'Current Budget' and 'Future Budget' variances. A current budget variance, for example, means that the incurred cost of work done to date is greater than the planned expenditure. It does not show, however, whether the project is behind schedule or if overspending has occurred. Further sub-dividing this variance into two more components as follows can see this:

$$\text{Performance variance} = \text{Budget value of work done} - \text{budget expenditure to date}$$

$$\text{Efficiency varaiance} = \text{Incurred cost} - \text{budget value of work done}$$

The 'Performance Variance' indicates that the progress of the project is ahead of schedule if it is positive, or behind schedule if it is negative. The 'Efficiency

Variance' on the other hand indicates over-spending if the variance is positive, and under-spending if it is negative.

An extension of the idea of the method of variances is the Earned Value Analysis technique. In this system the original tender prices are used, together with the schedule, to establish what should have been spent (or earned) at any time. As work progresses, the normal variances can be calculated but, in addition, the actual work performed is evaluated using the original tender figures and the budgeted value of work performed is calculated. Using the planned and actual values of work performed enables comparison of the current and future states against an independent measure. The tender is commonly used for this purpose.

This technique is relatively popular. However, it requires rather more data and effort to calculate than the other systems described so far. It also produces a large number of parameters to describe the state of the project. This makes it more difficult to use and rather more difficult to communicate to all levels of staff. The 'forecasts' just as with the previous systems are based solely on the plan and not statistically reliable.

## 4. Measures of effectiveness of control

In practice, a control system consists of making measures of performance; judging these against standards, and taking any necessary control action. The effectiveness of control is an amalgam of the effectiveness of each of these features.

In this work control action is assumed standard and the efficiency of the control system is directly related to the content and clarity of the information provided by the monitoring system. There are many different means by which a cost control system can indicate efficiency or inefficiency. To be effective, a cost control system must draw the project management's attention to problem areas. The detail and reliability in which any particular system can do this may be considered as a measure of its effectiveness. For example, a system which can only indicate project profit or loss may be considered less effective than one which can highlight the fact that carpenters are working below standard on column formwork. The effectiveness, if so defined, is not necessarily the only reason for choosing a particular system.

The control system should also take into consideration the amount of detail required in reports, which will vary according to the level of management for which the reports are introduced. Usually higher management level will be interested in the overall picture of the performance of the project while project management level will require more detailed reports, but still not as the detail required by the site agent or the site engineer.

Another area of indication of the efficiency of any cost control system is that of providing information to estimators. This should include cost of jobs with full descriptions of the conditions and work involved. Work conditions in the construction industry tend to vary considerably between one contract and another and hence there is a need for using this information wisely. It is perhaps most useful when the information is concerned with the outputs of machines on the site.

The cost control system should also provide data for the evaluation of variations which may occur during the contract, in order to help the contractor to build up his new rates of the work according to this information.

Finally control action will be based on the information provided by the control system and therefore the information should be clear and good at showing to the different levels of management any divergence from the planned performance.

## 5. Model structure

To test the effectiveness of the various monitoring systems described above, a project model has been developed to realistically simulate the progress of a construction project and which generates information relevant to these monitoring systems. The model can be used to simulate any project but the project used in this work represents the construction of a bridge that is represented by a 40 activities precedence network.

The model is designed so that it can provide data about the progress of the project in order to be used by the different monitoring systems. An outline flow chart of the model is shown in Fig. 1.

### *5.1. The scheduler*

The model is designed to be a day-by-day scheduler that has variable resource levels and which gives variable duration for the activities. It is a serial sort scheduler in which the network calculations are performed only once at the beginning of scheduling [7,9,10]. It is based on the assumption that a certain predetermined number of each type of resource required by the activities being available for the use of the project. The scheduler uses the latest start time as a major sort. This implies that, at any one time, if two or more activities compete for the same resources when there is insufficient number of these resources to operate all of them concurrently then priority will be given to the activity with the earliest latest start time. If required, this decision rule can be changed without any alteration to the structure of the model.

The scheduling of the activities in the model is considered daily. If an activity needs either of resources or of materials cannot be satisfied then that activity has to

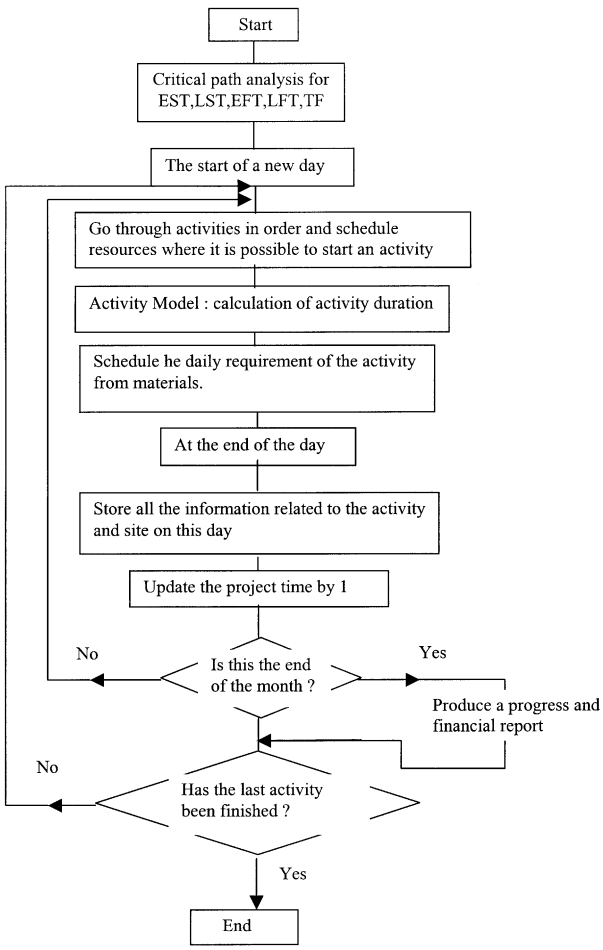


Fig. 1. The model flowchart.

be abandoned for that day. As a natural consequence of this, an activity can be stopped due to the shortage of either resources or materials and then restarted when there are enough of both of them to schedule the activity. This means that an activity can be split over two or more periods of time and then proceed at different rates of progress depending on the level of resources available.

The model allows changing the duration of an activity by altering the amount of resources between specified limits. Several authors in the past have suggested this type of model since variable duration activity, in general, is closer to real life than fixed duration model [9,12]. An upper limit of each resource is assumed above which an increase of that resource will not affect the speed of the activity. This limit differs from one resource to another. This assumption is made because, in real life, the number of resources working on an activity is usually affected by the type of work involved and the space available for these resources to work on that activity. There is a physical limit, for example, to the number of excavators and labourers that can work in or near a hole to be excavated on a construction site. If the number of resources on the activity exceeds a certain limit, it will result in extremely inefficient working conditions and might result in no work being carried out at all. Also too many resources in a limited space will undermine safety on site.

As well as the upper limit of resources that can be used by any activity, a minimum limit of resources below which work will not proceed is assumed, such as 1 labourer or 1/10 of a machine. The allocation of part of a machine to an activity means either a full machine is working part of the duration or a full machine is shared with other activities. For convenience of simulation, the division of machines has been made into 10 parts.

The duration of an activity for a resource can be calculated as shown:

$$D_{i=}\frac{w_i}{n_i}+M \tag{1}$$

where $D_i$ = the duration required by resource $i$ to complete the activity; $w_i$ = work quantity for resource $i$; $n_i$ = number of resource type $i$ used; and $M$ = minimum duration of the activity.

In addition to the limits of resources on activities, the model also simulates the effect of supervision on the progress of the work and the productivity of labour. It uses exponential mathematical relationship between the productivity of labour and the ratio of the number of foremen to the number of operatives. It assumes labour productivity to be 50% of the optimum if no supervision is involved in the work. Using such assumption, a 'productivity factor' is calculated using the following formula:

$$\mathrm{PF}=1-\frac{0.5}{e^R} \tag{2}$$

where PF = Productivity factor
and

$$R=\frac{\text{Number of foremen}}{\text{Number of operatives}}$$

The final duration of an activity can then calculated as being the maximum duration based on resources divided by the productivity factor as indicated in formula 3.

$$D=\frac{D_i\ (\max)}{\mathrm{PF}} \tag{3}$$

### 5.2. Model representation of resources

Physical resources in the model have been divided into three categories:

1. Operatives, skilled and unskilled.
2. Machines.
3. Subcontractors.

Each of these categories was given a different code number in order to be able to distinguish between them during scheduling.

The utilisation factor of the resources in the model is calculated as being the ratio between the total resources employed and the total resources provided.

To be realistic, the model also addresses the problem of non-attendance of resources by using a uniformly distributed random number between 0 and 0.2 for the allowance of absenteeism within labour. This means that there is a possibility of non-attendance of 20% of the total number of labour every day as a maximum.

The hiring and firing of resources in the model take place at the end of every week if required. The decision of hiring and firing is made in accordance with the planned schedule times of these resources. The procedure is performed in such a way that the type and number of resources are associated with the section number for or from which these resources are hired or fired.

### 5.3. Model representation of materials

In order for scheduling to take place in the model, requirements of activities from materials should be also gratified. Materials in the model have been classified as consumable, special and re-usable. Consumable materials are used throughout the project by all the activities such as sand, cement, etc. Materials of this kind usually become part of the work they have been used to construct and therefore can be used only once.

Special materials are those that are not in common use among many activities. They are used for special kinds of activities and not for the others. An example of such materials would be bridge bearings.

Re-usable materials differ from the others in that materials of this kind can be used more than once (e.g. shuttering and scaffolding).

A different wastage factor for each material is assumed from experience and wastage is considered to occur on delivery, although in reality it is generally a function of duration and condition of storage as well as usage. This has been done to simplify the model.

The problem of orders and deliveries of materials in real life has been simulated in the model by keeping a predetermined list of order and delivery times for all the materials on site. The delivery of each kind of material then takes place automatically at the specified time.

### 5.4. Model representation of finance

#### 5.4.1. Bill of quantities

The estimate prepared for any project forms an important means for financial control of that project. In order to make the simulation model behaves like a real system, the financial aspect of the project involved in this work is based on the original bill of quantities for the bridge project mentioned above. This in turn is based on CESMM (Civil Engineering Standard Method of Measurement), see Barnes [11], with some modification to the code numbers of the items. For example all the (E) items representing the different types of the excavation of foundations have been combined into one bill item (1), which represents the total amount of excavation in foundations.

A ‘ bill split’ has also been produced; see Scott et al. [13]. This is the distribution of the bill of quantities items to the activities. For example, the activity which represents the construction of pier 1 contains 5% of bill item 4 (designed mix for ordinary concrete structures...), 50% of bill item 8 (Reinforced concrete column and piers, cross-sectional area 0.25–1.0 $m^2$ ), and 4% of bill item 14 (Reinforcement mild steel bars diameter 15mm). The bill split has many uses, including giving the facility to calculate the value of the work done. This can be done quickly at any time according to the percentages of work done on the activities.

#### 5.4.2. Cost heads

Cost heads are assumed to be of six different kinds namely labour, plant, materials, supervision, sub-contractor and overheads.

Bill items have been split under the earlier headings according to the estimated amount of each of these cost heads involved in any bill item.

All the other information required for the calculation of the value of work and the cost is included in the model. This includes the cost of resources, materials and the hire and fire cost of each resource.

## 6. Experimentation and findings

Many experiments have been carried out to test the effectiveness of the monitoring systems used, in showing the effects of some factors, on the cost and progress of the project. Several factors are used, each represent a change. Among the changes introduced and imposed on the original project are, for example; increase in the costs of resources and materials with time due to different inflation rates; sudden changes to specific resources and material costs and the use of a more optimistic plan.

The method employed was to change one factor at a time and fix the others. In this way it was hoped to determine which of the monitoring systems indicates the effect of that factor. Samples of the results produced from some the experiments are discussed later.

### 6.1. The project prior to changes

The following sections are concerned with the discussion of the graphs, which represent the state of the project prior to any change.

Fig. 2 represents the results obtained using the leading parameter technique. It represents a typical section in the project, which uses concrete as a leading parameter. The graph shows that the concrete work in the project commences during month three in both the plan and actual and finishes at month eight and nine respectively. The graph indicates that actual cost per leading parameter was less than the planned except at month three and five. The earning values per unit of the leading parameter were almost according to plan.

Fig. 3 shows the variances of the project plotted cumulatively over the duration of the project. It can be seen that except for month four, 10 and 11, the total cost of the work done was less than the planned expenditure as indicated by the negative current variance. The graph also shows that the project has a negative performance variance between month five and nine. This means from the definition of this variance that the project is behind schedule during this time. The efficiency variance is also negative at the same time, which means that money has

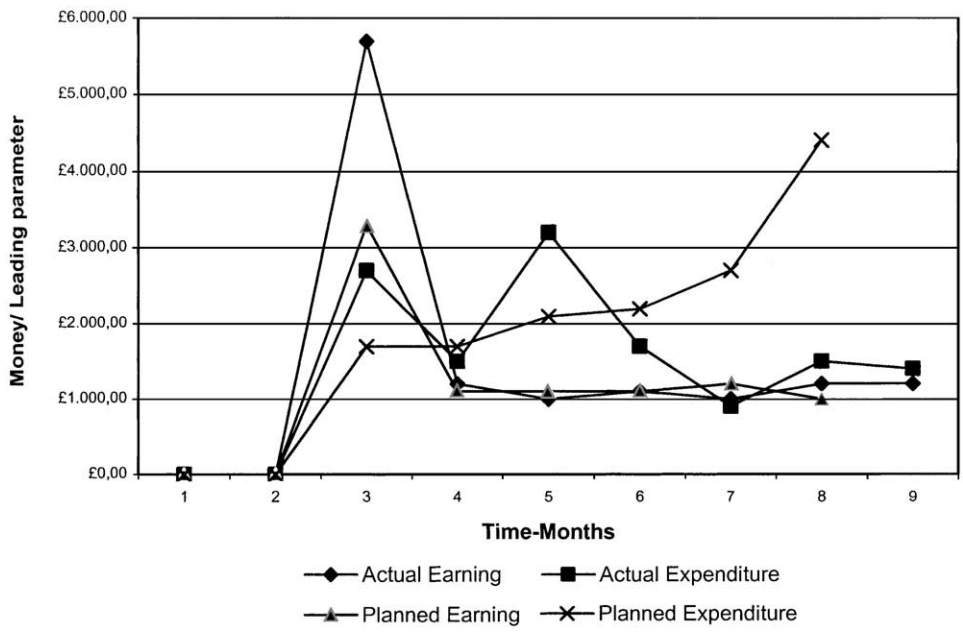


Fig. 2. Period expenditure and earning results of concrete as a leading parameter prior to any changes.

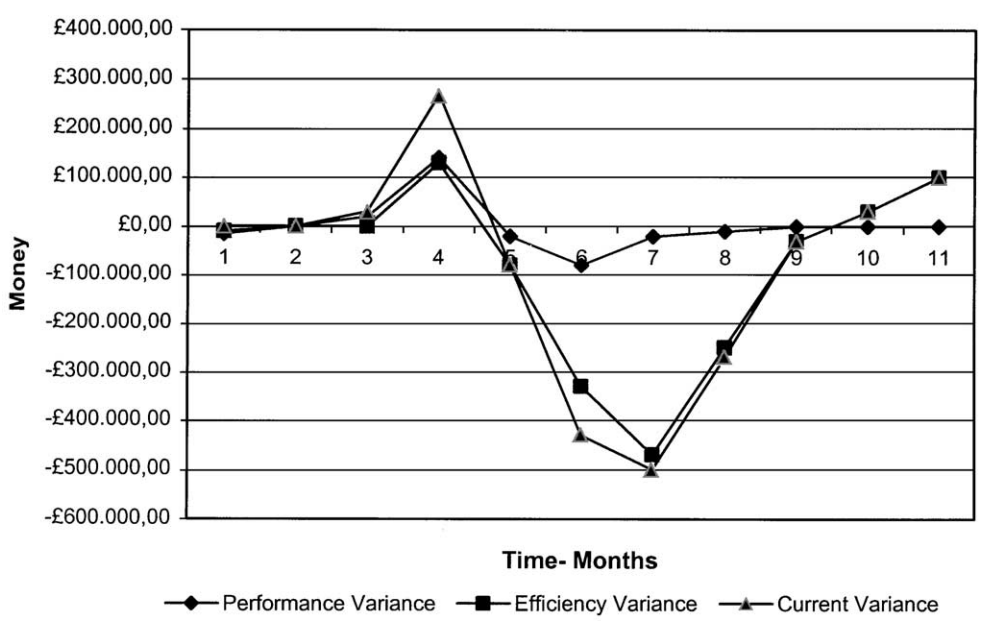


Fig. 3. Cumulative Variances of the project prior to any changes.

been saved compared to the plan. Overspending however has occurred in the other periods. The overall picture given by this graph is that the cost of the project, on average, was almost according to the planned expenditure.

The activity based ratio technique has also been used in the experimentation as shown in Fig. 4. This figure represents the cumulative efficiency of the activities and the whole project. It can be seen that the activity efficiency was better than that of the whole project. This could be caused by a number of things such as material wastage or excess overheads. It also indicates that the total project was running at an average efficiency of 95% of the plan. This is almost the same picture given by the other monitoring systems graphs.

### 6.2. The project after changes

Figs. 5, 6 and 7 were produced from one experiment and show for example how the various systems reflected the effect of a 54% inflation rate per year on the progress

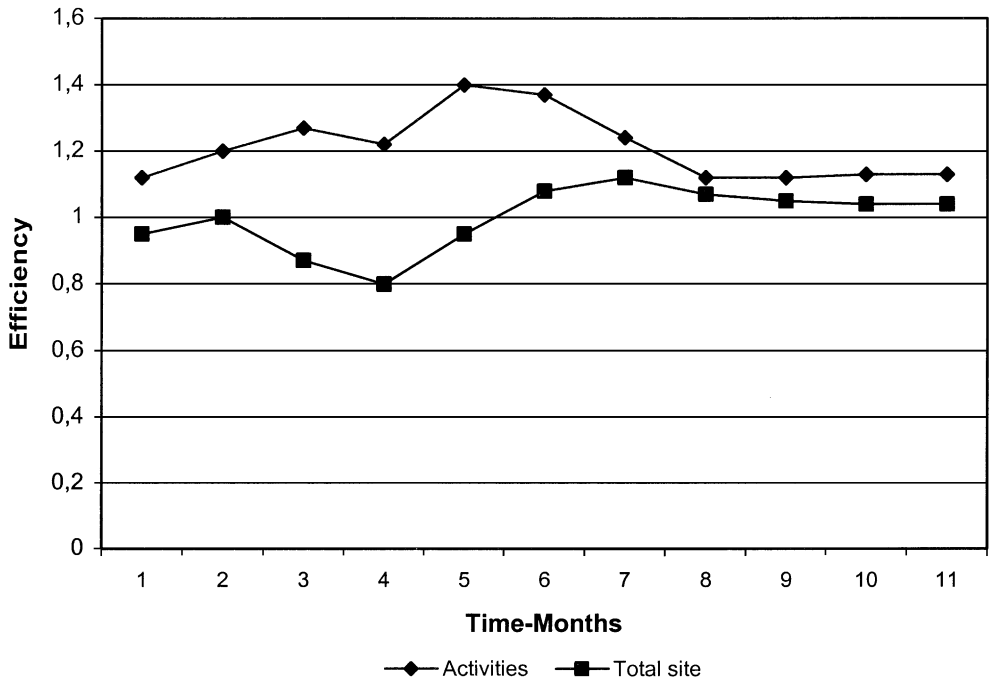


Fig. 4. Cumulative project efficiency results prior to any changes using activity based ratios.

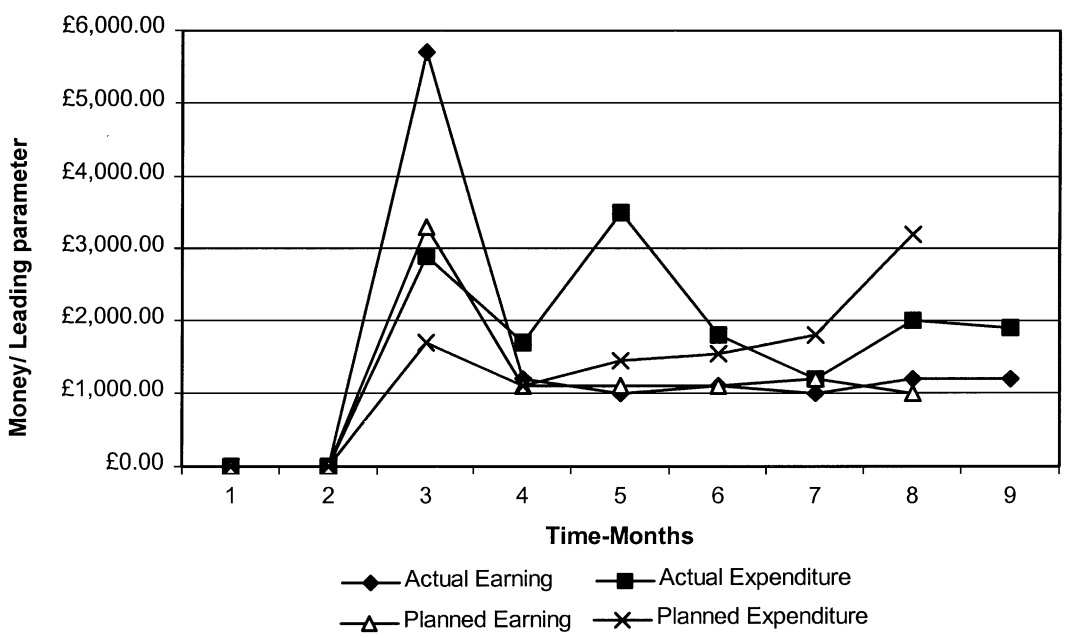


Fig. 5. Period expenditure and earning results of concrete as a leading parameter with 54% rate inflation.

and cost of the project. These results are to be compared with those of the project performance without the influence of this change as shown already in Figs. 2, 3 and 4, respectively.

Fig. 5 represents the results related to concrete as a leading parameter. The graph shows again that the actual cost per unit of concrete works was more than the planned at the time between months three and six, however, it does not show a clear indication of the effect of inflation when compared with Fig. 2.

In the case of the Variance method as shown in Fig. 6, it is indicated that the cumulative current variance in this case was very high and hence indicates clearly that the actual incurred cost of the work done to date was greater than planned. The small positive performance variance also means that the project was slightly a head of schedule. In contrast to the previous fig. this graph simply shows, at an early stage of the project, that work was not according to plan and that control action should be taken.

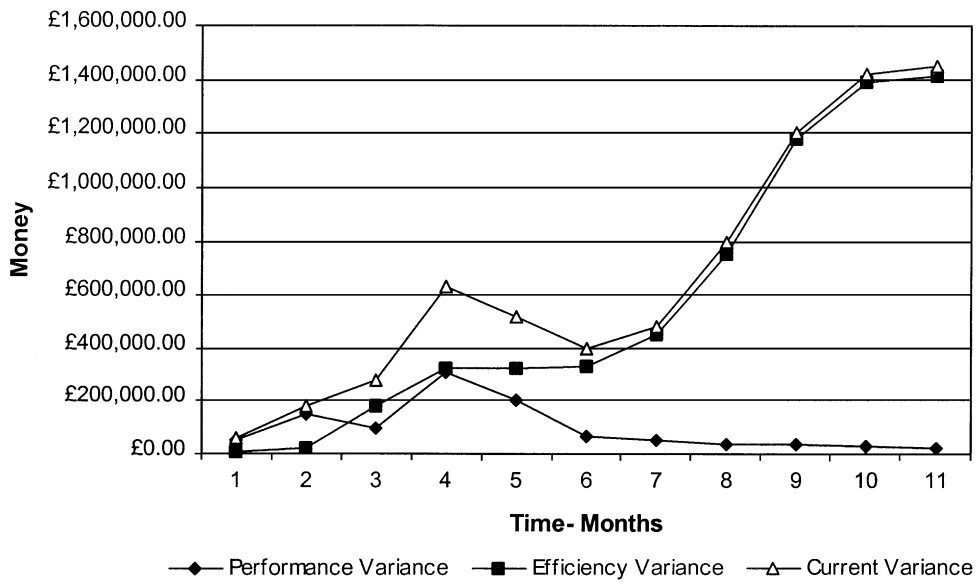


Fig. 6. Cumulative Variances of the project with 54% rate inflation.

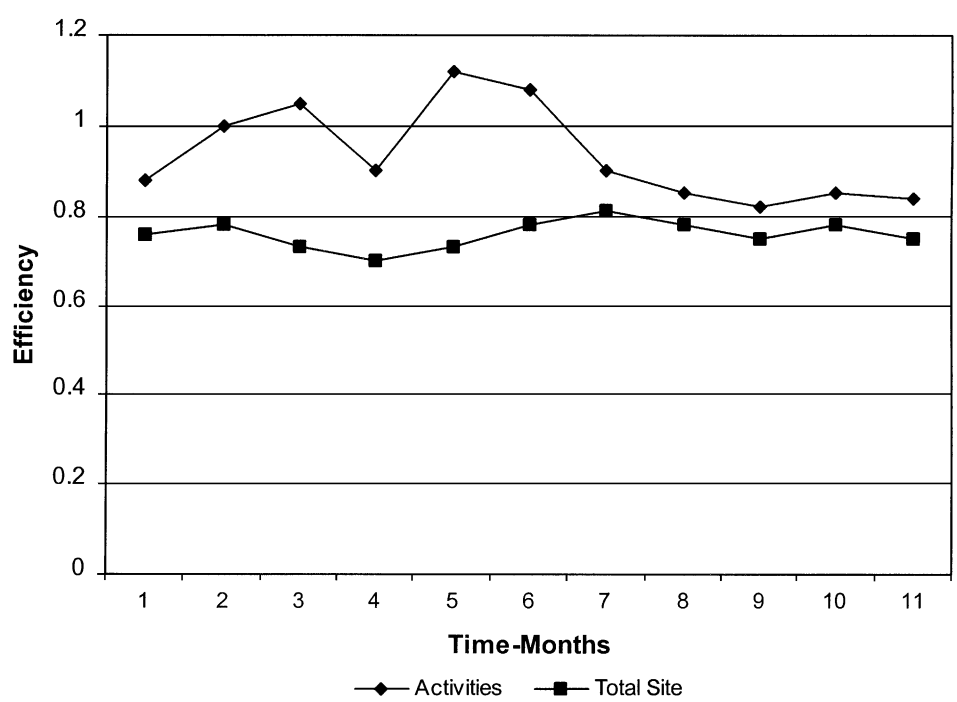


Fig. 7. Cumulative project efficiency results with 54% rate inflation using activity based ratios.

In the case of the ' Activity based ratios' technique, Fig. 7 indicates that although the efficiency of the activities was almost as planned in the beginning, it was then started to diverge at month seven until the end of the project. It also clearly shows that the efficiency of the total site, on average, was only 75% of the plan compared to an average of 105% before inflation as shown in Fig. 4.

The results of the experiments indicated that the effectiveness of the monitoring systems in showing deviations of the project performance from the plan varies considerably from one system to another and that both the 'Activity based ratios' and the Variance systems have shown the effects of the introduced changes better than the 'Leading parameter' technique.

It is noticeable from all the earlier results that the ' Activity based ratios' technique gives a simpler and a clearer indication of the overall progress of the work than the other two systems. In the case of Fig. 4 for example, it is indicated in a very clear way that the efficiency of the total project was not according to plan, but on average only 75% of it, and that control action should be taken.

## 7. Conclusions

This paper has introduced several monitoring techniques and their use for project cost control. Comparisons of these systems on a theoretical basis have indicated that different systems are suitable for different situations. 'Activity based ratios' technique for example is more suitable for short-term applications than 'The Variance method'. The results of comparisons have also shown that some techniques are simpler and clearer to interpret than others. Depending on the system to be used, the amount of information required by the system and consequently its use as a communication tool have to be considered.

It can be also concluded, on the basis of the experiments carried out, that the effectiveness of the monitoring systems in showing deviations of project performance varies considerably from one system to another. Some systems are more effective in indicating the need for control action than others. The paper has indicated that the 'Activity based ratios' and the 'Variances' techniques have both shown the effect of cost factors on the system better than the ' Leading Parameter' technique. It has also been found that the 'Activity based ratio' technique gives a simpler and a clearer indication of the overall progress of the work than the other two systems. It remains however very difficult to generalise these results on the basis of the limited results presented.

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