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# Using systems dynamics to better understand change and rework in construction project management systems

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## Abstract

The management of construction is complex enough without changes (e.g. to design/specification/client requirements), yet it is a familiar characteristic of in construction projects. To effectively manage change, project managers have to undertake detailed planning; to integrate the work activities of consultants, subcontractors and suppliers. In this context, changes are unplanned disturbances that (typically) interfere with the intended progression of work. Given this 'interference', what are the consequences of such disturbances on project performance and how can/do/should project managers deal with changes effectively? This paper describes how changes (and their actions or effects otherwise known as dynamics) can impact the project management system. Using a case study and the methodology of systems dynamics, the major factors influencing a project's performance are observed. The need for understanding of how particular dynamics can hinder the performance of a project management system are highlighted.

*Keywords:* Change; Project management; System dynamics; Dynamics; Rework; Variation

## 1. Introduction

Both the internal and external environments of construction projects are dynamic and relatively unstable. Changes that occur during a project's development may have significant and often unpredictable effects on its organisation and management. Thus, project managers must react appropriately to change and understand how it can influence the behaviour of the project system. Only then can changes be managed effectively.

Typically, project organisations comprise team members from different organisations who engage the project at different points in time to form a temporary multi-organisation [1], or an ephemeral shifting coalition [2]. Relationships between team members are governed formally by the contract(s) but are supplemented and moderated by informal understandings and protocol that have evolved over time; very often to cope with unforeseen difficulties. The latter characterise construction [3] and numerous studies [4,5] have identified these uncertainties. The nature of relationships within a project team is one of 'independent autonomy' with interdependence and uncertainty being inherent characteristics.

Project organisations are subject to an array of influences, from regulatory control to political and industrial intervention [6]. To deal with uncertainty, various tools and techniques (such as risk management) have been introduced; focussing on risk identification, risk analysis and risk response [7]. However, risk management assumes that risk factors can be identified and evaluated before they occur, and that necessary response strategies (or preventive methods) can be applied, particularly, through contractual arrangement [8]. In order to ascertain risk throughout a project's life cycle, a complete understanding of the complexity and dynamic nature of the construction environment is called for.

## 2. System dynamics

Idiosyncratically, a project organisation comprises of functionally interdependent entities; each striving to

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achieve a set of identifiable goals [2]. The composition of a project organisation can essentially be viewed as a system; so in the context of systems theory, the focus is upon how sub-systems interrelate to pursue and achieve these goals [9]. With this in mind, project management can be considered a sub-system, with planning, organising, controlling, and co-ordination of project activities, being inherent characteristics.

The inputs to this sub-system are identification and development of a client's objectives (e.g. utility, function, quality, time, cost), project resources (e.g. staff, materials, labour, plant, finance), and the formalisation of relationships between these variables. The ultimate system output is a completed project, which (hopefully) satisfies the client's objectives. Construction's dynamic environment means that the relationships between variables can be vicissitudinous in nature. Consequently, this may become a barrier to the project manager inasmuch as the project organisation's responsiveness to change may be inhibited by its organisational structure [10].

Building on the concept of systems and contingency theory, Stoner et al. [11] used the term *dynamic engagement* to describe the modern construction project management system. Stoner et al. suggest that managers need to re-think the way in which activities are performed in the face of unprecedented external changes. Dynamic engagement emphasises how managers react to change over time. By being able to understand the implications (of type and rate) of change, managers are better able to adjust to the environment within which they operate. Invariably, a project will experience changes (e.g. design changes and omissions) so resultantly, contingencies and construction buffers often represent a mechanism for anticipating such. When unexpected changes do occur, the planning, organising, motivating, directing, and controlling of construction can become an arduous and problematic task.

Construction project management (CPM) is a unique discipline with its own tools and techniques. Traditional control mechanisms (such as Work Breakdown Structure, Gantt Charts, PERT/CPM networks, Project Crashing Analysis, Trade-off Analysis, etc.) are not entirely adequate for managing complex projects. Many researchers have suggested the use of a system dynamics (SD) methodology in planning project activities [12–14] and determining the causes of rework in construction projects [10,15]. Additionally, a system dynamics methodology can improve decision-making at a strategic level. Rodrigues and Bowers [16] suggested that the management of projects could be categorised as follows:

1. *Level 1* — consideration given to the interactions of a specific project with the rest of the contractor company. The most important consideration here is whether the project objectives are compatible with overall company objectives.
2. *Level 2* — management is primarily concerned with strategic alternatives of an individual project. For example what are the major targets (milestones) and the form of organizational structure?
3. *Level 3* — here, specific details of a project's targets, activity schedules, manpower allocation, etc, are considered.

Traditional CPM tools and techniques are adequate for dealing with specifics in level 3, but are unable to fully address issues in levels 1 and 2. This is where SD can be used, to take a holistic view of the project management process. SD can focus on information feedback and offer a method for modeling and analyzing complex project systems [11]. A SD model can also incorporate technical, organizational, human and environmental factors [17], while simulating the behavior of major outputs of a project system over time. This paper describes how changes, actions or effects, otherwise known as dynamics, can impact the CPM system. Using case study examples and the SD methodology, major factors influencing a project's performance are investigated. The paper highlights a need for understanding how particular dynamics can hinder a construction project management system.

## 3. Dynamics of project management in construction

The dynamics that impinge upon a project system are derived from two basic sources: *planned activities* and *uncertainties*. Planned activities include the established operation programme, the arrangements of daily duties, planned material and plant operations, etc. These activities are designed to initiate change, that is, the progress of construction works.

In this paper *the dynamics of planned activities are called 'attended dynamics'*, which is synonymous with 'intended dynamics' a description often-used in SD literature. The term 'attended dynamics' is preferred because it assumes that an observed behavior is the direct result of active interventions. Attended dynamics can affect a project's objectives in either a positive or negative way. Positive influences would indicate that through policy intervention, progress had been made towards achieving a project's objectives. Conversely, negative influences would indicate that progress toward project objectives had been hindered. Similarly, *'unattended dynamics' otherwise known as 'unintended dynamics'*, places emphasis on factors beyond the control of project managers. Like attended dynamics, unattended dynamics can also have positive and negative influences. Uncertainties or unexpected events can significantly affect the operation of a project; such events either improving or hindering project performance. Both attended and unattended dynamics coexist throughout a project's life cycle.

## 4. Attended dynamics

For any project, a project management team typically establishes a programme and the sequencing of activities required to be undertaken. These activities are *dynamics* designed to implement management objectives. The major attended dynamics of a project management system include:

1. *Decision-making*: decisions are the most important initial dynamics and result from a large number of specialists involved in the project process. Decision-making is interrelated with project organisation and structure, such that information, feedback, advice, etc., are received by the decision-maker from appropriate contributors (e.g. consultants, site manager, foremen, subcontractors, etc.), at the appropriate time(s).
2. *Techniques and technology*: these are the basic dynamics for implementing any system. They include the level of education/knowledge of staff, management skills, information techniques, and various facilities and machines within (and between) any organisations involved in a project. The techniques employed and ways of applying them are fundamental to achieving the organisations' and client's planned objectives, but may vary from company to company.
3. *Behavioural responses*: responses of individuals are the direct attended dynamics for the operation of any system. Their effects are closely related to motivation, education, role relationships, and personal goals and values [17]. Behavioural responses directly affect the performance of an organisation. In this context, performance can be improved through effective human resource management, adequate training and personnel development schemes.
4. *Project structure:* the project procurement route essentially establishes its organisation; assigning specific responsibilities and authorities to people and systems. It also defines the relationships of various elements in a project structure [18]. A project's structure juxtaposed with the contract(s) in force establishes the communications structure, which dictates information flow (feedback mechanisms) and affects (principally the speed and reliability of) decision-making processes.

## 5. Unattended dynamics

The characteristics of unattended dynamics are represented by unexpected events or uncertainties' causing changes to a project system, and thus potentially affects its performance. For example, a change in economic conditions can affect a client's budget, forcing modification of original objectives. Major sources of unattended CPM dynamics can be classified as internal uncertainties or external uncertainties.

### *5.1. Internal uncertainties*

Major internal uncertainties exist in the following areas:

1. *Project-related uncertainties:* these include location conditions, uncertainties in the contract, uncertain durations for activities, uncertain costs, uncertain technical complexities, and resources availability and limitations.
2. *Organisation-related uncertainties*: different project stages require different skills, different contributors and other resources. Project participants vary through the construction process.
3. *Finance-related uncertainties*: a company's financial capability/policies can change. The changed financial status of any party within the project team can affect, or in the extreme even jeopardise, the project's expected outcome.
4. *Interest-related conflicts*: although all project participants may appear to desire realisation of project goals, the interactive constraints and interests between disciplines often cause conflict. This can hinder co-operation in dealing with changes and affect performance.
5. *Human-related uncertainties*: people and situations need to be treated on their merits, thus Fryer [19] suggested that a contingency approach is needed. The effectiveness of human resources is affected by individual traits, social background, religious beliefs, customs, life style, education level, work conditions, etc.

### *5.2. External uncertainties*

The external environment can significantly affect a project system. For example, changes in government regulations (especially in the context of workplace reform). External uncertainties mainly exist in the following areas:

1. *Government-related uncertainties*: acts passed by government may be very costly to a client. The impact from a change in regulation can also affect a contractor's profitability. For example, the enforcement of noise control policy may require the use of pneumatic plant for piling operations rather than percussive plant. As a consequence any extra costs will be either borne by the contractor, subcontractor or passed on to the client. Furthermore, changes in taxation and interest rates can

affect a project's financial viability or its planning and execution.

2. *Economy-related uncertainties*: uncertain inflation and interest rates, and changing exchange rates, etc. can affect a project in terms of cash flow, costs of materials and salaries, etc. Changing economic conditions will also affect the state of competition, the availability of finance, materials and labour. For example, high economic activity can produce a high level of demand, which may result in shortages of materials, which in turn may delay a project. Similarly such changes may also affect a supplier's financial situation — see Nicholas et al. [20] for a more complete rationale of this concept.
3. *Social uncertainties*: the public can significantly influence a project's outcome. For example, resistance from the community to the use of overseas construction workers. Moreover, the construction of a building may have adverse social consequences due to its particular nature and location. The changing social environment may also affect an individual's attitude and behaviour, for example, in terms of demands for better working conditions.
4. *Legal uncertainties*: changes in legislation may directly affect a client's objectives through the implementation of new safety law, planning law, building regulations, etc. These changes will particularly affect operational procedures on-site, and ultimately, a project's programme. Legislation changes can also influence contractual relationships between different parties through the introduction of new case-law precedents, etc.
5. *Technological uncertainties*: new technology can directly influence design and construction. Technological uncertainties include possible changes in using materials, techniques, labour, facilities, machines, etc. The impacts of changes on technology can result in redesign, and the use of new/alternative materials. The development of new materials or machines, or new staff with better skills or education can help project managers improve their planning, scheduling, organising, cost control, quality management and co-ordination.
6. *Institutional influences*: professional institutions can affect the conduct of their members through conditions of engagement, fee scales, etc. Professional codes of conduct and education regulations can affect project organisation and decision-making processes.
7. *Physical conditions*: external physical conditions may significantly affect project performance. Factors to be considered here include infrastructure/transportation, degree of saturation, district development plans, and site access/egress for material and labour transportation.
8. *Acts of god/force majeure:* uncertain weather and other natural forces such as flooding, earthquake or tropical typhoon can have obvious ramifications.

Both attended and unattended dynamics that can influence a CPM system have been identified and described. In order to execute a project successfully, the project manager should continuously monitor these dynamics throughout its life cycle. It is acknowledged that a life cycle approach can only be considered if an organisation is responsible for the procurement and operation of an entire facility.

### 5.3. *A conceptual framework for understanding project dynamics*

Under the action of various dynamics as described earlier, a project exhibits ever-changing levels of cost, time, and quality performance throughout its progression. These changes require effective (and often quick) responses from the project team. In response to these changes, the team needs to remain dynamic and continuously establish new relationships between resources, and adjust the mix of resources assigned to various team members. Taking this a step further, these dynamics (i.e. factors) may have either a positive or negative influence on project objectives. Those with positive impact are defined as *positive dynamics*, and those with a negative impact are defined as *negative dynamics*. The dynamics of the construction project management system are shown in Fig. 1. The aim of this (positive/negative) approach is to help management improve the effects of positive impacts and reduce negative impacts.

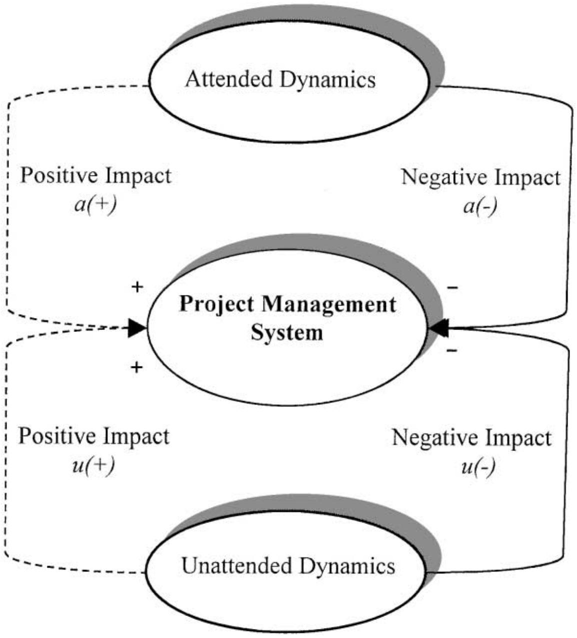

Fig. 1. The impact of *unattended* and *attended* dynamics on the project management system.

## 6. Changes over time

A central tenet of dynamics is the focus on changes over time. This involves continuously assessing and evaluating project dynamics at regular (e.g. predetermined) intervals. Assessment and evaluation of both attended and unattended dynamics in this way will invariably lead to more appropriate management responses. The objective here is to reduce the influence of negative dynamics, and increase the influence of positive ones. Continuous evaluation also ensures that the project team *learns* to reduce negative dynamic impacts (Fig. 2).

When a project is evaluated at the first phase of its life cycle, the following must be identified:

1. the positive impacts from attended dynamics $a_1(+)$;
2. the negative impacts from attended dynamics $a_1(-)$;
3. the positive impacts from unattended dynamics $u_1(+)$; and
4. the negative impacts from unattended dynamics $u_1(-)$.

This analysis will enable CPM to respond as appropriate. Actions and responses are the new attended dynamics that advance the project situation to the second stage. Assessment of project effectiveness at the second stage will result in the impact data: $a_2(+)$, $a_2(-)$, $u_2(+)$, $u_2(-)$. If management effectiveness is evident then the following relations will be true (albeit this is theoretically optimal):

$$a_2(+) > a_1(\mathrm{a})$$

$$a_2(-) < a_1(-)$$

$$u_2(+) > u_1(+)$$

$$u_2(+) < u_1(-)$$

Thus, leading on from this and for a general situation, the following sets can be used as criteria in evaluating whether proper actions and responses are taken along the whole project process:

$$a_i(+) > a_{i-1}(+)$$

$$a_i(-) < a_{a-1}(-)$$

$$u_i(+) > u_{i-1}(+)$$

$$u_i(-) < u_{i-1}(-)$$

Parameter $i$ refers to a project stage $i$ of the project management. When a project approaches completion, the negative impacts of dynamics should be gradually diminished, that is:

$$a_m(-) \rightarrow 0 \quad \text{and} \quad u_m(-) \rightarrow 0$$

(when $m$ is the final stage of project).

Changes in projects are primarily due to variations (also known as change orders), rework (the unnecessary effort of re-doing a process incorrectly implemented first

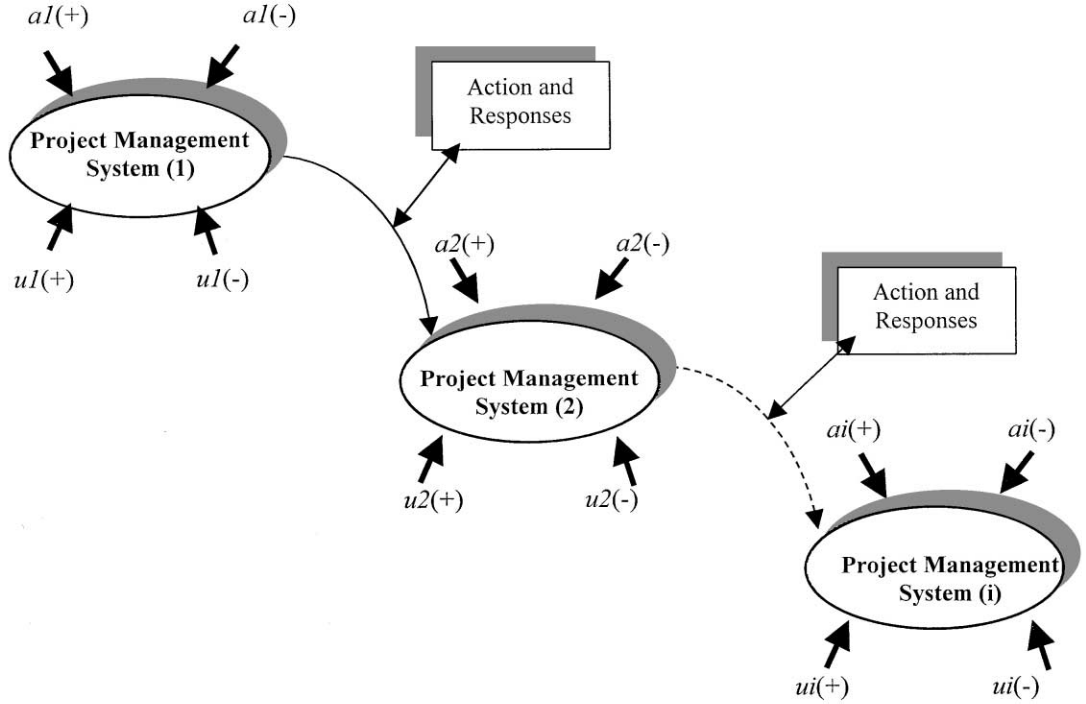

Fig. 2. Dynamics of the project management system.

time), or unexpected events such as industrial action, inclement weather etc. The two main causes of rework in construction are changes and errors. Design changes are usually introduced to meet the requirements of any of the following customers:

1. Owner — to fulfil their expectations regarding e.g. the operability of the facility;
2. Contractor — to enhance the constructability of the facility; or
3. Supplier/fabricator(s) — e.g. to facilitate the use of existing standard products.

Conversely, construction changes are introduced to meet the requirements of any of the following customers:

1. Owner — to achieve project schedule within budget;
2. Designer — to meet design modifications;
3. Subcontractors — to eliminate work assignment conflicts; and
4. Supplier/fabricator (s) — to ease the mobilization of material/products to and within a site.

Clearly, design and construction changes/errors may contribute to rework; for example, the rerouting of services due to clashes from poor information displayed on the contract drawings. Hence, rework can take the form of a variation claim if it directly influences a project's progress and causes disruption.

To demonstrate how attended and unattended dynamics can affect project performance, a case study is now presented. The causes and impacts of major changes experienced in the project are described. The findings are used to develop a causal loop model, based on the concept of SD, to determine the fundamental dynamics affecting project performance.

## 7. The effect of project changes: a case study

The case study project consisted of two six-storey residential apartment blocks, containing a total of 43 units. Underground parking, a landscaped podium and swimming pool are among the facilities incorporated into this development. The contract value was $A10.96 million, with a contract period of 43 weeks (Table 1). The project was procured using a traditional lump sum contract, with the client employing a project manager to act as development representative. The role of the client's project manager was to administer, integrate and coordinate the consultants and principal contractor.

## 8. Data collection

Data was collected from the time construction commenced on-site up until completion of the defects liability period. Interviews (unstructured and semi-structured) were conducted with the project's client, site management team, consultants, subcontractors and suppliers. The project was visited three times a week throughout its duration. Two block-visits of 4 days each project were included. These block visits were undertaken during times of increased site activity. Interviews were primarily used to determine those dynamics that influenced change, for example, rework and variations. Coyle [21] advocated such an approach for identifying and establishing dynamic relationships. Direct observations, and documentary sources provided by the contractor, consultants, subcontractor and suppliers were also used to derive data. Numerous other sources such as variation lists, site instructions, day work sheets, extension of time claims and non-conformances contributed also to identifying rework events and determining their effect on project performance (time and cost). Such a methodological approach is commonly known as *triangulation* [22].

The dynamics that influenced changes such as rework and variations in the project were determined from interviews with the client, project manager, architect, contractor, subcontractors and end-users.

Table 1
Case study project details

| Project details | Residential development |
|---|---|
| Original contract duration | 43 Weeks |
| Extension of time | 5 Weeks |
| Original contract value | $10,960,000 |
| Revised contract value | $12,065,900 |
| Variations — changes and omissions | $806,356 |
| Rework — variations | $299,544 |
| Rework — non-variations | $40,960 |
| Rework — defects | $5,000 |
| Rework as a % of the original contract value | 3.15% |
| Variations as % of original contract value | 7.35% |
| Overall cost of variations and rework % the original contract value | 10.50% |

## 9. Findings

It was found that information contained within the contract documents was consistently inaccurate, conflicting, and incomplete. Both the architect and engineers stated that the program they were given was unrealistic, inasmuch as they were allocated only limited time periods to prepare contract documentation. In fact, they suggested that they did not have the resources to sufficiently complete the documentation, because their fee was based on the concept brief and as a result the scope of error detection was low. They further suggested that they had only allocated so many hours per week to the project and did not realize the true extent of the work to be undertaken. Mainly, this was a result of the brief evolving simultaneously with the design.

### 9.1. Purchaser changes

To complicate the design process even further, the project manager sold the apartments ’off the plan’ as the design was emerging. As a result, purchasers constantly requested changes during construction that naturally affected the construction program and resulted in variations, rework and copious amounts of non-productive time being experienced. Tables 2–4 inclusive identify the cost, type, and causes of the changes and rework experienced in the project. Table 2 and Fig. 3 specifically highlight the forecasted expenditure against the actual expenditure of the project. The additional costs experienced were primarily caused by negative attended dynamics and did not emerge until the project was about 50% complete. More interestingly, it appeared that as these negative dynamics did emerge, the client’s project manager did not take appropriate action to mitigate their effects or prevent similar events reoccurring.

### 9.2. Design freezing

Design changes as a result of error detection during construction, were found to be common occurrences.

Table 2
Monthly costs over the project duration

| Month | Forecasted cost ($) | Variation cost ($) | Rework cost ($) | Actual cost ($) | Forecasted cumulative cost ($) | Actual cumulative cost ($) |
|---|---|---|---|---|---|---|
| February 1996 | 75,000 | 3,200 | – | 78,200 | 75,000 | 78,200 |
| March | 395000 | 5,600 | 25,287 | 425,887 | 470,000 | 504,087 |
| April | 750,000 | 12,850 | 28,460 | 791,310 | 1,220,000 | 1,295,397 |
| May | 1,280,000 | 56,700 | 22,839 | 1,359,539 | 2,500,000 | 2,654,936 |
| June | 1,450,000 | 45,890 | 32,439 | 1,528,329 | 3,950,000 | 4,183,265 |
| July | 2,078,000 | 65,740 | 44,784 | 2,188,524 | 6,028,000 | 6,371,789 |
| August | 1,500,000 | 112,870 | 41,229 | 1,654,099 | 7,528,000 | 8,025,888 |
| September | 1,280,000 | 101,230 | 76,382 | 1,457,612 | 8,808,000 | 9,483,500 |
| October | 985,000 | 123,650 | 42,304 | 1,150,954 | 9,793,000 | 10,634,454 |
| November | 450,000 | 115,320 | 18,516 | 583,836 | 10,243,000 | 11,218,290 |
| December | 480,000 | 95,210 | 5,764 | 580,974 | 10,723,000 | 11,799,264 |
| January 1997 | 237,000 | 68,100 | 7,500 | 312,600 | 10,960,000 | 12,111,864 |
| Total | 10,960,000 | 806,360 | 345,504 | 12,111,864 | | |

Table 3
A breakdown of the causes and costs of variations

| Cause | No. of events | Non-productive time (days) | Total cost ($) | Mean cost per event ($) | % of Contract value |
|---|---|---|---|---|---|
| Client changes | 49 | 10 | 105,620 | 2155 | 0.96 |
| Occupier changes | 132 | 14 | 235,440 | ,78 | 2.14 |
| Design omissions | 83 | 13 | 265,980 | 3205 | 2.43 |
| Local Authorities (Rates/Taxes/Fees) | 5 | 2 | 146,080 | 29,216 | 1.33 |
| Extension of Time (Claims) | 6 | – | 53,240 | 8873 | 0.49 |
| Total | 275 | 39 | 806,360 | 2932 | 7.35 |

Table 4
A breakdown of the causes and costs of rework

| Cause | Number of events | Non-productive time (days) | Total cost ($) | Mean cost per event ($) | % Contract value |
|---|---|---|---|---|---|
| Design change | 65 | 20 | 182,893 | 2814 | 1.67 |
| Design error | 12 | 13 | 59,233 | 4936 | 0.55 |
| Design omission | 2 | 7 | 6837 | 3419 | 0.06 |
| Construction change | 14 | 2 | 72,979 | 5213 | 0.66 |
| Construction error | 120 | 14 | 19,514 | 163 | 0.17 |
| Construction omission | 2 | – | 760 | 380 | 0.006 |
| Construction damage | 3 | 14 | 3288 | 1096 | 0.03 |
| Total | 218 | 69 | 345,504 | 1585 | 3.15 |

For example, the contractor asked the client's project manager on numerous occasions for a design freeze because changes were affecting programme, project cost and motivation of site management and subcontractors. This was not granted and as a result, extensions of time totalling five weeks ensued. Love and Li [23] suggested that a design freeze should be applied as early as possible so as to reduce changes. A design freeze would only have been effective if the concept and project brief were developed by a highly skilled professional who could have taken control of the design process and then communicated the client's requirements to all participants involved.

### 9.3. Information management

The lack of attention to quality by consultants was costly in time and money. Site management spent up to 30–35 h a week for the first 10 weeks of the project checking the architectural, structural and service drawings to ensure that dimensions, etc. coincided with each other. When errors were found, the designers had to re-design and re-schedule the necessary elements. Noteworthy, the designers did not use any form of Computer-Aided-Design (CAD), and instead relied solely on traditional manual systems. The use of a convenient and common platform for information transfer and exchange could have significantly reduced the impact of changes experienced in the project.

### 9.4. Building regulations

A significant amount of rework occurred as the entire mechanical exhaust system for the basement car park had to be re-designed [because it did not comply with the building code of Australia (BCA)]. Dimensions on the architectural drawings for the basement significantly differed between section, elevation and plan. The foreman noticed these errors within 2 days of being on-site. The basement excavation was about to commence, and this subsequently allowed the design team to correct their errors without affecting the project's critical path.

### 9.5. Consultants fees

The contractor waited over 3 weeks for the architect and structural engineer to co-ordinate and approve the 'shop drawings' for procurement of structural steel. This delay had a negative impact upon the contractor's programme and required certain elements of the project to be re-scheduled. Again, the architect and structural engineer found that they did not have the resources available to check and approve shop drawings any quicker. A symptom of low design fees had meant they only allocated so many hours per week to each project they undertook. As the project progressed the design consultants blamed low design fees for any errors made in the documentation. They stressed that the scheduled programme and a lack of resources prohibited them

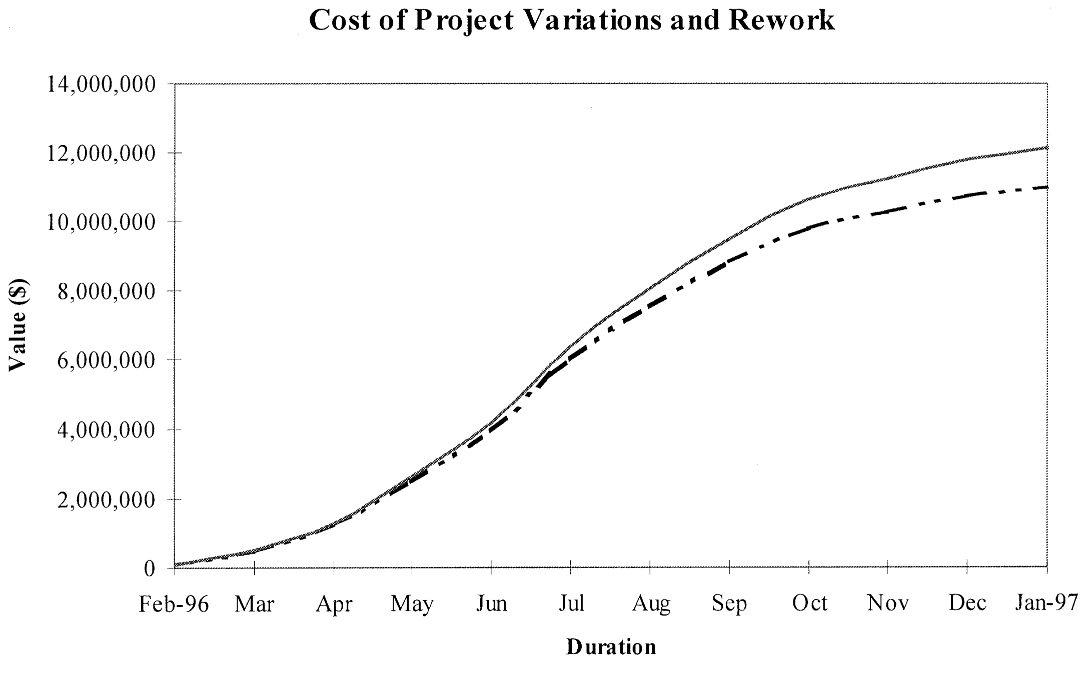

Fig. 3. Forecasted versus actual costs of construction.

from producing fully documented working drawings. The contractor identified discrepancies in the documentation. Accordingly, those problems that arose were solved on-site. This was a time-consuming process for the contractor and increased the incidence of rework and non-productive time (Tables 3 and 4).

### 9.6. Communication

The uncertainty and poor quality of the documentation delayed the procurement of materials and contributed to the creation of 'walls' between the contractor and the designers, which negatively affected communication and stimulated conflict. For example, it was found that both the architect and engineer had overlooked the BCA and eschewed coordinating their drawings during the design process. The pitch of the roof was changed and this required a major re-design. This alone delayed fabrication of structural steel for the roof by 6 weeks and as a result the contractor had to re-programme major elements of the project. The draftsman raised over 90 requests for information (RFIs) relating to the geometry of the roof.

Answers to most RFIs took more than 2 weeks. Consequently, this meant that architectural technicians were given limited time to produce functional 'shop drawings'. Staff had to work overtime and additional resources had to be employed. This had a negative effect on other projects being undertaken by the same drawing office. The draftsman estimated the cost to generate each RFI at $A90 and taking approximately 1 h to prepare. The estimated cost of correcting the shop drawings was $A16000. This sum included the indirect costs of two contracts worth $A3000 and $A5000.

### 9.7. Coordination and integration of the project team

Rework and variations were generated from different phases of the project's development process. Most of the changes experienced however were generated from the conception and design stages (Tables 3 and 4). Fundamentally, lack of understanding and incorrect interpretation of customer requirements, inadequate resources, design errors, and errors in the drawings or specifications juxtaposed with poor coordination and integration, were the cause. It is much easier and cheaper to prevent or correct an error during the design process than in the later stages of a project. Design errors can be reduced if consultants/project managers understand, develop, and practice, the facets of quality management. The relationship between consultants and contractor was considered by all parties to be unpleasant. The consultants had not worked with the contractor before and it was axiomatic that there was a great deal of tension between parties and reluctance to work together. The contractor perceived that lack of attention to quality by the designers inhibited the development of teamwork and joint problem solving. As the project progressed and design errors became increasingly prevalent, the more time the contractor had to spend trying to solve problems on-site.

### 9.8. Training and skill development

Findings from the interviews with the quantity surveyor and contractor revealed that they both considered a large portion of rework costs as attributable to the poor skill levels of the client's project manager, and of the design team and subcontractors. The main causes of rework identified as a result of poor skills were defective workmanship, disturbances in personnel planning, delays, alterations, failures in setting-out and co-ordination failures. The cause for 50% of the rework costs arose from poor motivation levels of the architects and engineers.

Training and skill development were not issues that the consultants addressed, primarily because of associated costs. The researchers (through conversations with the architect and design engineers) came to the conclusion that lack of training (and skill development with information technology applications such as CAD) adversely affected motivation levels among employees. From the findings identified in this case study a generic casual loop diagram of the project management system was constructed, which is provided in Fig. 4.

Changes, be they from variations, rework or a combination of both can have significant impact on the project's rate of progress. Variations and rework can be caused by both attended and unattended dynamics. In the next section of the paper the need to manage project dynamics is discussed, particularly with reference to the case findings and Fig. 4.

## 10. The need to manage project dynamics

To manage *attended* dynamics, various project management techniques have been developed and applied over the years. The management of *unattended* dynamics is however much more complicated. This requires identification of source, assessment of nature (i.e. whether positive or negative) and to conceive methods to enhance the positive impacts, while at the same time reducing negative impacts.

In managing unattended dynamics, it is crucially important to select and use the most effective management methods. For example, in the case study described above a SD methodology is used to determine the relationship and consequences of a change. When changes occur, they should be dealt with as soon as possible. At the initial stages of a project, gross development value, land cost, construction cost, time and profit are the main concerns of the client. When the economic envir-

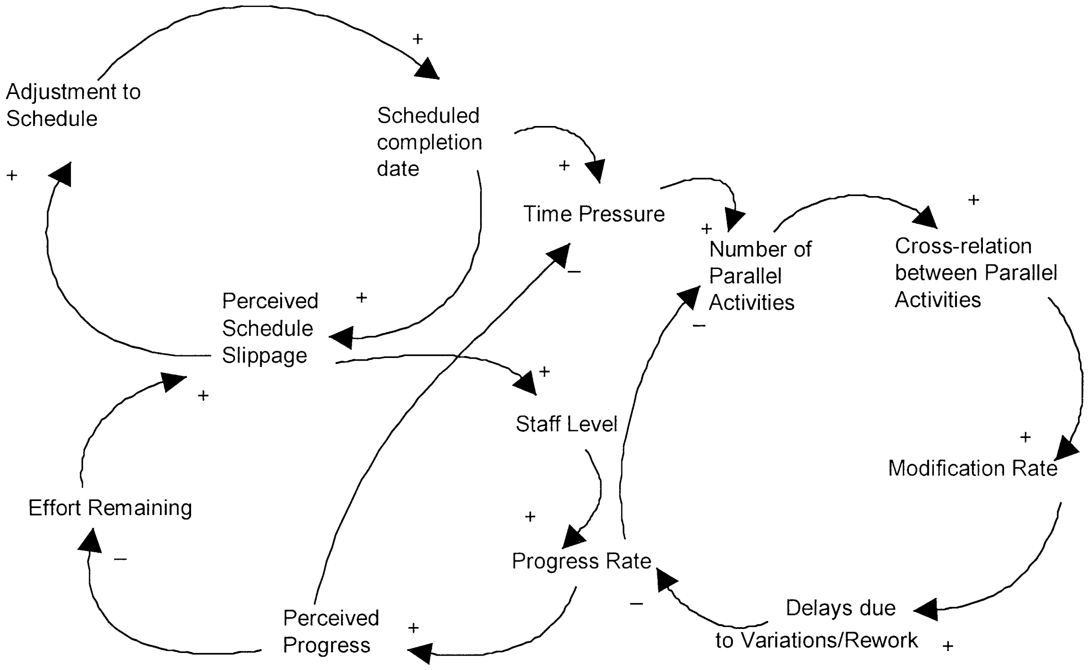

Fig. 4. A casual loop model of the project management system.

onment changes, then the developer may change the plan or strategy so as to reduce or eliminate the negative impacts of any change that is incurred. For example, if there is a reduction in land supply and a shortage of labour, then the developer may alter the size of an apartment and the number of storeys to reduce these potentially negative impacts. Resultantly, the objective of the project is adjusted.

Methods used in a risk management approach can be applied in dynamic approach. For example, risk identification techniques can be applied to identify unattended dynamics. However, the dynamic approach is much more comprehensive compared with risk management per se. The dynamics approach is to consider all attended dynamics and all risks during the whole construction process. It requires prompt decisions regarding changes. This indicates that managers consider experience; and prompt subjective judgements are essential for arriving at a correct response [17]. Contractors should use recognized CPM techniques to adjust to the changes and to forecast problems ahead. Based on findings from the case study, it is suggested that the dynamics of a project system should be monitored and evaluated by project managers in accordance with the following functions: planning; organizing; commanding; and controlling. Each of these functions is described later.

### 10.1. Planning

Planning is a necessity for managing complexity. It allows managers to be proactive to change. Many techniques have been developed for project management planning; to interpret ideas, implement actions, and allow for uncertainty. The use of techniques such as Stewards Design Structure Matrix during the design process can be used to assist decision-making [24,25]. In essence, this technique can be used to re-organize and re-prioritize design tasks by de-coupling, consolidating and re-sequencing tasks, and inserting new decision points so as to improve the flow of information between project team members.

### 10.2. Organizing

Organizing is to allocate tasks to people, request resources and co-ordinate all tasks into a working system. In a construction project, a matrix structure is useful for defining responsibilities of line functions and staff, and catering for the required flexibility in handling changes. The impacts of change on organizational structure may lead to re-distribution of duties, jobs, and other resources, or example, via the introduction of a horizontal process-based organizational structure in construction [2]. Moreover, technological changes may also necessitate structural adjustments (for example, the development of computer expertise may lead to the establishment of a computer services department).

### 10.3. Commanding

Commanding involves leading, delegating, communicating, motivating, coordinating, cooperating with and disciplining people. In a dynamic environment such as construction, a management hierarchy needs to be established that is responsible for making decisions and determining specific milestones. Using a management-by-objectives approach, project team members could be given freedom to choose appropriate techniques to deal with changes in the environment. The improvements or corrections of changes can be obtained by modifying employees' or a subcontractor's behavior without changing technology or organizational structure. For example, quality and efficiency may be enhanced through on-the-job training. Similarly, managerial effectiveness can be improved by implementing development and training programs in such areas as decision-making, leadership, and employee/supervisor relationships.

Managers need social skills for persuading, negotiation, inspiring confidence, creating loyalty and engendering trust. In particular, coordinating is one of the most important commanding measurements. However, organizational structure will dictate the degree of coordination required. An effective information system should be developed to enhance the integration of different project participants. Construction projects often require significant capital investment and rigorous management of progress, finance and quality. The amount of finance and other resources required in such projects may be too great for one contractor to invest, thus the participation of several parties including various consultants, subcontractors, and clients may be necessary.

### *10.4. Controlling*

One way used by the project manager to exert their overall control of a project is to set contingencies and subsequently control their release. The controlling process is one of the key measures of project management. Essentially, it is used to find deviations from plan and then implement corrective measures. The existence of dynamics requires implementation of continuous control measurements throughout the project process. Project control is the process through which managers ensure that ongoing activities meet planned requirements in terms of cost, time, quality and safety. However, random fluctuations — unattended dynamics — tend to cause output to differ from planned objectives. By controlling, management establishes standards and methods for measuring performance (cost, quality, time, behaviors, etc.). The performance measurements are reported periodically and compared with performance standards, and thus deviations are identified.

## 11. Conclusion

This paper has considered the project management system in construction, as a dynamic system, which is subject to both attended and unattended dynamics. It is suggested that emphasis should also be placed on understanding how particular dynamics *can* hinder the performance of a project management system, so that appropriate actions and responses can be undertaken so as to maximise the effect of positive dynamics and minimise the effect of negative ones. Using examples from a case study and the methodology of system dynamics, the major factors that influence project performance have been identified and discussed. The paper highlights the importance of developing the ability of properly identifying project dynamics, in particular, those unattended ones, and the importance of developing the ability to respond promptly to changes within the construction project management system. Unless such an approach to unattended dynamics is formalised, the problems identified in the case study projects will continue to plague the industry, and contractors will remain frustrated while clients' satisfaction with the industry will remain below optimal levels.

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