

System dynamics in project management: a comparative analysis with traditional methods

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Recent dramatic project failures have highlighted weaknesses in the traditional approaches to project management and in particular their failure to cope with strategic issues. System dynamics models provide a useful tool for a more systematic management of these strategic issues. There have been a number of applications of system dynamics in project management; this experience permits a tentative comparison with the more traditional approaches and to examine the particular benefits of system dynamics. The conflicts of opinion between their supporters stress the different perspectives underlying the two approaches. The comparison of the approaches is focused on the "view" of the project management process. Although, ultimately, they both assume a system perspective, identifying a cycle of planning, implementation and control, the level of detail in which they consider the project system is different. Traditional models

The increasing rate of change and the complexity of the new technologies and markets impose the need for quick and effective responses. As a consequence many organisations are now adopting "management by projects" as a general approach (Turner 1993) and project success is a primary factor for the survival and prosperity of organisations. However, projects are also becoming more complex and project failure is unfortunately another major trend. Over-runs of 40 to 200 per cent are common, while other projects are cancelled before completion but after considerable expenditure (Morris and Hough 1987). The important role of project management in modern life has highlighted some of the deficiencies of traditional techniques and the search for an alternative. Traditional techniques can encourage a narrow, operational view of the project, concentrating on the detailed planning and several studies (Davidson and Huot 1991; Morris and Hough 1987) have identified the need for a more strategic approach. Systems dynamics appears to offer this strategic alternative, assuming a holistic view of the organisation with an emphasis on the behavioural aspects of projects and their relation with managerial strategies.

This paper addresses the need for a better understanding of the nature, differences, similarities, and purposes of traditional and system dynamics approaches. If system dynamics models are to play a core role in the future developments of project management, it is important to understand their distinctive contribution to the current body of knowledge and their place in a future methodology.

The traditional approach

A large collection of techniques has been developed in response to the practical problems of project implementation. These techniques focus on the definition of the project work structure and the production of detailed schedules and budgets for monitoring and controlling performance throughout the project life cycle (Nicholas 1990). Table 1 briefly describes the most important techniques used in the traditional approach and their roles in project management. The vital contribution of the various techniques is to help communication providing graphical representations, reports, observations and supporting review meetings (Nicholas 1990).

The traditional techniques are founded on the premise that, while each project may be unique, many of the constituent elements have been experienced

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support the project manager in the detailed operational problems within the process, while system dynamics models provide more strategic insights and understanding about the effectiveness of different managerial policies. The two approaches provide complementary support to project management; this suggests it could be of major value to integrate the best of both worlds.

before. The project work is therefore decomposed into elements, for example activities, which can be individually related to previous experience. It is then possible to produce reasonable estimates for each element's duration, cost and resource requirements. The logic of the project, such as represented in a network of activities indicating their inter-relationships, supplies the basis for reconstructing the project from its parts and deducing the whole project's duration, cost and resource requirements from those of its elements. The approach assumes a well ordered project that progresses in well defined stages to completion, though the reality may be quite different. In particular, the imposed discrete view, inherited from the construction industry, might not be appropriate to model the more continuous nature of design and development projects.

While the individual techniques assume a strictly linear analysis, the ideal of the traditional approach is based on a systems methodology: the classic control cycle. It considers that project management is based on a dynamic control process that takes place within a project system and interacts with the external environment. The project system comprises a human organisation, called the project organisation, and a sub-system of materials, equipment and facilities.

Table 1. Overview of traditional project management techniques and tools

Technique/Tools	Purpose
Work Breakdown Structure—WBS	Basic definition of the project work. Precedes the project schedule and cost estimations
Responsibility matrixes	Integration of the project organisation with the WBS—assignment of responsibilities
Bar charts or Gantt Charts	Simple representation of the project schedule. Does not show the precedence relationships among activities
Project network techniques: PERT, CPM, PDM, GERT, and others.	Network techniques for work scheduling. Provide the analysis of the scheduling impacts that activities have on each other and the determination of critical activities and float times. Basis of cost estimation, resources allocation and management and risk analysis
Cost schedules	Identification of the capital requirements for resources. Estimation of realistic budgets that provide standards, against which project performance is measured
Project control: variance analysis, PERT/cost, earned value and others.	Assessment of project performance with the generation of performance indices. Provide for the detection of project overruns and the need of corrective actions. The WBS, Gantt Charts and other scheduling techniques are usually incorporated in the project control process

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The project organisation is integrated with the project work structure, providing the assignment of responsibilities to the people involved in the project. Control and planning are continuously practised as the implementation process proceeds. Under this perspective the idea that the traditional approach is "static and closed" (Davidson and Huot 1991) can be countered.

Strategy in project management

With the increasing complexity of projects and their ever more important role within organisations' way-of-life, *strategic* project management has become an increasingly crucial issue to project success. Nevertheless, project managers have a reputation as excellent fire-fighters, more "interested in the here-and-now of next steps rather than strategic questions of definition, which were generally seen as someone else's responsibility" (Morris 1994). Turner (1993) also notes project managers' common emphasis on short term planning, identifying the need for a model for the strategic management of projects. This relative lack of emphasis on strategy in project management is reflected in the literature: while the concept of strategy has been examined exhaustively in the context of other management areas, e.g. corporate strategy (Andrews 1980) and operations strategy (Anderson *et al.* 1989), there has been relatively little explicit analysis of project management.

However, translating definitions of strategic management to a project context, the characteristics of a project management strategy are:

- the individual scheduling, budgeting and resourcing decisions should have some pervasive logical *pattern*;
- strategic decisions have a widespread effect, i.e. on numerous activities;
- a project's strategy should define its position relative to its environment recognising the critical constraints;
- the strategy should ensure that the project contributes to the organisation's long term objectives.

Turner (1993) distinguishes three levels of project management reflecting these characteristics:

- *Level 1:* the interaction of the project with the rest of the business; do the project's objectives contribute to the business's objectives?
- *Level 2:* the individual project's strategy, which may be centred on the systems design and provide the basis for determining the major targets, i.e. milestones, and the appropriate allocation of responsibilities.

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- *level 3*: the tactical plan specifying the means of achieving the project's targets, typically via the activity schedule.

In level 1 management is primarily concerned with the project's compatibility with the organisation's objectives (project selection/portfolio management). At this strategic level, management is concerned about issues beyond the individual success of a project: as an example, within a strategy of market diversification a project resulting in high overspend and overrun may still have contributed to the long term organisation's success. Level 2 also refers to strategic management but now focused on an individual project (or set of projects being implemented in parallel). In this paper the term "strategic project management" corresponds to level 2 of Turner's classification.

Within the traditional approach practically all of the techniques offered to project managers are designed for use at the tactical level (level 3). Operational issues are more readily analysed and are natural candidates for the discrete models typically incorporated in the traditional techniques. The operational decisions typically assume well defined objectives and constraints that provide the boundaries for the decomposition of the project into a set of well specified activities, resource availabilities and costs. Given this detailed specification, a simple discrete analysis can deliver a precise output providing a comforting timetable of activities and the associated cashflows. However, identifying the appropriate objectives and constraints, a major element of the strategic analysis of the project (level 2), requires a different approach. This strategic analysis typically demands a more flexible tool which can model a variety of complex and not so readily quantifiable issues. Nevertheless, contrasting with the proliferation of analytical techniques that assist detailed operations, there seems to be little analytical aid on these strategic, higher level issues (Cooper 1980). The lack of a strategic analysis as the basis for a project's management has been cited as a major reason for the failure of many projects (Morris and Hough 1987).

The nature of project failure

Project failure can be blamed on many factors. Uncontrollable external forces are often cited but the real cause may well be internal: a defective project management system with ineffective organisation, practices and procedures (Nicholas 1990). Good project management should be able to cope with many of the adverse external influences and ensure a successful completion despite the environment. However, despite considerable attention, such as the development of project risk management, devoted to this field during recent years,

dramatic failures still occur. Morris and Hough (1987) undertook a survey, the results of which suggest that the main causes lie in areas such as the political/social environment, legal agreements and human factors. The majority of the factors relate to strategic issues of project management and are not addressed explicitly by the traditional project management techniques. Project managers have been using informal mental models, based on their own experience and vision of reality, to support strategic decision-making. Once the key strategic decisions have been taken, the traditional techniques are deployed to support the detailed operational planning, but the crucial mistakes may already have been made. This analysis suggests that poor, informal strategic judgement may be the root cause of many project failures. This problem has been reinforced by an apparent reluctance of organisations to learn effectively from these failures. The transfer of lessons from the past into future practice can offer a crucial competitive advantage (Senge 1990) but in practice this process is seldom implemented to its full extent; often it is constrained by cultural and political factors (Abdel-Hamid and Madnick 1990).

The process of estimating the duration of activities in a project network analysis provides an example of the relationship between the strategic and operational analyses. The estimated duration of project activities is based on the assumption that the staff employed will work at a certain productivity level. On making this estimation, the project manager naturally considers subjective factors like workforce motivation, schedule pressure, workforce experience, and possible errors. However, if in practice this informal analysis fails, all the effort employed in the development of the work schedule plan will be wasted. A good, experienced project manager may well make adequate allowance for all the factors, but the traditional techniques do not encourage their consideration by any explicit analysis. Another typical case relates to project monitoring: the project control process is based on *human perceptions* of the project status. In the real world errors tend to remain unperceived and, as a consequence the real progress differs from the perceived progress. This illusion of project progress may be exacerbated by political factors which encourage a trend to overlook errors in the early development stages of projects (Abdel-Hamid and Madnick 1990). Detailed plans based on these misleading perceptions can result in ineffective or even counterproductive efforts. Eventually the problems have to be confronted and considerable effort is then expended in correcting errors. Despite much activity and expenditure, time passes with little change in the apparent progress and the project remains at the nearly, or 90 per cent, completion level; this phenomenon is usually referred to as the "90% syndrome" (Abdel-Hamid 1988; Cooper 1993c) and its persistent occurrence highlights poor organisational learning.

Two main reasons can be identified for the failure of traditional techniques to consider explicitly most of these human factors (so called *soft factors*):

1. Their intrinsic subjectivity seriously restrains an appropriate quantification, particularly at the level of detail assumed by the techniques;
2. Their *local* impact on the individual elements of the project system is perceived to be of minor relevance and hence empirical assumptions can easily be made; their long-term impacts result from less visible compounding effects that ripple throughout the project life-cycle.

These same arguments support the idea that an appropriate analysis should require a strategic perspective. As an example, the use of schedule pressure to ensure high staff productivity might look a simple issue when the analysis is focused on a single individual activity: while the small team might have been able to meet the tight schedule, the long-term effects of staff exhaustion and low work quality are not visible, yet. To cope with these effects the manager needs a more *holistic* view of the problem and hence a strategic perspective: how should schedule pressure be used throughout the project life-cycle to provide a beneficial outcome? Reinforcing this idea, the explicit definition and possible quantification of many human factors such as staff attrition, training and communication overheads, or management willingness to change workforce, also demand such an aggregated view. While other soft factors may take place at lower levels of detail, the assessment of their impacts on project performance still demands a strategic perspective, with which traditional techniques are not compatible.

A project is a man-made goal-oriented open system and as such it tends to be unpredictable and unstable. The complexity of projects and of their environment has increased the disruptive effect of subjective human factors. Personal judgement based on past experience is no longer sufficient to cope with this problem. There is a need to understand better the strategic issues of project management and to learn effectively from past failures; this can only be achieved through a more formal systemic analysis.

The system dynamic approach

The system dynamics approach to project management is based on a holistic view of the project management process and focuses on the feedback processes that take place within the project system. It offers a rigorous method for the description, exploration and analysis of complex project systems

(Wolstenholme 1990) comprised of organisational elements, the project work packages and the environmental influences.

Some of the major developments of system dynamics in project management are summarised in Table 2. A first model was proposed by Roberts (1964) to explore the basic dynamics of R&D projects and here the concepts of perceived progress and real progress were first introduced, addressing explicitly the fact that managerial decisions are based on perceptions which may be at significant variance with reality. This model was improved by Kelly (1970) to cover the management of concurrent projects.

The model developed by Cooper (1980) at Pugh-Roberts Associates was the first major practical application of system dynamics to project management. The model was initially developed as a *post mortem* diagnosis tool to support a major claim of “delay and disruption” in a large-scale shipbuilding program. Further versions of the model were developed and used to support strategic analysis of prospective shipbuilding programs. One of the major novelties of this work was the concept of the *rework cycle*, a structure at the core of the model which incorporates explicitly the concepts of undiscovered rework, time to discover rework, work quality and varying staff productivity. All these concepts have played an important role in subsequent models.

Richardson and Pugh (1981) presented a model for the management of R&D projects that summarises the basic feedback structures of the project management process and focuses on the trade-off between the managerial decisions of allowing schedule slippage and hiring more staff. The model developed by Cooper was the basis for the development of the Program Management Modelling System (PMMS Model 1993) at Pugh-Roberts Associates. This is the most comprehensive model developed so far and is currently being used to support the management of several large programmes. Other studies have examined the dynamics of specific types of projects, the most relevant being the model developed by Abdel-Hamid and Madnick (1991), used for *post mortem* diagnosis of a software development project.

The three major problem areas addressed by the models indicated in Table 2 are:

1. project monitoring and control,
2. rework generation, and
3. human resource management.

These system dynamics studies were undertaken in R&D, software development and design and development applications, perhaps reflecting the relatively high proportion of project failures in these areas and an accepted need to improve management methods. Also important to note is that these three

Table 2. Summary of some work and research developed since 1964 on the application of system dynamics to project management.

Author	Project type	Problems addressed
Roberts (1964)	R&D	Dynamics of R&D: perceptions vs reality (1)*
Kelly (1970)	R&D	Dynamics of R&D among concurrent projects (1)*
Cooper (1980)	Large design and construction program	Rework cycle: staff productivity, work quality, rework generation and discovery (2)* Staff hiring and manpower allocation (3)* Material acquisition and allocation High-level work scheduling Progress monitoring Interdependencies between work phases: schedule slippage, work quality, resource sharing Interdependencies among concurrent programs
Richardson and Pugh (1981)	R&D	(1)* Productivity and rework generation (2)* Policy of hiring staff: increase workforce vs schedule slippage (3)*
Jessen (1988)	R&D, Construction, Decision support	(1), (2), (3)* Project team motivation vs productivity Client and project team relationship
Keloharju and Wolstenholme (1989)	R&D	(1), (2), (3)* Cost-time trade-off
Abdel-Hamid and Madnick (1991)	Software Development	(1), (2), (3)* Cost and schedule estimations Quality assurance policies
Abdel-Hamid (1988, 1989, 1992) Abdel-Hamid et al. (1993)	Software Development	(1), (2)* Project staffing policies (3)* Multiproject staffing policies Multiproject scheduling 90% syndrome Quality assurance policies Cost and schedule estimations Managerial turnover/succession
Barlas and Bayraktutar (1992)	Software development	An interactive simulation game to evaluate staffing policies (3) in quality assurance and rework (2)*
Cooper (1993, 1994), Cooper and Mullen (1993)	Programs, Defence and commercial software development	The rework cycle: quality, productivity, and time to discover rework (2)* Project monitoring (1)*
PMMS Model	Large design and production programs	PMMS - a software simulation tool: • Diagnosis of over-runs • Impact of design and workscope changes • Estimation of cost and duration of on-going programs • Risk analysis of prospective programs

Table 2. *Continued*

Author	Project type	Problems addressed
		• Effectiveness of management strategies
Williams et al. (1995a; 1995b)	Large design and manufacturing	The models focus on: resource acquisition and allocation (3)*, high-level work scheduling, progress monitoring(1)*, rework cycle (2)* <i>Post mortem</i> diagnosis for dispute resolution (delay and disruption). Analysis of the “vicious circles” of parallelism and their role on the impacts of design changes and delays.

Main areas:

* (1) Project monitoring and control, (2) Rework generation; (3) Human resource management. See text.

categories of projects can be characterised as being of continuous nature, contrasting with other more discrete types of projects. The work developed by Williams *et al.* (1995a; 1995b) is more singular and of particular interest, using a system dynamics model for a *post mortem* diagnosis in which the project behaviour is described from a network perspective. It identifies important feedback processes responsible for the vicious circles of parallelism: work being developed in parallel increases cross-relations between concurrent activities, increasing the duration of activities, which in turn increases the degree of parallelism as the project struggles to achieve its original completion date.

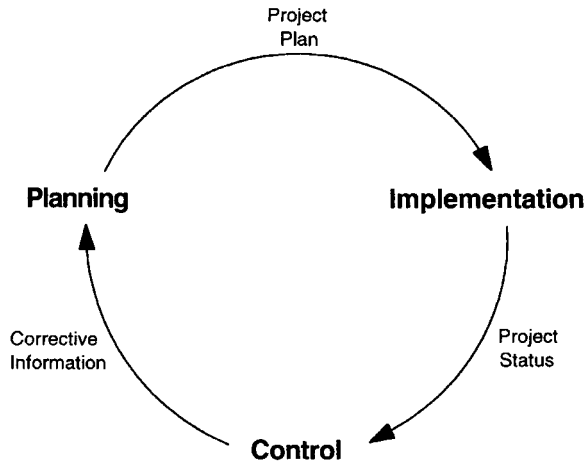
Comparative analysis

The view of the project management process

Both the ideal application of the traditional project management methodology and system dynamics approaches consider project management as a dynamic process of planning, implementation and control, as illustrated in Figure 1. Planning is concerned with the specification of the actions that have to be performed to implement the project. Control is the process of assessing the project status and generates information for corrective actions. According to this view, the project is continuously being assessed and re-planned as the work is being undertaken.

In traditional project management, tools and techniques such as the Work Breakdown Structure, PERT/CPM network and cost schedules are employed within this dynamic process. They are dominated by the project workstruc-

Fig. 1. The generic process of project management



ture and network, and the act of decomposing the project into its constituent elements. The project plan includes in great detail:

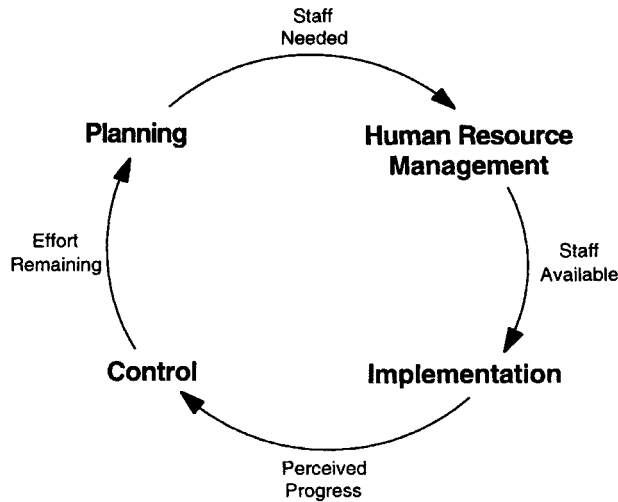
- a definition of the work,
- a work schedule specifying the timings for each work package,
- a resource schedule specifying the allocation of human and material resources among the project activities,
- cost schedules that specify the capital requirements and provide the estimation of budgets.

The assessment of the project status is based on the comparison of the current state of the work with the project plan. The corrective information generated to support re-planning specifies in detail the deviations, which may include schedule and cost over-runs of specific activities and of the whole project.

In contrast, the primary objective of a system dynamics model is to capture the major feedback processes responsible for the project system behaviour, with less concern about the detailed project components. The project management process is put into a wider context including the many soft factors that are often external to the project work but critical to its outcome. There is a strong focus on human factors as these are considered to dominate the feedback structures. This motivates the explicit consideration of a human resource management process. The issues addressed in each of the four main problem areas in Figure 2 may be summarised as:

- *Planning*: examines the trade-off between delaying the project completion date and hiring more staff. The models explicitly incorporate staff manage-

Fig. 2. System dynamics view of the project management process



rial policies and issues related to the acceptability of delaying the project, including critical soft factors such as “willingness to change workforce” (Abdel-Hamid 1989; Keloharju and Wolstenholme 1989). The main output from these analyses is guidance in the allocation of additional staff to minimise schedule over-runs. The PMMS Model (1993) may also be used to explore high-level planning options, such as alternative relationships between testing and production.

- *Human resource management*: although traditionally this is considered as part of the planning process, in a system dynamics model it is considered separately and addresses several issues related to hiring more staff for the project. It usually includes factors such as workforce training, workforce experience level, workforce assimilation time and communication overheads. Abdel-Hamid (1989) provides a good analysis of this problem. This process is responsible for the generation of the actual level of staff working on the project.
- *Implementation*: focuses on the problems associated with the generation of errors that remain unperceived. Cooper (1993a; 1994) addresses this problem through the definition of the *rework cycle* concept. The PMMS Model (1993) addresses more complex rework problems, such as customer delays in providing information and equipment, design changes and process changes imposed by the customer. Other models (Abdel-Hamid and Madnick 1991) focus on issues such as quality assurance policies and project underestimation. Such models offer a better basis for estimating true project progress.

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- *Control*: addresses the issues related to monitoring the project status. The difference between the perceived and the real project status is considered explicitly as a way of addressing the problems of the 90% syndrome. Cooper (1993b; 1993c) provides a good overview, introducing the concept of progress ramps. Managerial perceptions of productivity, quality, work completed, project size and other aspects provide an estimation of the effort remaining, which is used to plan project re-scheduling and staff allocation.

System dynamics models assume a high-level view of the whole project management process, focusing on human factors and managerial policies. They have an inherent flexibility which enables them to incorporate a wide range of influences specific to particular applications. The models used in the traditional focus on the project work structure and are more specialised, assuming a detailed view of the individual parts of the project management process. The traditional techniques are more rigid, enforcing a particular view of the project; this can ease their implementation but at the expense of some reality: while ensuring rigorous monitoring of the project past, their view of the future is focused on a “planned success”. In contrast, system dynamics simulation models provide a laboratory to test several different scenarios for the project, delivering a clearer and perhaps more realistic view of the possible futures.

The project estimations and the project work

One of the most important differences between traditional and system dynamics approaches is in their approaches to modelling project work. Although both assume that project implementation is based on the process of performing work through the employment of resources, they differ in the level of detail in which the work is considered and in the range of factors they address explicitly.

The tools of the traditional approach, such as Gantt charts and PERT/CPM network models, provide a detailed description of the development process, including specific estimates of costs and duration. The models view the project work as a set of work packages, or activities, with their implementation dependent on resource requirements, availability, and their technological precedence relationships. This approach considers in detail the direct causes of the estimated project cost and duration.

In contrast, the system dynamics approach employs a high-level perspective in its model of project work. It is generally represented by a continuous flow of units of work that change from the initial state “to be done” to the final state “done”, as the staff allocated to the project perform their tasks. Different models may consider this view at different levels of detail by decomposing

this flow of work into several phases or stages according to the life-cycle of the specific project (Cooper 1980; Abdel-Hamid and Madnick 1991; Rodrigues and Williams 1995). As an example, such a comprehensive model could be used to analyse whether allowing early design milestones to slip would have a beneficial impact on the project. Extra effort expended in improving the quality of the design might result in some initial project delay, but this could be outweighed by savings in rework in the later development stages. The comprehensive model would enable a quantitative and rigorous assessment of the internal quality-time trade-offs. Nevertheless, the decomposition of this model is still far from a detailed consideration of what work is done when, and by whom; there is no attempt to describe the detailed responsibilities, as there is in the traditional work breakdown structure and responsibility matrix. Instead the system dynamics approach requires the input of an initial estimate, perhaps based on an approximate, high-level work breakdown analysis. With this estimate as a basis, a wide range of factors, such as rework, changes in work-scope, quality, productivity and motivation, may then be built into the model. A system dynamics model does not show in detail the direct causes of the estimated project cost and duration, but it considers explicitly the indirect causes that result from the feedback processes which are often responsible for over-run and overspend.

The fact that both approaches provide estimates for project cost and duration raises a potential conflict. Traditional models focus on a detailed view of the project work and in evaluating possible alternatives they only assess the direct impacts on cost and time, while other higher-order effects can be very important (Weil and Dalton 1993). The inaccuracies in the estimates provided by traditional models can only make over-runs more likely. System dynamics models focus on the feedback processes and assume a holistic view of the implementation process. In evaluating possible alternatives, they consider a wide range of subjective and disruptive factors, but by ignoring the detailed logic of the work structure, as represented by a network, they may overlook important operational issues. This suggests that both the operational detail of the traditional approach and the systemic view incorporating the feedback processes are crucial for the generation of accurate estimations; a combined operational and system dynamics model may offer a useful approach to improving project estimates.

The credibility of traditional models depends on the validity of the underlying assumptions typically drawn from individual personal experience, such as the assumption of a particular productivity level for the staff. The assumptions provide a mechanism for handling subjective issues that are difficult to quantify but they are often implicit and too readily taken for granted. The weakness of this more classic operational research approach is that the

assumptions are not always applicable and can result in a model divorced from reality. This is particularly true when the analysis targets a complex social system such as a project.

A system dynamics project model is validated by comparison with past projects. As in any modelling exercise even a perfect reproduction of past behaviour cannot guarantee the accurate forecasting of the behaviour of a new project. Projects are characterised by their uniqueness and particular caution is needed when extrapolating past experience, whatever the modelling methodology. While more evidence of the validity of system dynamics models would be desirable, experiences in project management indicate that their holistic approach is valuable, avoiding a narrow, detailed view of those aspects that happen to be more readily quantified.

The managerial needs addressed

The comparison of the traditional and system dynamics approaches has to be performed within the context of requirements of project managers. As a basis for a comparison of the success of the two approaches in satisfying the managerial requirements the following issues were considered:

- the nature of the managerial needs,
- the factors explicitly considered,
- the basic managerial decisions evaluated,
- the impacts of uncertain events addressed,
- the project estimations provided.

Tables 3 and 4 provide a brief summary of this analysis. While the traditional approach encapsulates a recognised set of project management tools, the sys-

Table 3. The nature of the managerial needs addressed by the traditional and system dynamics approaches

Nature of the managerial needs	Traditional approach	System dynamics approach
Specification of the work	Yes	No
Assignment of responsibilities to the work within the organisation	Yes	No
Work scheduling	Yes (detailed)	No or high level (life-cycle phases/stages)
Resources management / scheduling	Yes	Yes-high level
Cost Estimation / budgeting	Yes	Yes
Project control / monitoring	Yes	Yes-high level
Evaluate the impacts of decisions	Yes (not effectively)	Yes
Evaluate the impacts of uncertain events	Yes (not effectively)	Yes
Post mortem diagnosis	No (not practical)	Yes

Table 4.
Comparison of some
important
characteristics of the
traditional and
system dynamics
approaches

	Traditional approach	System dynamics approach
Factors explicitly considered	Logic of the work structure Cost of resources Indirect costs Constraints on resources availability Work resources requirements	Quality of work performance Staff productivity Staff experience level, learning, and training Schedule pressure on the staff Rework generation and discovery time Mismatch of perceptions and reality Staff motivation Client and project team relationship
Managerial decisions	Cost-time trade-off: crashing activities Changes in the schedule of activities Scheduling resources among activities Changes in the logic of the project work structure	Hiring staff vs delaying the project completion date Introduction of new technologies Effort on quality assurance Effort on rework discovery time Cost-time trade-off: hiring staff Multiproject scheduling Multiproject staff allocation Managerial turnover/succession Estimation of schedule and cost Changes in the schedule of the project life-cycle phases/stages
Uncertain events	Delays in the completion of activities Constraints in the schedule of activities Resource constraints Uncertainty in the duration of the activities (simulation)	Changes in the project workscope Changes in quality and productivity levels Customer/vendor delays in delivering information and materials Constraints in the staff levels
Major estimation	Project duration Project cost Resource allocation	Project duration Project cost Staff allocation Demand on staff

tem dynamics approach is less well defined, though the PMMS Model (1993) is probably the most complete tool developed, incorporating many of the issues addressed by other models. In this comparison the system dynamics model is assumed to be a compilation of all the models of Table 2.

Table 3 indicates that many of the basic managerial needs are addressed in both approaches. However, it is important to note that the level of detail of the analysis is different: traditional models suggest decisions focused on operational issues, while system dynamics models focus on the strategic issues providing more general directions. System Dynamics models have the potential to consider a highly aggregated view of the project work structure and their

focus on the causal feedback loops driving project behaviour enables a high level model to be built without much detailed information about the past; this makes system dynamics particularly useful in the diagnosis of historical cases such as in supporting dispute resolutions (Cooper 1980; Williams *et al.* 1995a; 1995b).

Table 4 emphasises the ability of system dynamics models to consider a wide range of subjective factors that are often ignored in traditional operational models or only addressed by simplistic assumptions. The managerial decisions which they aim to support are complex and the possible use of quantitative models of the traditional approach typically require excessive effort; similar difficulties are experienced when traditional quantitative techniques are used to examine the effect of uncertainty on a project. While both approaches provide project estimations for cost and schedule, system dynamics models assume a more aggregated view of the project work structure, and adopt a more high level strategic perspective of the management and implementation processes.

Conclusions

The traditional view of project management has produced an undue focus on the project work (Turner 1993). There is a need to expand this view into a wider context reflecting the importance of the relationships between project components and their effect on management performance. These strategic issues have been handled implicitly, encapsulating personal experience in crude rules of thumb; the holistic approach offered by system dynamics has emerged as an attempt at a more systematic approach.

Traditional and system dynamics models are not incompatible as their objectives are quite distinct and individually both look incomplete. The traditional models have not been able to cope with the complexity of the strategic issues (Cooper 1993a) and the system dynamics models, having emerged successfully as a tool to support strategic management, can provide important strategic insights. Furthermore, comprehensive system dynamics models might go beyond this point to provide on-going practical support. As Cooper advocates "system dynamics modelling is not just about insight-gathering, as wonderful as that is, but also about real practical help in designing operational actions." The PMMS Model (1993), and the work being currently undertaken at BAeSEMA (Rodrigues and Williams 1995) support this idea. Nevertheless, the holistic perspective of system dynamics, reinforced by the continuous nature of the simulation models, imposes a level of aggregation with no immediate translation into the more detailed world of operational

actions. Traditional and system dynamics models also offer very different perspectives on project estimating and this suggests there could be particular value in integrating the two forms of estimate more rigorously.

Project management will still require operational models to provide the detail necessary for the effective implementation of strategic decisions. If traditional and system dynamics models are to be combined in a single practical methodology, two research actions are required: current traditional models have to be improved to incorporate quantitative data from system dynamics models, and system dynamics developments need to be reviewed and synthesised. This paper has highlighted both the differences between and similarities of the system dynamics and traditional approaches in an attempt to begin the development of a single integrated project management methodology.

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