A factorial approach to control the construction phase of small projects

Elena Bellardi (1), Franco Caron (P), Mauro Mancini (2)
Politecnico di Milano
Department of Management Economics and Industrial Engineering
P.zza Leonardo da Vinci 32
20133 Milan - ITALY
E-mail: Mauro.Mancini@polimi.it

Abstract

The present article contributes to Project Management, in particular the control of a project in the private residential building sector. We propose a method, validated by the analysis of a specific residential building project, to provide adequate frequency monitoring (at least greater than that found in the case analysed) of progress in the completion of the site work.

The proposed method derives from the application of the parametric approach used to estimate project costs, which is re-adapted to estimate of physical progress in the construction phase and provide with relative ease a clear picture of the actual progress on the site.

The State of Works Progress as the first part of project control can, thereby, provide effective and continual support over time (Conroy & Soltan, 1998) to the Project Manager’s decisions and not merely produce data for their own sake or to fulfil a contractual obligation (Rossi, 2003); The resultant quantitative information may support a broad and in-depth analysis of project performance, and the reasons for both project success and project management success (Terry Cooke-Davies, 2002).

1. Control of progress

Realisation of an EPC project in the residential building sector demands a considerable use of resources in a limited amount of time. In particular, a major site control and monitoring effort is required from the Main Contractor to ensure that all the actors involved, specifically the sub-contractors, complete the tasks in the defined ways and times, so as to satisfy the time/cost/quality commitments agreed with the customer on contract acquisition. Management of the multitude of resources involved must be carried out in recognition of the fact that the deliverable is often fully defined only at the completion of the project.

A clear understanding of the progress of the project together, obviously, with careful planning makes it possible to recognise the feasibility of the objectives in the realisation phase and to identify immediately any critical situations requiring ad hoc corrective measures, so controlling effectively the dynamics governing the normal and frequent changes in a project (Reichelt & Lyneis, 1999, Love et al. 2000).

In the management of a project, we would hope to have information documenting the state of the works, in order to ensure continuous feedback on the results of activities completed and, thus, on the progress of the deliverable in each stage of development. This should verify that the progress planned in the Preliminary or Original Estimate are respected.
The calculation of progress in the realisation phase has a two-fold objective: first to provide the most objective possible measure of the past, so certifying what has been done up to that moment, and second to provide a basis for the most reliable forecast of the future and, with that, an estimate of completion from time-now.

The question of how to calculate project progress has been widely discussed in the literature on project management in function of the reliability of the information available. Particular attention must be drawn to the Earned Value method (Burke, 1999; Fleming & Koppelman, 1999; Turner, 2000; Kim et al. 2003), as within a Cost Schedule Control System (C/SCS), this approach guarantees a rigorous estimate of project progress. The same C/SCS method is, moreover, proposed in various systems to assess project performance, alongside Balanced Scorecard (Barber & Miley, 2002) techniques and indicators providing specific analyses of project performance (Pillai et al., 2002).

Reference must also be made to techniques expressly based on the means of breakdown of a project into its elementary tasks or Work Packages. These techniques include: Interim Milestones; 0-100% rule; 50-50% rule; Percentage of Completion; Standard or Equivalent Units; Level of Effort; Apportioned Effort.

2. The approach used

The C/SCS technique provides a detailed view of the state of progress, but requires the collection and processing of significant quantities of data, with the risk that the information may not arrive on time. The model proposed below seeks to overcome this difficulty, so making the information feedback sleeker and more rapid, while taking appropriate account of the cost-benefit trade-off.

The model’s underlying criterion derives from the techniques of project cost estimating, which, we recall, are of two types: parametric and analytical. We use, in particular, the parametric approach.

The approach identifies a reference cost-driver from which the cost of the entire plant is estimated. The cost-driver may be directly the plant capacity, if cost curves are available showing the cost/plant capacity ratio of similar plants realised by the company or a competitor (these are called maximum estimates).

Another approach half-way between the parametric and the analytical type is the so-called factorial method, in which the cost driver is the cost of the main components (items), and the estimate of the total cost is derived with corrective co-efficients which take account of the costs of bulk material, labour, services, etc.

Regarding, then, the different methods proposed in the literature to estimate progress during the realisation phase, we note a tendency to use analytical approaches which in some way seek to overcome a project’s intrinsic imprecision. Some use the resources (e.g. Man-hours) which carry out the activities, others are based on the physical output generated, others again produce accounting and financial data. We can see that the procedures used to measure and interpret the state of the activities at the control date can be both costly and extremely disparate.
Starting from a decision to use a parametric approach to provide a frequently updated estimate of the progress of works and obtain continual feedback on the development of the situation, the present study assesses the applicability of the “Leading Parameter” approach (Al-Jibouri, 2003) in an Italian case.

The aim of the Leading Parameter methodology is to provide a continual and exhaustive view of the state of a project using a limited quantity of data (i.e. the parametric approach). Taking a structural element, e.g. concrete for a bridge, we derive information on the progress of the entire work. Thus, by monitoring a defined, but significant, group of work packages, we keep the entire project phase under control.

The steps leading to the definition of the present method are as follows:

1. formulation of a methodology to choose the Leading Parameter of the construction phase (the ‘parametric’ component);
2. definition of the Multiplicative Factor (‘factorial’ component).

Once the structure of the model had been defined, its applicability was verified in a residential building project.

3. Identification of the Leading Parameter

In the course of the analysis of the project in question, it proved necessary to define a structured methodology to identify the parameters to use to calculate progress in the construction phase, as it is difficult to generalise the example presented by Saad H. Al-Jibouri which refers to a simple realisation. A bridge can be approximated to just concrete, but for more complex structures, more elements are needed. A petroleum plant will include, among other things, the piping, a hospital the air conditioning, and a hotel the finishes, etc.

To formalise the choice of parameters, we have to identify a common language and a generally recognised criterion for the breakdown. Despite obvious approximations dictated by the uniqueness and un-repeatability of projects, the UNI norms are an excellent tool for this purpose. The procedure employed for the implementation of the model, which is applied to a residential building site and is summarised in the following block diagram, uses the specific UNI 8290-1 for the sector.

Using this norm, we establish which elements are fundamental for a generic building. These are found in the specific WBS in question, i.e. the site for which we wish to determine progress. We calculate the progress of the leading parameter (the identified single technical element) using the expressions given in the section below based on a corrective factor. These steps are repeated and the number of parameters considered at the same time

![Block diagram](image-url)
increased until the approximation is considered adequate.

This prompts the question: when is an approximation adequate? The answer to this question is very complex, as it is not easy to assess the costs and benefits of an analysis undertaken at different levels of detail. The model described in the section below has been tested on data from a site nearing completion at the time the model was being defined. Final figures on the progress of all activities undertaken were therefore available. The 'adequate approximation' refers to the comparison between the progress achieved in the construction phase (the final figures available) and the proxy calculated with the proposed method. Obviously, if the method is to be applied to future projects, we will have final figures, at time-now, for only some of the activities, so it will not be possible to compare the proxy calculated with the model and the actual state of the site, precisely because the second term of the comparison is not available. The use of the block diagram can thus be seen as a means of creating a database of pre-analysed cases. Once the choice of specific parameters has been seen to be correct in a number of projects that is sufficiently large to ensure that the process of selection is reliable and stable, these parameters are taken as fixed in monitoring any new project, and the multiplication factor is calculated for the new case.

4. Definition of the Multiplicative Factor

The definition of the corrective factor derives from the following simple consideration. If we wish, for example, to use concrete as the only leading parameter, we must highlight how this item can become a part for the whole, that is a more or less significant portion of the entire deliverable. Therefore, we must also in some way bear in mind the percentage of missing parts, i.e. all those items which constitute the building, but are not included under the label 'concrete'.

With the project data available, these missing parts can be weighted with the following multiplicative factor:

\[
MF(LP, t) = 1 - \frac{C.C.(LP)}{\sum C.C.(All)}
\]  

(1)

where the multiplicative factor is a function of the selected L.P. (Leading Parameter) and of time. The terms mean:

- **MF - Multiplicative Factor**
- **C.C.(L.P.) - Cumulative cost of L.P. (leading parameter) works**: is the cumulative cost up to time-now according to the Preliminary Estimate for the parameters linked to the chosen leading parameter;
- **\( \sum C.C.(All) \) - Sum of cumulative cost of site works**: indicates the cost sustained according to the Preliminary Estimate by the entire site up during the developing period of the activity related to the leading parameter.

At this stage, two points must be clarified. We prefer to use the cost of works rather than physical quantities (man-hours, weights and volumes used, etc.), as the majority of site works are often subcontracted, and progress is estimated by accounts, because the companies which
undertake the works raise invoices without distinguishing the individual cost items (and the costs are generally slightly higher).

The second point concerns the reason why we use data from the Preliminary Estimate. As stated, the purpose of the present method is to provide frequent monitoring of a limited number of elements of the structure which are believed to be the most representative of the whole (i.e. the leading parameters). For these elements, we have both progress against the estimate (planned progress in the Preliminary Estimate) and the final situation which is assessed and processed at the control date. For all parts of the structure, at the time-now in the realisation phase, we only know what should be the planned progress. In order that the multiplication factor is internally homogeneous, we must use data from the Preliminary Estimate in both the numerator and the denominator.

Approximated progress (absolute value) for the missing parts of the entire site is obtained from:

\[
\text{PROXI}_{\text{miss}}(\text{LP}; t) = MF(t) \cdot \text{Pr}g_{\text{LP}(t)} \cdot \sum \text{C.C.}(\text{all})
\]  

where the terms mean:

- MF - Multiplicative Factor
- PROXI_{miss}(PL; t) – Approximated progress of the missing part using Leading Parameter
- PrgLP – Progress of leading parameter: is defined as:

\[
\text{Pr}g_{\text{LP}(t)} = \sum_m \%\text{Pr}g_m(t) \cdot p_m
\]  

where \%Prgm(t) is the percentage of completion (Progress) in function of the effective works undertaken for the single \(m^{th}\) parameter at time-now and \(p_m\) the weight of the single \(m^{th}\) parameter chosen, which together with the other parameters constitutes the leading parameter

\[
p_m(t) = \frac{\text{CPC}_m}{\sum_m \text{CPC}_m}
\]  

where CPC\(_m\) is the Cost from the Current Estimate at time-now of the \(m^{th}\) parameter.

- \(\sum \text{C.C.}(\text{All})\) - Sum of cumulative cost of site works: indicates the cost sustained according to the Preliminary Estimate by the entire site up during the developing period of the activity related to the leading parameter.

Generally the more useful value is not the missing part but the overall project progress (PROXI (LP, t)) that, according to the previous definitions, can be expressed (percentage value) as:

\[
\text{PROXI}(\text{LP}; t) = \text{Pr}g_{\text{LP}(t)} \cdot \frac{\text{C.C.}(\text{LP})}{\sum \text{C.C.}(\text{all})}
\]

5. Analysis of results

For the analysed site, we have the following data:
- the Preliminary Estimate of all activities undertaken on the site;
- the Current Estimate of all activities undertaken on the site at the time of the five surveys carried out by the Main Contractor managing the site;
The first parameter tested was concrete, shown in Fig. 1, in which the following information is given:

- the actual state from the Current Estimate of all activities undertaken on the site;
- progress of the leading parameter alone (Structures in Elevation);
- the PROXI.

We see that we have data on the leading parameter only for an initial period up to when the Structures in Elevation are completed:

Moreover, in the period 'covered' by the 'Structures in Elevation', the average divergence between the actual state of the site and the PROXI is above 10%, a figure considered excessive and unsatisfactory by the Main Contractor. The fact that in taking only the Structures in Elevation as the leading parameter, we can obtain the approximate state of the entire site only for an initial period is understandable if we consider the overall planned progress and the forecast for the Structures in Elevation according to the Preliminary Estimate for the site.

At this point, going through the block diagram given in the paragraph “Identification of the Leading Parameter”, we assessed the following categories for the present study:

- Structures in Elevation;
- Supply and services system;
- Vertical completion.

For each of these categories, the specific element found in the available WBS was:

- for the Structures in Elevation category, the Structures in Elevation.
- for supply of services plant, we chose the Electrical Installation;
- for vertical completion we considered Fillings and Brickwork.

We took account of the temporal sequence of the installation in the single parameters, so as to have the most complete 'coverage' of the the construction phase. As illustrated in the figure below, the three parameters selected ensured that the entire period of works activities as planned in the Preliminary Estimate was monitored (fig. 4).
By taking together Structures in Elevation and the Electrical Installation, the approximation is improved, as the average difference is reduced to approximately 6% using just 25% of the site data.

If we consider all three selected elements at the same time, we have a further improvement in the information obtained from the proposed model, with the average difference between the PROXI and the actual progress of the site around 5% using about 30% of the site data (fig. 5).

Given the type of information available, a further angle of investigation is to include the economic factor together with the technical aspect as a parameter of choice. We considered those parameters which taken together represented more than 2% of the total site cost and most closely followed the expected development of the entire project, (fig. 6).

On the basis of these parameters, the approximated progress differs from the actual value by an average of 3%. However, in this case, 50% of the available site data must be used.
6. Conclusions and future developments

The present study defines a model to assess the progress in works on a residential building site. We have applied the methodology to a real case and obtained the results given in the section above. To verify the value of the proposed methodology, obviously further tests are necessary using other projects (in which we have all the final data for the entire site, in order to answer the question, 'when is an approximation adequate?', as raised in the section 'Identification of the leading Parameter'). This will provide greater confidence in the chosen parameters, which could then be used in a monitoring system. The Multiplication Factor must also be investigated further.

We can therefore predict that the work will develop in two directions:

- the first concerns the extension of the principal components of the model ('Identification of the Leading Parameter' and 'Definition of the Multiplication Factor') to the Engineering and Procurement phases, developing these components in function of the particular features of these two phases;
- the second direction could involve the application of the model to other sectors, e.g. Plant Engineering or Public Works, formulating a new methodology to identify the specific parameters of the sector analysed and, at the same time, a new Multiplication Factor.

References


