The Role of System Dynamics In Project Management: A Comparative Analysis With Traditional Models

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Abstract

The increasing rate of change to which organisations are exposed, along with the growing complexity of projects and of the environment, has highlighted some weaknesses of traditional approaches in coping with the strategic issues of project management. 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 perspective underlying the two approaches. The comparison of the approaches is focused on the "view" of the project management process. Although they both assume a systems perspective, identifying a cycle of planning, implementation and control, the level of detail in which they consider the project system is different. Traditional models support the project manager in the operational problems within the process, while System Dynamics models provide more strategic insights and understanding about the effectiveness of different managerial policies. For effective project management both operational and strategic issues have to be handled properly. This paper suggests an approach to combining the lessons of System Dynamics and traditional models within a single, integrated project management methodology.

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INTRODUCTION

Project success is a primary factor for the survival and prosperity of organisations. 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[33]. However, projects also become more complex and project failure is unfortunately another major trend. "Overruns are common. Many projects appear as failures... (and) are often completed later or over budget, do not perform in the way expected, involve severe strain on participating institutions or are cancelled prior to their completion after the expenditure of considerable sums of money."[24] Over-runs of 40% to 200% are common[24] hence the question of how appropriate the traditional approach is for the management of modern large scale projects.

A new approach is now emerging based on System Dynamics models. Assuming a holistic view of the organisation this approach focuses on the behavioural trends of projects and their relation with managerial strategies. The need for the development of models capable of assessing the strategic issues has also been identified by Morris and Hough[24]: "... (traditional) project management has not addressed itself the factors which often really cause projects to fail... We feel compelled to agree that the need for such a (strategic management) model is real." Davidson and Hout[18] state: "It is difficult or even impossible, (to rely) solely on traditional PERT/CPM system approaches... the solutions require a new paradigm for the control of large projects... (based on) a framework of open and dynamics system theories as opposed to the traditional approaches that are static and closed."

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

The traditional approach to project management is based on a typical set of techniques and procedures intended to help the project manager to define and direct the project work. Over the years a wide collection of methods have been developed in response to the need of managing with the real problems of project implementation. These focus on the definition of the project work structure, scheduling and budgeting project activities, monitoring and controlling project performance while the work is being undertaken, evaluating and reporting project status along the project life cycle[25].

Table 1 briefly describes the most important tools and techniques used in the traditional approach. To assess the project status and keep the interested parts informed, several procedures are followed for collecting and communicating project evaluation information like graphical representations, reports, observations and review meetings[25].

The ideal of the traditional approach is based on a systems methodology. 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. 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 traditional approach is "static and closed"[18] can be countered.

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. Base 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.

Table 1 - Overview of traditional project management techniques and tools

THE NATURE OF PROJECT FAILURE

Many factors can be considered as responsible for project failure. Uncontrollable external forces are often blamed. However, the real cause may be bad project management, which is the result of a defective project management system -- organisations, practices, and procedures[25]. Despite the enormous attention devoted to this field during the last years, why do organisations continue to practice bad project management? Morris and Hough[24] suggest that the main causes are to be found in areas which have traditionally not been the concern of project management. Such factors arise from circumstances which are external to the project. They have classified and grouped these critical factors in the following categories: project definition; planning, design and technology management; politics/social factors; schedule duration; schedule urgency; finance; legal agreements; contracting; project implementation; and human factors.

A more detailed analysis of this survey reveals that the majority of the factors relate to strategic issues of project management and are not addressed explicitly by the tools and techniques of traditional project management. Based on their own experience and vision of reality, their informal mental models, project managers have been using their personal judgements to support strategic decision-making, which is then the basis for the application of the traditional operational models. Bad strategic judgements are often the root cause of many failures.

As an example, 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. 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. Factors of political nature have motivated a generalised trend to reject errors in the early development stages of projects[5]. Detailed plans based on these illusive perceptions direct useless or even counterproductive efforts. In the later stages of the project considerable effort is then spend in correcting errors. Managers tend to feel that the work never goes beyond the 90% perceived progress -- this phenomena is usually referred as the "90% syndrome"[2,17].

A project is a man-made goal-oriented open system and as such it tends to be scientifically unpredictable, disruptive and unstable. The complexity of projects and of their environment has increased the disruptive effect of subjective 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 this can only be achieved through systematic analysis. While traditional tools and techniques were not developed with that purpose System Dynamics models gather all the requisites to provide such approach.

THE SYSTEM DYNAMICS 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. This complex social system comprises the organisational elements, the project work elements and the environmental elements. Systems Dynamics approach provides a rigorous method for description, exploration and analysis of such complex systems[38].

The developments of System Dynamics in project management are summarised in table 2. A first model was proposed by Kelly (1970) to explore the basic *dynamics* of R&D projects. Later, Roberts (1974) developed "A Simple Model of R&D Project Dynamics", where the concepts of *perceived progress* and *real progress* were introduced, addressing explicitly the fact that managerial decisions are based on *perceptions* of reality usually different from *real* reality.

Richardson and Pugh[27] developed a model for the management of R&D projects where the basic feedback structures of the project management process were identified. New concepts such as rework, undiscovered rework, perceived progress, real progress, perceived productivity and real productivity became to play a core role on the development of future models proposed by other authors. Pugh-Roberts Associates has developed a software tool based on System Dynamics models, the *Program Management Modelling System*[26], which is currently being used to support the management of large programs. Abdel-Hamid and Madnick[1-10] have developed important research work regarding the management of software development projects.

The three problems addressed by the model proposed by Richardson and Pugh[27], project monitoring(1), rework generation(2), and staff hiring policies(3), are approached in most of the other models. The majority also refer to R&D or Software Development projects. The work developed by Williams[37] is more singular and of particular interest using a System Dynamics model for a *post mortem* diagnosis in which the project behaviour is described under 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, which increases activities durations, which under constraints increases parallelism.

Author	Project Type	Problems Addressed
Kelly	R&D	Basic dynamics of R&D projects
Roberts	R&D	- 'Perceived' *vs* 'Real' progress (1)
Richardson, Pugh[27]	R&D	- (1) - Productivity and Rework generation (2) - Policy of hiring staff: increase workforce *vs* schedule slippage (3)
Jessen[21]	R&D, Construction, Decision-Support	- (1), (2), (3) - Project team motivation *vs* productivity - Client and project team relationship
Keloharju, Wolstenholme[22]	R&D	- (1), (2), (3) - Cost-time trade-off
Abdel-Hamid, Madnick[1,5]	Software Development	- (1), (2), (3) - Cost and Schedule estimations - Quality assurance policies
Abdel-Hamid[1-10]	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, Bayraktutar[12]	Software Development	An interactive simulation game to evaluate staffing policies (3) in quality assurance and rework (2)
Cooper, Mullen[14-17]	Programs, Defence and Commercial Software Development	- The rework cycle: quality, productivity, and time to discover rework (2) - Project Monitoring (1)
Pugh-Roberts Associates[26]	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 - Effectiveness of management strategies The models focus on: resource acquisition and allocation (3), high-level work scheduling and progress monitoring(1), labour productivity(2), rework requirements (2).
Williams, Eden, Tait, Ackerman[37]	Manufacturing development project	*Post morten* diagnosis for dispute resolution. Analysis of the 'vicious circles' of parallelism.

Table 2 - Summary of some work and research developed since 1970 on the application of System Dynamics to Project Management.

COMPARATIVE ANALYSIS

The view of the Project Management Process

Both 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.

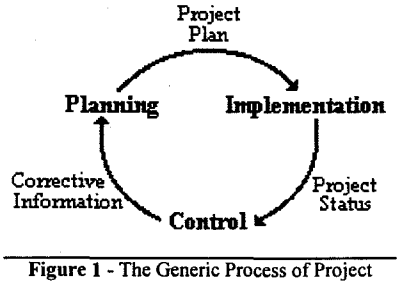

Figure 1 - The Generic Process of Project Management

In traditional project management tools and techniques such as the Work Breakdown Structure, PERT/CPM networks, and cost schedules, are employed *within* this process. They also have the important characteristic of focusing on the project work structure. 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, and 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.

The primary objective of a System Dynamics model is to capture all the relevant feedback processes responsible for the project system behaviour. The project management process is put into a wider context which includes many soft factors often external to the project work. 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, as shown in figure 2. The issues addressed in each of the four components are as follows:

Planning: addresses the trade-off between delaying the project completion date and hiring more staff. The staff managerial policies and issues related with the acceptability of delaying the project are explicitly represented in the model. Managerial policies often include soft factors like "willingness to change workforce"[4,22]. The main output from the planning process is the decision of allocating more staff to balance schedule over-runs. The PMMS[26] model also considers decisions of high level work scheduling.

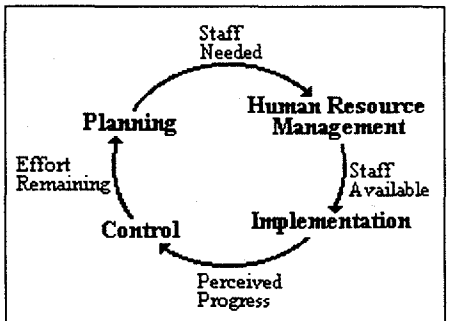

Figure 2 - System Dynamics view of the Project Management process

Hman resource management: addresses issues related with hiring more staff to the project. Usually includes factors such as workforce training, workforce experience level, workforce assimilation time, and communication overheads. Abdel-Hamid[4] 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 problems related with the generation of errors that tend to remain unperceived. Cooper[14-17] addresses this problem through the definition of the *rework cycle* concept. The PMMS model (table 2) addresses more complex problems such as customer delays in providing information and equipment, design changes, and process changes imposed by the customer. Other

models[1-10] focus on issues such as quality assurance policies and project underestimation. This process is generally responsible for the estimation of the work progress.

Control: process addresses the issues related with 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[14-17] provides a good overview introducing the concept of *progress ramps.* Managerial perceptions of productivity, quality, work completed, project size, and others, provide an estimation of the effort remaining which is used to plan project re-scheduling and staff allocation.

System Dynamics models assume high level view of the whole project management process focusing on human factors and managerial policies. The models used in the traditional approach focus on the project work structure and are more specialised, assuming a detailed view of the individual parts of the project management process.

The Project Estimations and the Project Work

One of the most relevant differences between traditional and System Dynamics approach is the way in which they model the 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 explicitly address.

In the traditional approach tools like Gantt charts and PERT/CPM network models provide the detailed development of a project schedule which is used for the estimation of the project cost and duration. These models view the project work as a set of work packages (activities) that have to be performed through the use or consumption of resources and according to their precedence relationships. The direct causes of the estimated project cost and duration are considered in detail.

In the Systems Dynamics approach the project work is modelled under a high level view. It is generally represented by a 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 the work. There is no specific consideration of what work is done when, and by who. The traditional Work Breakdown Structure is not considered. However, a wide range factors like rework, changes in workscope[26], quality, productivity, and motivation, are considered in the model. A Systems 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, and are often responsible for over-runs.

The fact that both approaches provide estimations for project cost and duration raises a conflict. Traditional models focus on a detailed view of the project work and on evaluating possible alternatives they only assess the *direct impacts* on cost and time, while the *full impact* usually includes other higher order effects[26]. This important argument suggests that the estimations provided by traditional models are not accurate and over-runs will occur. System Dynamics models focus on the feedback processes and assume a *holistic* view of the implementation process. On evaluating possible alternatives they consider a wide range of subjective and disruptive factors, but by ignoring the logic of the work structure they may overlook determinant operational issues. Particularly, they assume that the rate of work progress is imposed by the level of staff working in the project. In real projects, issues related with the management of material resources are often critical to the final project cost and duration.

The credibility of traditional models depends on the validity of the underlying assumptions. These are a mean of handling with subjective issues that are not possible to quantify. The weakness of this classic *Operational Research* approach is that the assumptions often mismatch reality. This i

particularly true when the analysis targets a social system. Projects are long term planned actions which are complex, unique and undertaken within a social system. This fact reinforces the insufficiencies of empirical assumptions based on personal experience.
In a project management context the validation of System Dynamics models is based on the accurate reproduction of past cases or other reference modes of behaviour. However, a project is unique and is implemented under unique circumstances. This accurate reproduction may not be sufficient to assure accurate forecasting of the behaviour of a new project.

The current trend of project failure shows clearly that accurate project estimations cannot be achieved on the sole basis of operational models. System Dynamics models still have to prove with more evidence their accuracy on providing such estimations. This would suggest that a less detailed view on the whole is more effective than a narrowed detailed view on the parts. In the opinion of the author both operational details and a wide view of the project system capable to capture the feedback processes are crucial for the generation of accurate estimations. This can only be achieved by combining operational and System Dynamics models within an integrated analysis.

The Managerial Needs Addressed

To understand the role of System Dynamics approach in project management it is of major importance to identify the managerial needs it covers in comparison with the traditional approach. In fact, many of these needs are covered by both approaches and although a final judgement about their effectiveness in providing solutions is premature a comparative analysis may provide important conclusions.

The application of Systems Dynamics models to project management is still in an early stage of development. Unlike in the traditional approach there is not a well established consistent set of tools and techniques intended to support the project manager throughout the project life-cycle. The PMMS[26] developed by Pugh-Roberts Associates is probably the most complete tool developed, incorporating many of the issues addressed by other models. The comparison offered here reflects the current literature but is not intended exhaustive. For a better understanding of both differences and similarities of the two approaches 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, and the project estimations provided. Table 3 and table 4 provide a brief summary of this analysis.

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	No or High Level
Resources Management / Scheduling	Yes	Yes - high level
Cost Estimation / Budgeting	Yes	Yes
Project Control / Monitoring	Yes	Yes
Evaluate the impacts of decisions	Yes	Yes
Evaluate the impacts of uncertain events	Yes	Yes
Post Mortem diagnosis	No	Yes

Table 4 - The nature of the managerial needs addressed by both approaches

Table 4 for shows 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 ignore the logic of the

project work structure but their applicability extends to the diagnosis of historical cases which is particularly useful in supporting dispute resolutions[37].

Table 5 emphasises the ability of System Dynamics models to consider a wide range of subjective factors that are very difficult to incorporate in operational models, and are usually addressed in the traditional approach by simplistic assumptions. The managerial decisions they support are complex and most of them are not supported by the quantitative models of traditional approach. The same kind of analysis applies to the uncertain events addressed. The common characteristic of the approaches is that they provide similar project estimations. However, System Dynamics approach divorces completely from the project work structure assuming a strategic perspective of the managerial issues.

	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
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 - Constraints in the staff levels
Major Estimations	- Project duration - Project cost - Resource allocation	- Project duration - Project Cost - Staff allocation - Demand on staff

Table 5 - Comparison of some important characteristics of the traditional and System Dynamics approach

Summary and Conclusions

The analysis provided by traditional models is centred on the logic of the project work structure. They assume a narrowed detailed view of the different parts of the project management process. The core of the System Dynamics approach is the feedback structure of the whole project system, which is strongly dominated by a wide range of subjective factors of human nature.

The managerial policies addressed in the System dynamics approach relate to staff allocation and high level project re-scheduling. The models consider explicitly a wide range of factors that affect the work progress. Traditional models focus on decisions of detailed work scheduling, resource allocation, and cost-time trade-off. Both approaches assess the impacts of different managerial decisions and uncertain events on project *cost* and *schedule*. However, traditional approach is primarily concerned with the development of an effective implementation plan, while the primary aim of System Dynamics models is to provide understanding about the project behaviour along with the evaluation of managerial policies.

The weakness of traditional models[15,26] is that they do not address properly the strategic issues of project management. In practice complex and detailed implementation plans continue to be overwhelmed and become obsolete by the influence of strategic factors. The weakness of System Dynamics models is that they ignore the operational issues suggesting important insights and strategies but no means of how to translate them into operating actions.

It is clear from this brief comparison that System Dynamics models emerged in the project management field to provide a systematic analysis of the vital strategic issues of project management. In the early days focus was given to the project work structure and as a consequence tools and techniques were developed to support operational decisions. Strategic decisions were left to be answered by roles of thumb and personal experience. This analytical gap is now being filled by System Dynamics models.

The conflict arising from the generation of different project estimations raises important questions. First the nature of the estimation is different: System Dynamics models *simulate* a reality where the project behaviour dictates the estimations, while traditional models *predict* a *one-step* reality and the estimations are based on the detailed analysis of the work schedule. A second question has to do with the possible relation between both estimations. If the project is to behave according to the patterns provided by the System Dynamics model there will have to be an *operational translation* of such behaviour. This idea needs further analysis but clearly it is of most value for the project manager to know *how* the behavioural patterns will be translated into the operational level. This would provide the development of more realistic implementation plans and over-runs could be avoided.

System Dynamics models can also be applied to problems of project management for which the operational models are not the appropriate tool. As an example models have been used to support the resolution of a wide range legal disputes related with the implementation of projects. This is usually achieved through the development of models for *post mortem* diagnosis[37] which provides the evaluation of the impacts of decisions undertaken by the different parts involved in the project.

THE FUTURE

Although System Dynamics models provide a systematic analysis of the strategic issues of project management the developments on this field have not been undertaken within an organised framework. An important step is to synthesise all the work developed, eliminating redundancies and merging models where possible. This would also identify the areas where the potentialities of System Dynamics models are not being properly explored.

The traditional view of project management has produced an undue focus on the project work[35] and it is necessary to expand this view into a wider context. However, this should not suggest that traditional models have to be totally replaced or abandoned. The future of project management still relies on operational models as these are the tools required for effective implementation of strategic decisions. The current models need to be improved and it is opinion of the author that this can be better achieved by exploring the potential synergy of combining strategic and operational models.

If System Dynamics approach is to play a core role on the future of project management its integration with the traditional body of knowledge is inevitable. This paper has highlighted both differences and similarities of System Dynamics and traditional approach. It is expected that this contributes to the framework required for the development of a single integrated project management methodology.

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