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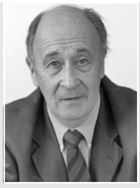

Albert Hamilton
Senior Consultant, Professor, National Centre for Project Management, Middlesex University, London, UK

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Project design: tasks that need to be managed

A. Hamilton BSc, CEng, FICE, FIMechE, FIEI, FAPM

In many projects, design is an essential process whose purpose is to create, describe, and communicate that which is to be implemented. Managing the design process normally means setting the design objectives, evaluating design performance and coordinating the associated design activities. A systems approach to managing projects, where all phases are integrated and use the same basic method for planning work activities and tracking performance, is an important aspect of 'best practice'. Based on techniques generally in use in managing the physical delivery phase, a practical and generic model to managing a project's design is described in this paper. The model, a computerised spreadsheet, which accurately captures design status, is in stark contrast to the often-found practice of subjective assessment as design work progresses.

1. INTRODUCTION

The end product that the design process creates is often a facility that satisfies some aspect of societal need (public sector) or some deliverable required by an owner or customer (private sector). Satisfying societal need is paid for out of Exchequer funding and often other contributions that are provided from internal revenue streams and/or external donations. The private sector pays for projects from existing equity or through loans raised. Planned project expenditures need to be based on the total capital costs. When developing the budget requirements for each project the total forecasted cost needs to be identified. The total budget of any project must include the costs of conceiving, designing, procuring, constructing, commissioning, training and other processes needed to provide the 'something that does not exist'. The operational costs for a new facility are likely to be treated separately as part of the annual direct and indirect costs paid for by the operator.

The time of greatest human decision-making impact on a project's cost is during the early stages of a project; in general, the earlier the greater the impact (Fig. 1). In later periods, namely post-design, the cost of introducing design changes could well exceed the initial estimated total cost of a project. A recent example is the Holyrood Project—the new Scottish Houses of Parliament—which during construction was subjected to a peak of 545 design changes per month that contributed significantly to the 20-month delay and the £220 million cost overrun.

The ability to influence the costs of a project over the full design period is estimated by the author at 75%, meaning that opportunities are restricted to influencing only 25% of the budgeted project cost after design completion. This can be discerned from Fig. 1.

Figure 1 also indicates (solid line) that the cost of the concept stage is traditionally between 5 and 10% of total design cost. In general, to complete the design work to the end of preliminary stage can equate to an expenditure of about 20% of the design budget, and 80% by the end of the detailed stage, but of course each project's design cost profile is particular to its design requirements.

Within the concept phase and subsequent design phases the traditionally accepted five-step iterative management process, IPECCO, applies. It has been found that the use of best practice project management is associated with better performance of project outcomes. The management process[1] of (*a*) initiate, (*b*) plan, (*c*) execute, (*d*) control and (*e*) close out (the five-step process shown on Fig. 1) is a best practice for all phases of a project including the design phase.

The management of the process that creates a project from what starts out as a need or an idea, and then a series of possible options, one of which could be the approved project, can be critical to delivering the correct, value-for-money, solution.[2]

Adequate conceptualisation of any project during the initial phase is sacrosanct. During this phase all alternative schemes that could satisfy the need must be compared for technical and financial efficacy and these concept studies must be compared with the 'do-nothing' option. Too often preliminary design is started before the outcome of conceptualisation is known and sometimes the concept phase is ignored because of some external (e.g. political) influence or through a misguided internal intervention. There are numerous projects that proceed but do not provide 'value for money', others that are in some, or many, ways functionally inadequate and do not deliver the requirements, and there are some that experience tells us should never have been built.

Ideally, all the stakeholders in a project need to participate in its design. It is important that a 'lowerarchy' and not a 'hierarchy' concept is used as the means of determining the requirements.[3] For example, a roads project needs the involvement of road users, a prison project needs the involvement of prison officers and

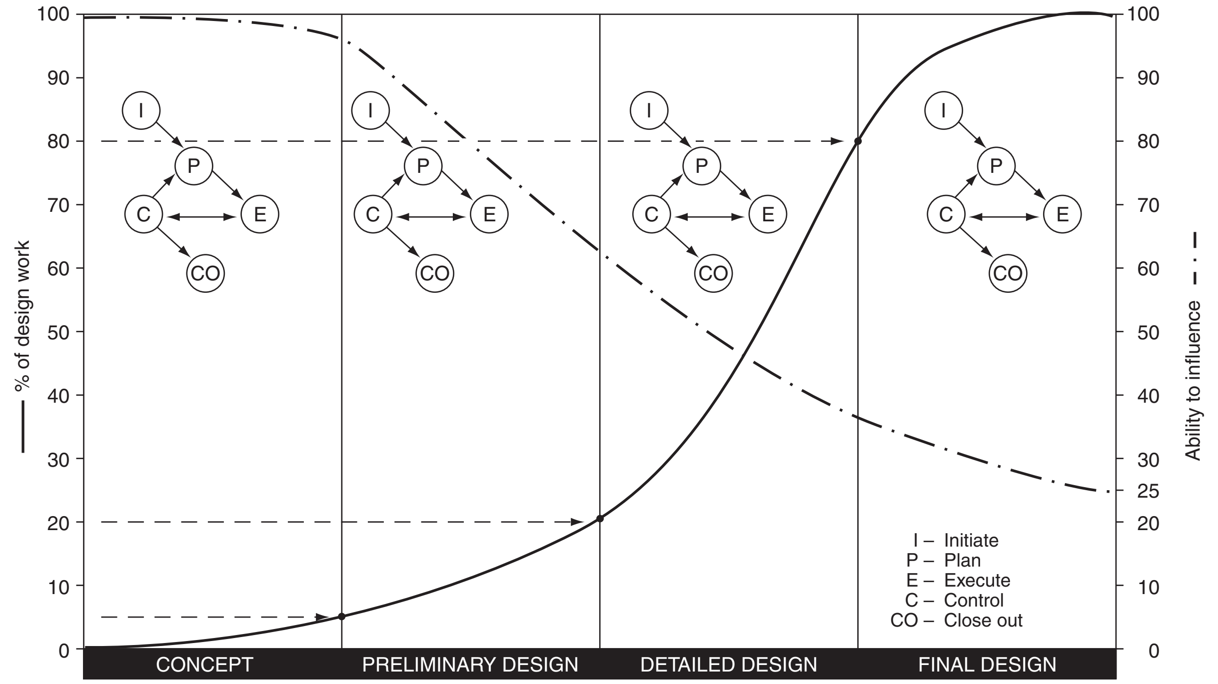

Fig. 1. Design phases, effort and impact

prisoners, a schools project needs the involvement of teachers and pupils, and so on. As the simultaneous involvement of all members of a society is not feasible, it is normal to employ a sequential process. This involves conceptual design by a relatively small core group. The group's designs are then widely circulated along with requests for suggested changes and additions. The core group subsequently takes these into account, and the modified design(s) recirculated. This cycle is repeated until no new changes are suggested.

The process is then followed for preliminary, followed by detailed design and then the final design stage, but the stakeholders are likely to decrease in number and may well have a somewhat different profile to that during the concept stage.

2. DESIGN PROCESS

Design is likely to have two organisational parts to it that, although integrated, perform separate functions. The parts are

(*a*) technical design
(*b*) design management.

Technical design is the information processing that emanates from such inputs as: customer need, design codes, designer knowledge, designer experience, technical literature, government terms of reference, etc. Design management is the transformation of the various inputs to plan and resource the design process, monitor status, control the design schedule and budget, lead and encourage the design team, administer design changes, etc.

Computer-aided engineering technology is rapidly altering the design-service delivery process. The implementation of this technology is affecting the management of design production as well as associated quality control activities. Many, but not all, of the manual tasks of the traditional design process have virtually disappeared. Some industries, such as civil engineering, use design processes that are an amalgam of manual and computer-aided.

Researchers have stated that the cost of design is roughly 3–10% of the total out-turn cost of a project.[4] This relatively small percentage of the total cost perhaps suggests the reason why management of the 'downstream' phases have invariably been the focus of much past research. Regardless of the actual percentage, the amount of money spent on capital works design, and the volume of design work carried out year after year, is sizeable. Design effort can be the single most important influence on the out-turn costs of a project. Therefore, the effectiveness of design management can be a significant determinant of the quality of design outcome and, of course, design cost.

The results of research[5] in North America indicate that over 50% of change control costs occurring during construction can be traced to errors with plans and specifications. Almost 48% of design errors are due to lack of integration and coordination between the subsets of plans and specifications needed for the complete design of a project. About 32% of errors are due to omissions, about 17% are due to fundamental error(s) in what is being proposed, and about 3% are due to calculation error.

During the design process, designers often are required to revise designs and drawings for a variety of reasons contributing to wasted effort and extra cost. The author's view is the cost of design wastage can be as high as 40–45% of the design cost of certain capital works projects. In the UK the factors that contribute to wastage are often classified as managerial.

3. DESIGN: A SUB-PROJECT TO BE MANAGED

An analysis[6] of 450 respondents in 113 North American design firms showed that managers of design groups were above average to outstanding in technical expertise but were average to below average in managerial attributes, leadership skills, human relations skills and administration experience. It was found that one in three projects failed to achieve their anticipated design cost and design schedule objectives.

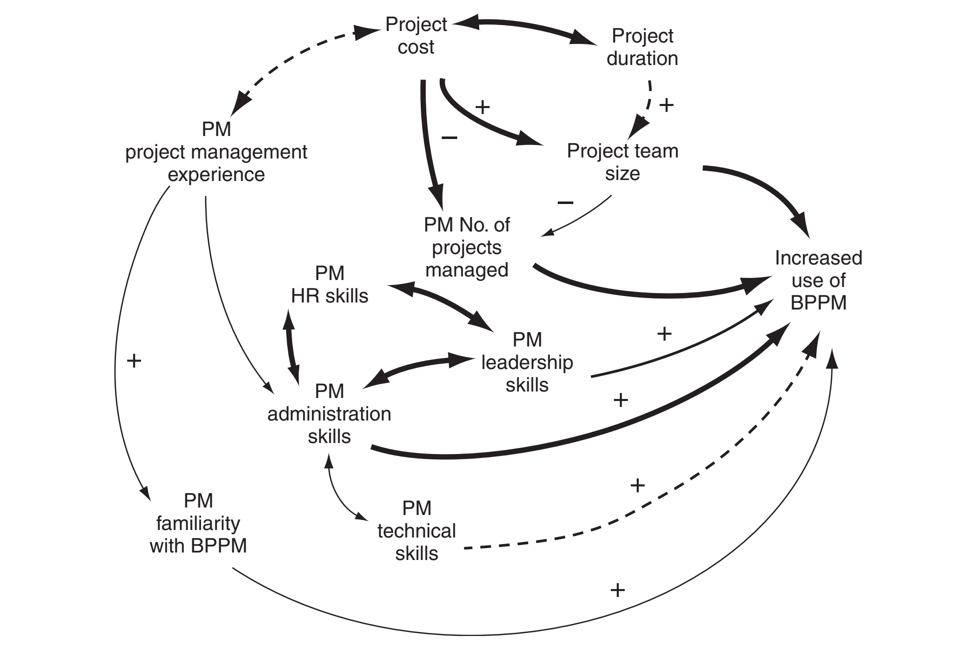

Fig. 2. Project design management system; BPPM, best practice project management; PM, project manager

Managing projects is a complex process that has been described as a combination of hard system and soft system approaches.[7]

Figure 2 is a multiple-cause diagram showing key relationships and causality that represents, *inter-alia*, the design management system. The arrows mean 'cause', or 'contribute to', or 'enable'; the arrows show the direction of a relationship and the thickness of connecting lines indicate the strength of a relationship. A plus sign signifies that a change in the variable at the tail produces a *similar* change in the variable at the arrowhead. A minus sign signifies that a change in the variable at the tail produces an *opposite* change in the variable at the arrowhead.

The size of the design sub-project, the number of people in the design team, and the dedicated role and management skills of the selected design manager are aspects of the design system that have considerable influence on increasing use of best practice project (design) management.

4. TECHNIQUES FOR MANAGING DESIGN

Selected management techniques[8] that are used in the projects' environment and are applicable to managing design are described in the following paragraphs.

4.1. Work breakdown structure (WBS)

The design work packages identify the individual design tasks. The individual tasks may be the human work effort required within, say, five technical headings. The traditional headings include: *drawings* (general arrangement, detail, method statements, sketches, steel schedules, etc.); *specifications* (general, technical, etc. descriptions of what is required and its quality); and *material documents* (bill of materials, data sheets, purchase orders, contracts, etc.). Other headings might include: *manuals* (site investigation procedures, welding procedures, operations manuals, etc.); and *management* (supervision, quality control, design management, etc.).

4.2. Responsibility assignment matrix (RAM)

Each task identified in the WBS has assigned to it the individuals who need to be involved. Assigned human resources typically include those (*a*) responsible for creating and completing, (*b*) assisting the responsible person, (*c*) providing some sort of input, (*d*) approving the approach to be used, and (*e*) signing-off the outcome, and so on. The RAM is the integration of all stakeholders to the design work tasks by assigning individual involvement.

4.3. Critical path method (CPM)

The WBS elements and tasks are sequenced, to place them in a planned order of how the work is to be performed; this sequence is called a logic diagram. Individual elements and tasks are evaluated to determine the needed resources from which the duration of each task can be established. A mathematical analysis of the logic diagram determines (*a*) the overall design duration, (*b*) the critical path and hence the critical tasks, and (*c*) offers the means by which the plan can be modified to take account of a time constraint and/or a cost constraint.

4.4. Activity estimates and budget baseline

From the CPM and RAM an estimate of resource usage per task provides a task cost estimate. Where there is uncertainty in the resources to be used or in the estimation of the cost of any task, use of probability theory provides a task's 'value of centrality' and a 'range of values'. Aggregating the range of all 'uncertain' tasks to the estimate for the 'certain' tasks and distributing when the costs are likely to occur, provides the baseline cost of the design. The baseline cost, which is time related, is commonly referred to as the *planned value* (PV).

4.5. Central limit theorem (CLT)

For both the time analysis and the cost analysis of a project's design, the procedure for applying ranges of task duration and task cost, application of the central limit theorem provides a means of linking these variables with their probability. CLT is used to determine a range of design period durations, and design costs, versus the probability of their being achieved.

4.6. Value management (VM)

During design the techniques of value management may be applied to maximise project functionality at minimum total life-cycle cost. Using stakeholder workshops is a common method for deriving different design options. By scoring each option against the value criteria a best design option becomes apparent. A range of techniques[9] are normally used that include (*a*) cost modelling, (*b*) functional analysis system technique, (*c*) basic and secondary function, (*d*) life-cycle costing, (*e*) criteria ranking, and a number of others.

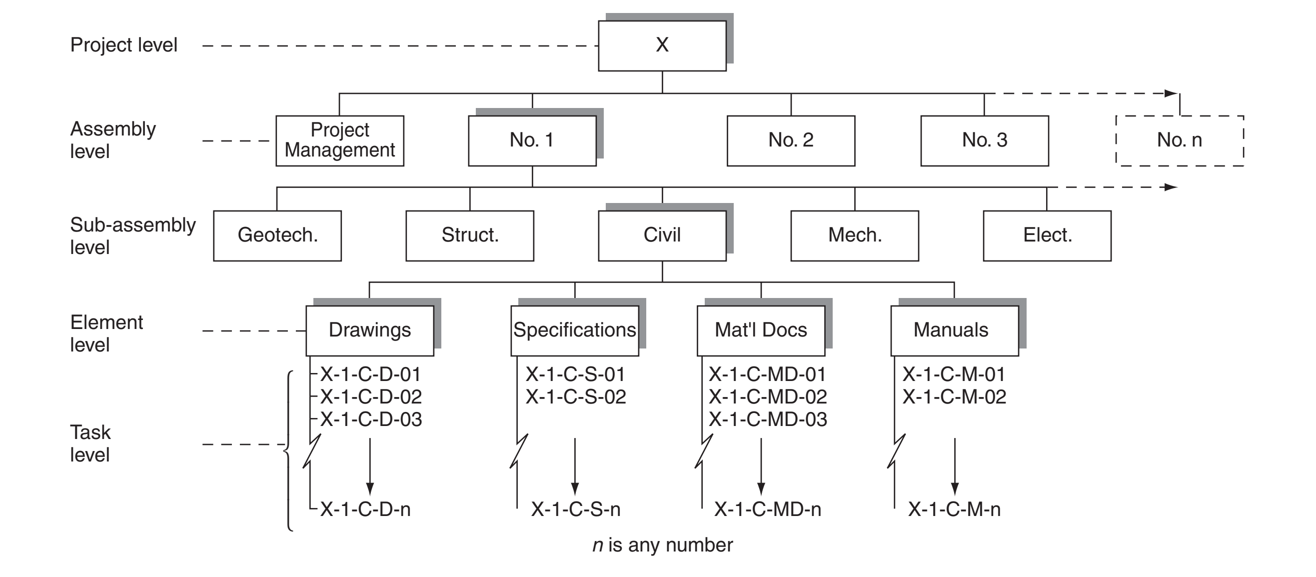

Fig. 3. Design phase work decomposed into WBS format

4.7. Management plans (MP)

Plans need to be prepared and documented that specify how (*a*) health and safety, (*b*) integration, (*c*) procurement and (*d*) quality of the design phase are to be managed. Such plans, with the measurable objectives, are sufficiently detailed to state what is to be produced, who is responsible, when the *what* is to take place, and how the *what* is to be achieved for each of these four management areas. Such plans need to be part of the design management of any project.

5. PLANNING AND SCHEDULING THE DESIGN PROCESS

Because management plans for health and safety, integration, procurement, and quality are very project-specific, the model proposed for managing the design phase or stages of a generic project is based on the other seven classical tools/techniques.

Initiating an overall plan for design work includes all project stakeholders, those contributing to the design process and possibly aspects of a project's implementation, at early-convened workshops. These workshops, best led by an independent facilitator, are extremely valuable vehicles for gathering informed people and for creating and analysing design-stage information. If there is more than one design option that could satisfy the need then the stakeholders are best placed to score each option against the value criteria to confirm the preferred design option.

Assuming there is a preferred design option, a next step is to decompose the design products (assemblies, sub-assemblies, elements, etc.) for the preliminary design, the detail design, and the final design. The outcome is a product-related structure that identifies all related activities needed to undertake the scope of design work. A WBS of design phase activities is the result of decomposing the design work.

The decomposition of a project's design (Fig. 3) is accomplished by horizontally separating the design into a series of assemblies (facilities) which includes project management, sub-assemblies (technical disciplines), elements (drawings, specifications, material documents, and manuals) and vertically by identifying the tasks or individual work items. The design work items are provided with a unique code that is developed from the hierarchy of the WBS.

By identifying each work item a first attempt can be made in assessing the personnel responsible for creating and completing, assisting, approving, signing-off, etc. and documenting the outcome. A RAM is the commonly used tool for documenting such information. Although an inverted tree-type WBS structure (Fig. 3) is useful to start with, it is considerably more convenient to convert to a linear format suitable for inclusion within an e-spreadsheet.

Once complete, the WBS activities are sequenced with preceding tasks to the left and succeeding tasks to the right, as shown in Fig. 4.

Through facilitated workshops, stakeholders sequence the workflow, determine the duration for each task, and mathematically analyse the sequence to produce a scheduled plan. Tasks whose duration is uncertain become the focus of special quantitative assessment. Where there is uncertainty, the duration and cost of a task can be three-point estimates from which an expected value and an expected standard deviation can be calculated. Using probability theory and the CLT it is possible to link *design duration and cost* to the *probability of being achieved*.

Estimating the cost of each task's duration and distributing these estimated costs to reflect an activity's planned expenditure, through aggregating all distributions for the tasks, creates the design's cost budget. Budget data can be expressed in terms of monetary units (mu), person-hours, or any other work unit depending upon preference or the units that are normally used by the performing organisation. The total accumulated design cost against design duration can be linked (Fig. 5), and the result becomes known as the cost baseline or PV.

The result at V and H is an assumed standard normal probability distribution which links duration and budget cost with the

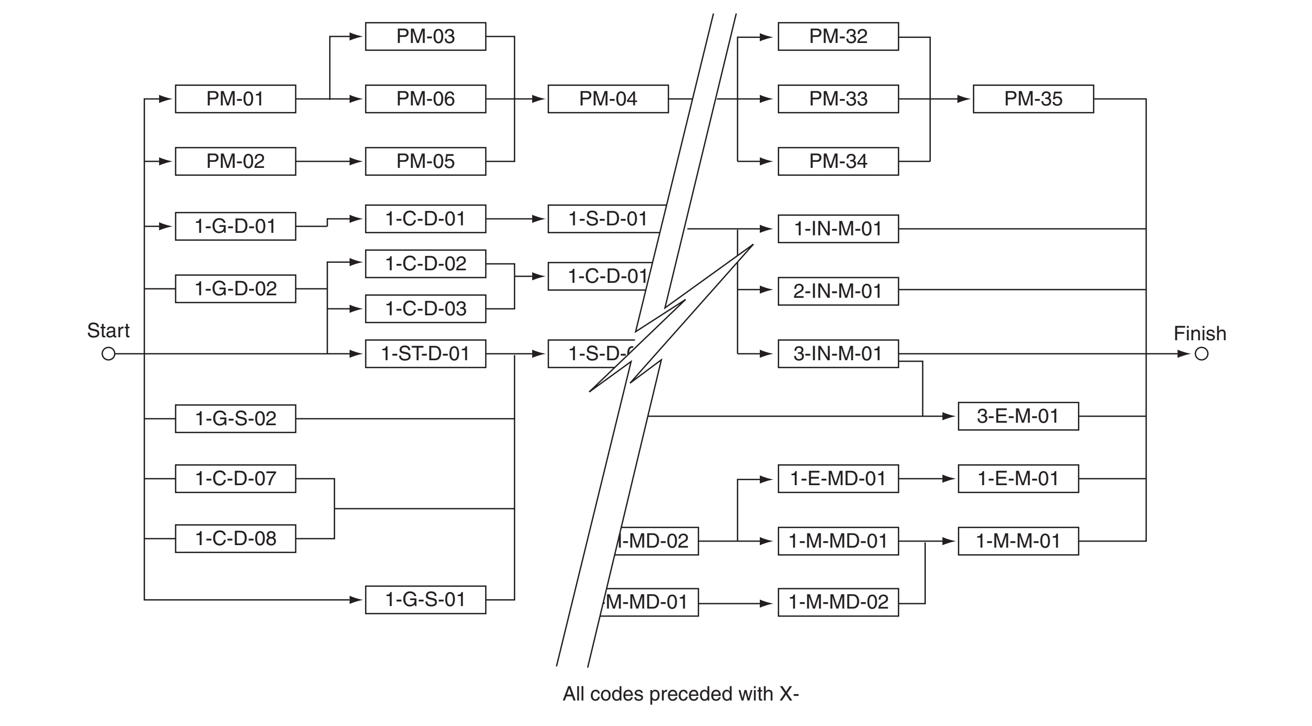

Fig. 4. In-part logic diagram of design tasks

probability of not being exceeded. Fig. 5 shows that for a duration of 28 weeks there is a 50% chance of it being achieved and for the projected out-turn cost of 660 000 mu there is a 50% chance of it being exceeded.

Figure 5 also shows variance (dotted curves) that are representative of the pessimistic (upper) and optimistic (lower) time–cost relationship that accommodates the certain plus uncertain tasks.

6. USING A COMPUTERISED SPREADSHEET

Earned value is the normal method for controlling task performance. This is best applied by setting control points (CPs) for each task. For example, the control points for a drawing could

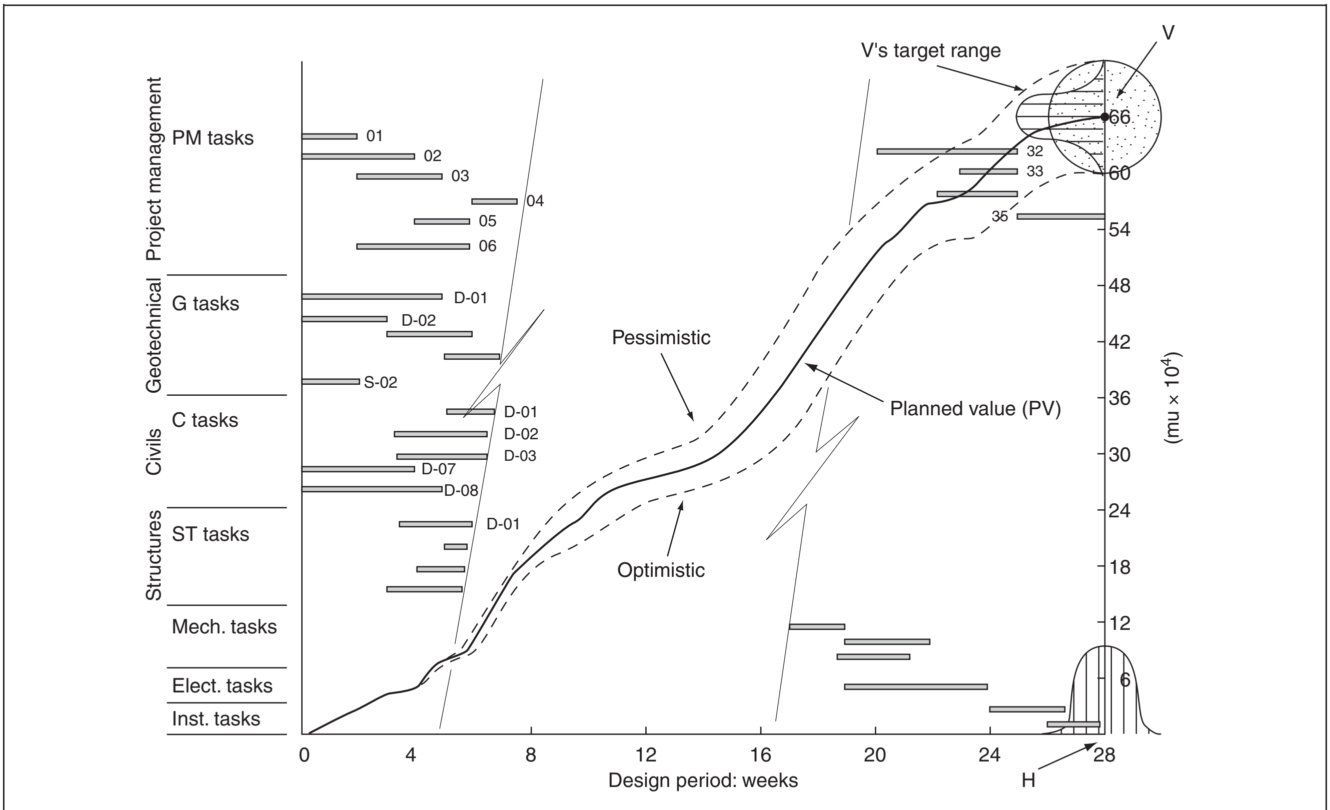

Fig. 5. Budget cost against design duration

(1)	(2)	(3)	(4)	(5)	(6)				(7)				(8)	(9)	(10)	(11)	(12)
					Assigned CP: %				Actual CP: %								
Task code No.	Initial task budget	Approved changes	Current budget	To-date actual	No. 1	No. 2	No. 3	No. 4	No. 1	No. 2	No. 3	No. 4	Percentage complete	Earned value	Perf. index (PI)	Current forecast	Current variance
PM-01	140		140	128	5	45	25	25	100	100	100	100	100	140	1·09	129	−1
PM-02	70	20	90	100	5	45	25	25	100	100	100	100	100	90	0·90	100	0
PM-03	70		70	70	5	45	30	20	100	100	100	100	100	70	1·00	70	0
PM-04	50		50	55	5	45	30	20	100	100	50	0	65	33	0·60	84	−29
1-G-D-01	130		130	125	5	45	50		100	100	100		100	130	1·04	125	0
1-G-D-02	60		60	60	5	45	50		100	100	100		100	60	1·00	60	0
1-G-S-01	100		100	120	25	25	10	40	100	100	100	100	100	100	0·83	121	−1
1-G-S-02	40	20	60	45	25	25	10	40	100	100	100	50	80	48	1·07	56	−11
2-G-D-01	80		80	40	5	45	50		100	80	50		66	53	1·33	60	−20
2-G-S-01	80		80	40	25	25	10	40	100	100	60	20	64	51	1·28	63	−23
1-C-D-01	220		220	240	5	45	50		100	100	100		100	220	0·92	239	1
1-C-D-02	250		250	240	5	45	50		100	100	100		100	250	1·04	240	0
1-C-D-03	250		250	230	5	45	50		100	100	100		100	250	1·09	229	1
1-C-D-04	120		120	110	5	45	50		100	100	100		100	120	1·09	110	0
1-C-D-05	100	10	110	110	5	45	50		100	100	60		80	88	0·80	138	−28
1-C-D-06	80		80	80	5	45	50		100	100	60		80	64	0·80	100	−20
1-C-D-07	80		80	70	5	45	50		100	100	30		65	52	0·74	108	−38
1-C-D-08	80	30	110	90	5	45	50		100	100	10		55	61	0·68	162	−52
1-C-S-01	120		120	90	25	25	10	40	100	100	100	40	76	91	1·01	119	−29
1-C-S-02	105		105	100	25	25	10	40	100	100	100	40	76	80	0·80	131	−31

Table 1. Snap shot of design task status

be when (*a*) the drawing is drafted and issued for review, (*b*) checked and signed by the supervising engineer and project manager, and (*c*) issued for construction. The earned value percentage for such an example could be, say, (*a*) 50%, (*b*) 75% and (*c*) 100%. Different CPs and earned values apply to the range of different tasks.

An in-part example of an e-spreadsheet that could form the basis for design control is shown in Table 1.

Table 1 is a database of input data as described in the following paragraphs.

Column 1 shows the task code number.

Column 2 shows the initial task budget.

Column 6 shows the assigned CPs.

Column 3 provides data on any approved variations or changes to the initial budget which when added to column 2 provides the current budget in column 4. Column 5 provides the to-date actual accumulated cost of each task. Column 6, as stated, shows the assigned percentage of the control points for each task and column 7 shows the actual status of each control point at some agreed date of measuring the status.

Column 8 is the percentage complete (PC) of a task and is found by using the formula $PC = \sum(CP_i) \times (A_i)$, where A_i is the actual progress accomplished on each control point expressed as a percentage.

Column 9 is the earned value (EV) and is found by using the formula EV = PC × current budget of work task.

Column 10 is the performance index (PI) and is obtained by dividing column 9 by column 5. Column 11 is the current budget forecast and is obtained by dividing column 4 by column 10. Column 12 is the current variance and is obtained by subtracting column 11 from column 5.

By examination, column 10 showing a PI of 1·00, or greater, is identified as good performance. Anything below 1·00 indicates less than satisfactory performance. An examination of the figures in column 12 shows those tasks that, to complete, require lesser (positive values) or greater (negative values) time and budget than that already expended (column 5). PI is a useful indicator for establishing those tasks, and perhaps those individuals, having high performance or low performance and can be used as a powerful communication tool.

7. CONCLUSIONS

Today's projects need a common approach to the management of all project stages. Focusing management effort on the post-design phase of any project is necessary but not sufficient; equally significant is a project's design stage. Design needs to be treated managerially as an integrated part of any project.

The well-proven techniques that are used in managing the implementation of capital works projects are appropriate for managing design. The method presented is based on a well-used method for construction that can be applied to the planning, tracking and controlling of a project's design phase.

The outcomes from using these techniques can be easily captured on a computer spreadsheet model that facilitates both reporting current status and performance, and simplifying future updates.

The approach has shown how the model can be simply adopted for a spreadsheet package such as Microsoft's Excel that is universally understood and has wide application.

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