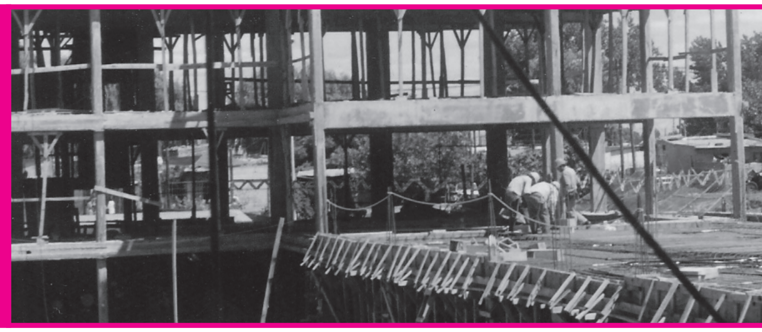
Desarrollo de un Marco de Sistemas Dinámicos con KPIs para Apoyar la Toma de Decisiones de los Administradores de Obra

Development of a Systems Dynamics Framework for KPIs to Assist Project Managers' Decision Making Processes



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Fecha de recepción 25/05/2010

Fecha de aceptación 16/06/2010

Abstract

Following a critical appraisal, redefinition and categorisation of Key Performance Indicators (KPIs) and their scope according to their use as an online management or monitoring tool (Roberts and Latorre 2009); this successive paper builds upon the first and focuses the research on the modelling of the construction project in terms of KPI driven goals using Causal Loop Diagrams (CLDs). The paper presents the results of a research project developed in order to identify the obstacles which prevent achievement of the overall performance desired for the UK's Construction Industry. Particularly, how project managers' decisions impact such performance.

The objective of this paper is to present the development of a KPI Hierarchy Model which will enable the contextualisation of the KPIs and allows for all relevant goals, elements and their interactions to be visualised easily. The integration, control and monitoring of this complex system and its objectives, feedback relations, delays and flow of information presents a need to understand and model how the components of these systems interact with each other.

The categorisation and subsequent development of Project and Company Level KPI CLDs suggests that the KPIs fit into separate hierarchies enable the proposed KPI Hierarchy Model to be modified and refined according to the real challenges that projects pose to the decision making process of project managers. The model explained in this paper presents the need for increased efficiency in the Construction Industry and the role that Key Performance Indicators (KPIs) have in driving these required efficiencies.

Key words: Project management, decision making, KPI, CLD.

Resumen

Luego de un análisis crítico, redefinición y re-categorización de Indicadores Críticos de Desempeño (KPI) y su alcance de acuerdo a su uso como herramienta en línea para la administración y el monitoreo (Roberts y Latorre, 2009); este artículo posterior se basa en el primero y enfoca la investigación en la modelación de proyectos de construcción en términos de objetivos basados en KPIs utilizando diagramas de círculo causal (CLDs). Esta publicación presenta los resultados de una investigación desarrollada para identificar los obstáculos que no permiten el cumplimiento del desempeño integral de la industria de la construcción en el Reino Unido. En particular, cómo los administradores de proyecto impactan en ese desempeño.

El objetivo de este artículo es presentar el desarrollo de un Model Jerárquico de KPIs que permite, a su vez, la contextualización de los KPIs y permite visualizar los objetivos, elementos e interacciones fácilmente. La integración, el control y el monitoreo de este complejos sistemas y sus objetivos, retroalimentaciones, retrasos y flujo de información generan una necesidad de entender y modelar cómo los componentes de estos sistemas interactúan entre ellos.

La categorización y consecuente desarrollo de CLDs de KPI Proyecto y Compañía sugiere que los KPIs calzan en jerarquías separadas permitiendo que el Modelo Jerárquico propuesto se modifique y refine de acuerdo a los desafíos reales que lo proyectos le presentan a los administradores de proyecto a la hora de tomar decisiones. El modelo presentado acá demuestra la necesidad de incrementar la eficiencia de la industria de la construcción y el rol preponderante que los KPI tienen en producir las mejoras requeridas.

Palabras clave: *Administración de Proyectos, toma de decisiones, KPI.*

Introduction

In the 1990's the UK government commissioned two influential reports: "Constructing the Team" (Latham, 1994) and "Rethinking Construction" (Egan, 1998); both reports contributed to the increasing recognition that improvements and change were required within the Construction Industry. As a result the need to develop a suitable measurement framework to manage the proposed improvements was identified; this led to the development of Key Performance Indicators (KPIs) which helps to drive forward the increase in efficiency within the Construction Industry (Construction Excellence, 2009; Cain, 2003).

This is the second paper in a series of two; the first paper (Roberts and Latorre, 2009) presented a critical appraisal of KPIs within a wider context. Through the application of the existing System Dynamics theory, particularly Causal Loop Diagrams (CLDs), the first paper explained this underperformance phenomenon by redefining and categorising KPIs and their scope, according to their use as an on-site management tool or as a monitoring tool for use at head office.

This second paper presents research which focuses on modelling the construction project in terms of KPI driven goals using CLDs. By focusing on the effect of changing the project performance objectives on the other objectives, via the feedback mechanism of the KPIs, this paper will present the results of a research project developed in order to identify the obstacles which prevent achievement of the overall performance desired for the UK's Construction Industry.

Background

For KPIs to be effectively utilised by project managers in order to improve project performance on a day to day basis, they need to be contextualised in order to be project specific. This contextualisation of the KPIs should allow for all relevant goals, elements and their interactions to be visualised easily. The integration, control and monitoring of this complex system and its objectives, feedback relations, delays and flow of information presents a need to understand and model how the components of these systems interact with each other (Dettmer, 1997). The objective of this paper is to extend and develop the ideas of Roberts and Latorre (2009), who proposed categorising KPIs according to where they should be monitored and by whom.

Table 1 presents the recommended frequency with which KPIs should be measured and how they should be monitored on-site. The table shows the two measurement levels of the KPIs; Project and Company. Roberts and Latorre (2009) conclude their critical analysis by categorising KPIs as either for use in on-site monitoring or for use as monitoring in HQ; these two levels are hereafter referred to as Project Level and Company Level. Project Level KPIs are those of use to the project manager directly. Company Level KPIs, on the other hand, do not relate to the needs of a specific

Table 1
KPIs categorised as proposed by Roberts and Latorre (2009)

Level	KPI	Designation	Frequency and Method of Measurement
Project	Cost	KPI 1	Using activity schedule and monthly cost reviews
	Time	KPI 2	Using project programmes. Monthly
	Safety	KPI 3	Using agreed monthly audits
	Profitability	KPI 4	Using activity schedule and monthly cost review meetings
	Productivity	KPI 5	Using agreed monthly audits (Tonnage or units per month)
	Defects	KPI 6	Using weekly and monthly quality audits
	Cost predictability	KPI 7	Audit at monthly cost review meetings (HQ)
	Time predictability	KPI 8	Audit at monthly project review meetings (HQ)
Company	Client satisfaction - product	KPI 9	Use agreed questionnaires and meetings at regular intervals to establish why the Client is dissatisfied. Monthly monitoring at HQ.
	Client satisfaction - service	KPI 10	
	Environment	KPI 11	Monthly
	Investment in staff	KPI 12	Monthly

project, but they serve the interests of the construction company as a whole. Of the ten Egan KPIs, eight have been identified as being measured at Project level. At Company level, Product and Service Client Satisfaction are two of the other KPIs identified and added to Egan's other two, Investment in Staff and Environment, creating a total of four measurable KPIs.

Given that KPIs are not independent variables, they are highly effective in assisting the decision making processes regarding the overall construction project performance; however their effectiveness is only pertinent when based on a small, selected set of data for relevant KPI only, as the use of KPIs does not allow for an overall view of the project. As a result, decisions made by project managers based on the information gained from KPIs may have a detrimental impact on other targets, and even the overall performance of the project (Roberts, 2007; Barr, 2004). Furthermore, cost, quality and time are not equally relevant to success of all construction projects (Latorre and Riley, 2010) performance measurement must take into account specific aspects of the project, context and client's needs. Santos *et al.* (2002) state it is widely accepted that effective performance measurement should provide decision makers (the project managers) with information regarding how well the various project objectives are being achieved.

Project managers have two obstacles when making optimal decisions regarding the project's objectives. The first is that the construction project is complex, and the complexity lies in the projects structure and dynamics (Sterman, 2001; Chapman, 1998) as there are many parties involved in several processes of interaction. The second involves the human capacity to process information; the rationality of human decision-making is bounded (Sterman, 2000), and humans make decisions on the basis of selective information as "their cognitive abilities are overwhelmed by the complexity of the system" (Sterman, 2000).

The development of setting goals in terms of KPIs is one strategy designed to assist the decision making process. Using the KPI goal setting strategy enables processes to be compartmentalised, with decentralised and unconnected goals set to be achieved. This reduces the tasks to smaller autonomous specific units which are responsible for producing output to the set goals; ultimately assisting the decision making process by 'selecting' the relevant information for each goal (or KPI). In setting the goals, each autonomous unit will tend to maximise its process without cognisance of preceding, undergoing or following processes, or of the ultimate project goal. This could potentially undermine the overall project's performance; this outcome is also supported by the ideas from the Theory of Constraints (Goldratt, 1988).

By using KPIs as they are currently proposed, the project objectives are translated into, and measured by, a set of targets for the project manager to be achieved. By basing decision making on several sets of 'selected' data, the project manager may not appreciate the interacting issues within the ultimate goal of the system in the convergent maximisation of all KPIs. However, the integration of KPIs under a systems framework allows for optimising KPIs whilst retaining an overview of the whole set of KPIs as a dynamic system.

A Causal Loop Diagram (CLD) is an illustration of the "cause-effect-cause" relationships between elements of a system, which, over time, generate the dynamic behaviour of the system being considered. As such, a CLD is a diagram that depicts the arrangement of the important parts of the structure of the system. Also known as system diagrams, CLDs are powerful tools that assist in understanding how complex systems work and are particularly helpful to demonstrate how a change in one factor may impact elsewhere within the project, or in showing how changing a factor may feed back to affect itself. CLDs are be used to present the results of this study.

Development of a KPI Hierarchy Model

As proposed by Roberts and Latorre (2009), this section analyses KPIs to develop a KPI Hierarchy Model. Initially, the use of each KPI is analysed exclusively to assess its ability and usefulness in supporting the project manager and providing worthwhile data for decision making during the execution of the project itself. Then, the KPIs are integrated into one system.

Construction 'Cost' and 'Time' are the first and second KPIs identified, they contribute to the knowledge of individuals making decisions within the construction project processes and hence assist the project manager during the construction phase. A score is generated from the third KPI 'Safety', based on number of accidents per hours of on-site work and the majority of companies have a monthly or weekly on-site safety audit in place and regular head office inspections. This measurement does contribute to a project manager's decision-making knowledge. KPIs four and five, 'Profitability' and 'Productivity', are company-based indicators. This measurement does contribute to a project manager's decision-making knowledge. KPI six, 'Defects', contributes to the knowledge of the individuals making decisions within the construction project processes and hence do assist project manager within the project real time. Usually, 'Cost Predictability' and 'Time Predictability', are KPIs which are used by clients and provided by the contractor's head office. The project team does not use them. These KPIs do not contribute to the knowledge of the individuals making decisions within the construction project processes and hence do not assist project manager within the project real time. An accurate prediction of either of time and cost KPI provides a 100% performance rating. KPIs nine and ten, 'Client Satisfaction', 'Product' and 'Service' use a rating system to provide a numerical method to establish a rate of client satisfaction at the end of the project. There is no mechanism for capturing the reasons why the client was dissatisfied (Swann and Kyng, 2005). These KPIs do not contribute to the knowledge of the individuals making decisions within the construction project processes and hence do not assist project manager within the project real time. Finally, KPIs eleven and twelve are "environment" and "Investment in Staff"; these are increasingly recognised as being important as aspects of the global sustainability agenda.

This categorisation suggests that the KPIs fit into separate hierarchies, with the project based KPIs forming a foundational **Project Level** that supports and informs the higher **Company Level**. This initial KPI Hierarchy Model is shown in Figure 1. It should be noted, that there will be a set of KPIs from each separate project feeding into the higher Company Level KPIs.

This KPI Hierarchy Model (Figure 1) is a theoretical representation which has been tested as explained in the Methodology, and the Results presented later enable the proposed KPI Hierarchy Model to be modified and refined according to the real challenges that projects pose to the decision making process of project managers.

Methodology

Starting with the KPI Hierarchy Model, this research utilises a qualitative multiple-method approach, involving two different data collection instruments, questionnaires and interviews, on the same sample. This allows triangulation and validation of results. Initially, open-ended questions (Fellows and Liu, 2008; Hoxley in Knight and Ruddock, 2008; McLean in Jupp, 2006) identified how KPIs were used by construction companies within each construction projects, and how the company defined their overall performance measurement. open-ended questions provide up-to-date information on contemporary construction management practice and unforeseen aspects of the problem, allowing a deeper understanding of its context (Fellows and Liu, 2008; Hoxley in Knight and Ruddock, 2008; McLean in Jupp, 2006). The questionnaire was sent to and received from respondents by email. The analysis of the questionnaire results allows the modification of the KPI Hierarchy Model, and finally the structured interviews develop the concept model.

In order to gather information from several different projects, project managers with more than 10 years experience participated in the study. They were asked to reflect upon how the proposed KPIs could effectively assist their decision making process for the projects they were working on at the time. These projects were at different stages, within a wide range of construction fields; this ensured a balanced and broad variety of views and issues to compare against the proposed model (Checkland, 1999).

Two contractors were chosen to trial the pilot questionnaire and provide feedback. All respondents were using partnering type contracts and thus the goals

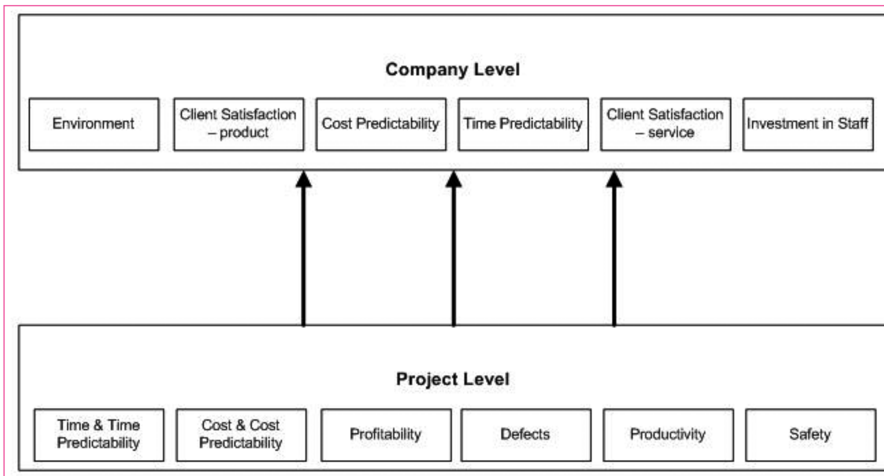

Figure 1
KPIs as proposed by Roberts and Latorre (2009)

of the contractors were assumed to be aligned to the goals of the client.

The questionnaire is divided into four sections. The first acquires factual information from the participant regarding the details of the project which enables the placement of the model into the correct context. Sections two, three and four are open-ended questions relating to the project and the company, gathering as much information as possible concerning events on site, how the company defines performance measurement and finally any changes made to the project.

The answers from the analysis of the questionnaire enabled changes to the KPI Hierarchy Model and to formulate the questions for interviews which derive a more detailed understanding of how these KPI CLD Models (Project and Company Level) can assist and inform project managers' decision making process. This second, interview stage, presented clients and contractors with the proposed KPI system as modified by the questionnaire. It also collected data in order to triangulate conclusions and recommendations with empirical results.

Results

One of the aims of this research was to understand how each of the individual KPIs within each of the hierarchy levels relates or influences others. The results from the questionnaires show that the use of CLD enables an influence chart to be developed permitting the focus of the influence from one KPI onto the other KPIs. This KPI Hierarchy Model is then used as the basis for development of the questionnaires and interviews, leading to KPI CLD Models (Project and Company Level). The influence of one KPI on other KPIs is modelled and represented by a CLD at Project Level (Figure 2). The description of the causal loops within Figure 2 are described below.

Cost and Time CLD (KPIs 1 & 2): As changes to the design or construction of the project occur, KPIs of Cost and Time will consequently be affected. If the project is running behind the allocated time schedule for completion then costs will be increased to enable timely finish of the project. For example, an increase in staff, materials or plant and equipment would be taken in an effort to decrease any time taken to do additional work and therefore maintain the time KPI to the project goal. On the other hand, if the project is running on or ahead of the planned schedule, site manufacture, staff, materials and plant on site can be decreased, in turn reducing costs. Cost and Time Predictability CLDs (KPIs 7 & 8) are a measure of the estimators' ability to anticipate the project and are designed to provide cost and time security to the client. Cost and time predictability are lagging measures taken at three set stages during the project time (overall, design and construction). They are the actual cost at end of stage less the anticipated cost at the start of the stage as a percentage of anticipated cost at the start of the stage. The KPIs of time and defects have the same positive and negative feedback polarity as cost.

Safety CLD (KPI 3): As changes are implemented on site during the course of the project, the safety will also increase due to legislation insisting on safety precautions. As a result, the increase in safety also means an increase in cost. However, in the long term, increased safety will decrease cost due to accident prevention and increased productivity. In addition, changes which cause decrease in time (such as increased productivity or pressure to decrease time), will cause safety to decrease. Also an increase in safety will decrease any time lost throughout the project, due to efficient methods and safe working conditions.

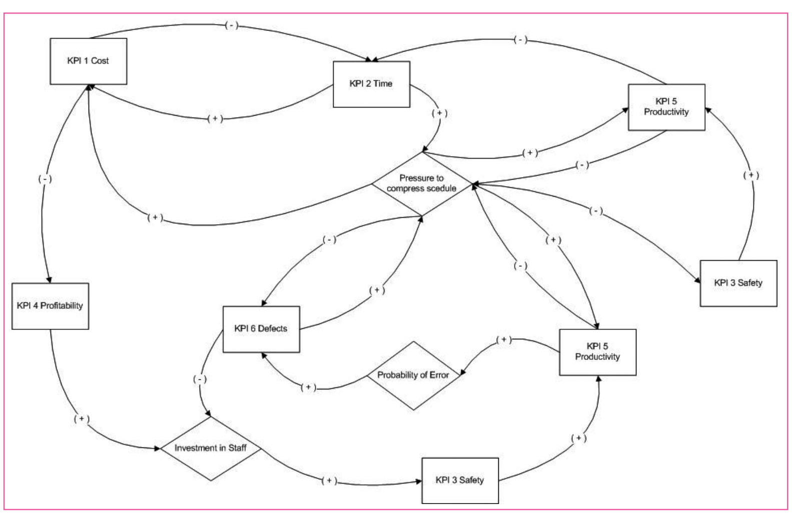

Figure 2
Project Level 6-KPI CLD

Client Satisfaction, product and service CLDs (KPIs 9 & 10) are measured at the end of construction and facilities management stages of the project and as such are lagging KPIs.

Profitability CLD (KPI 4): Profitability is the KPI with the least cause effect arrows as it is directly affected by cost; influences on profitability from other KPIs are indirectly sent through cost.

Defects and Productivity CLD (KPI 6 & 7): The optimal rate of productivity is set at the start of the project. When defects arise there is an increase in pressure to "catch up" and compress the schedule. As a result, this increase in productivity increases the change of errors made due to stress, tiredness and new members of staff, which in turn increases defects.

Each KPI has a negative balancing loop to bring the KPI to the desired state. The KPIs profitability and safety have the same positive and negative feedback polarity as productivity. These are not shown in Figure 2 to avoid duplication. The KPIs time and defects have the same positive and negative feedback polarity as cost. There are two ghost KPIs, safety and productivity. This is to avoid overlapping arrows and to simplify the diagram. They are the same KPI and in simulations the effects on them would be added together. The KPIs of profitability and safety have the same positive and negative feedback polarity as productivity. The selection of 6 KPI defines which need to be measured to ensure that project goals are achieved. The CLD for the company level is shown in Figure 3

The four Company Level KPIs are built up and measured from the six Project Level KPIs. This demonstrates the hierarchical nature of client satisfaction. Each project will have a strategy geared toward the requirement of each client. It will include details of the cost, time, quality safety and productivity. These will be the goals of the project. The successful management of these six interacting goals will provide client satisfaction with both product and service

The Project Level consists of three reinforcing positive loops. As the six goals of the Project level improve, then client satisfaction increases and this in turn increases the possibility of repeat work. Repeat work increases the knowledge and skills of the people involved in this type of project, improving team working and effectively reducing complexity and unknowns. This will result in improvements within the six KPIs and ultimately in client satisfaction in product and service.

If there is a levelling off of the six Project KPIs, client satisfaction may level off also and the rate of increase is reduced around the loops to a levelling off of performance. Further to this, if the six Project KPIs and the client satisfaction KPI decreases, then this decrease would propagate around the loop. Client satisfaction may decrease as the client has an expectation of incrementally increasing results, and this has an effect on repeat work for contractor and consultant. The client may decide to revert to traditional type competitive tender; this will decrease the knowledge gained from repeat work, decrease the KPIs, and decrease cost and time prediction after a time delay. As this is a positive

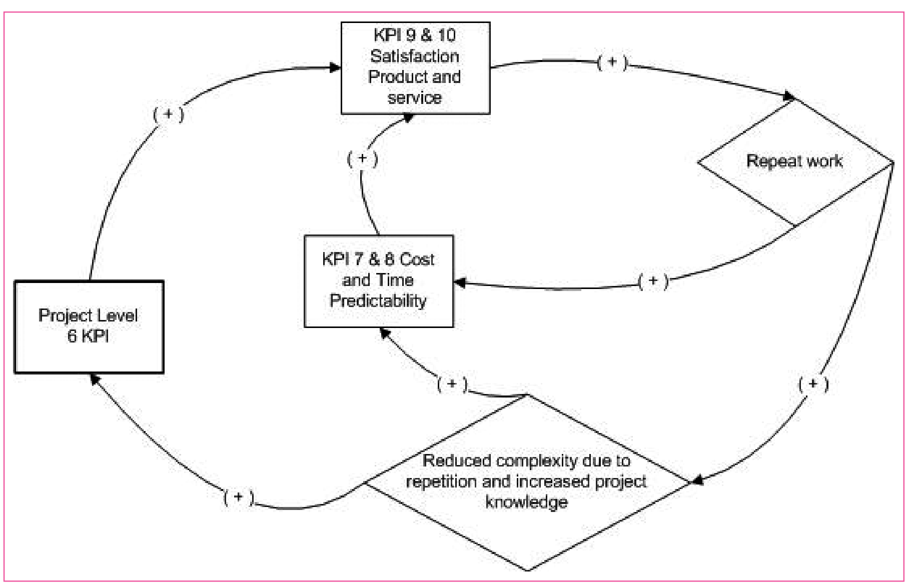

Figure 3
Company Level 4-KPIs CLD

reinforcing loop, it is seen that cost and time predictions and the improvement of the six objectives will decrease; this has the potential to cause a downward spiral.

These additional KPIs lead to changes in the KPI Hierarchy Model (Figure 1) and the revised model is shown in Figure 4.

Refining the KPI hierarchy model and CLD model based on interview results

The survey revealed that additional KPIs were required to reflect reality, as shown in Table 2. This table shows changes to the levels for some of the. The timing for collection of data is also given.

Changes to the Company Level KPIs

Changes derived from the data are shown in Figure 5. Profitability now appears in both levels. This reflects its importance and measurement at Project and at Company level, as recorded in the questionnaire replies.

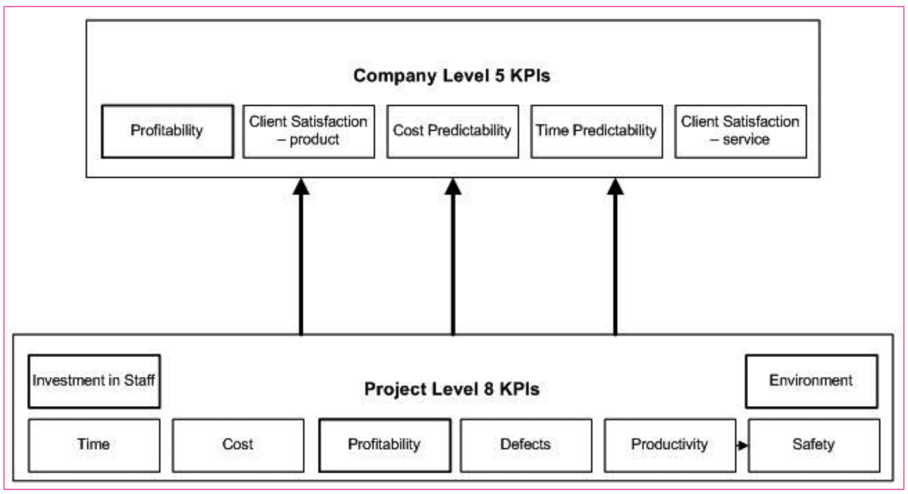

Figure 4
Decision Making KPI Hierarchy Model

Table 2
Showing proposed changes to KPIs following data collection

KPI	Designation	Frequency and method of measurement	CLD level
Cost	KPI 1	Using activity schedule and cost reviews.	Project
Time	KPI 2	Using project programmes.	Project
Safety	KPI 3	Using agreed monthly audits	Project
Productivity	KPI 5	Using agreed monthly audits.	Project
Defects	KPI 6	Using monthly quality audits	Project
Environment	KPI 11	Monthly	Project
Investment in staff	KPI 12	Monthly	Project
Profitability	KPI 4	Using activity schedule and cost review meetings	Project / Company
Cost predictability	KPI 7	Audit at cost review meetings	Company
Time predictability	KPI 8	Audit at project review meetings	Company
Client satisfaction - product	KPI 9	Use agreed questionnaires and meetings at regular and agreed intervals.	Company
Client satisfaction - service	KPI 10	Monthly	Company

Client satisfaction product and client satisfaction service has not been moved to appear on both levels as they are normally only measured formally at the end of the project. It is felt client satisfaction is reflected in the cost, time, defect, and safety KPIs. Its introduction on this foundation level would be counterproductive.

Changes to the Project Level KPIs

Productivity remained on the Project level for although the recognition of its measurement may not occur on Project level, the information for its productivity is present there in the form of time and cost and investment in staff (Figure 2). New KPIs were identified in (i) staff training and retention and termed "Investment in staff" (ii) environmental issues, which are imposed on the project via contract requirements or obligatory legal requirements. The effects of environmental considerations are not well established but are accepted as a factor which increases cost and time but which increased client satisfaction.

The Environment KPI was included from questionnaire survey, but its positioning and influence was confirmed by interview. It is placed in two locations affecting cost and time and secondly between investment in staff and productivity. This KPI is monitoring a growing field of the construction industry; legislation and taxation are causing traditional design and construction methods to be too expensive. This is an area of potential and growth where costs can be controlled through innovation and good public relations, and client satisfaction can also be achieved; in the CLD its effect is to decrease productivity and increase cost and time. In the future, due to legislation changes, costs may be reduced due to environmental innovations.

The Safety KPI shows that increasing safety will cost the project, but due to prior planning and a lack of accidents, productivity will improve.

An addition "ghost" time KPIs were inserted to reflect the effect of defects on time; an increase in defects would increase time for the project. However the longer loop of pressure to compress schedule, productivity, and time will work to counteract the delay to the project and reduce time. Changes are shown in Figure 6.

Discussion

The Project Level 8-KPI CLD (Figure 6) is a model of the eight KPIs required to be measured on the project; it makes explicit the objectives of the project, facilitating debate. It shows that increasing efforts on one particular KPI will have consequences on the other KPIs, but due to the complexity of the links the consequences of the initiatives employed may not provide the expected results.

The Company Level 5-KPIs CLD provides for the highest priority KPIs of client satisfaction and profitability. These are important for the business to satisfy shareholders and client in order to win repeat work. They are generated from the site based project activities, and it must be remembered that there will be several projects for one company.

Project teams can use the Project Level 8-KPI CLD model in two different ways:

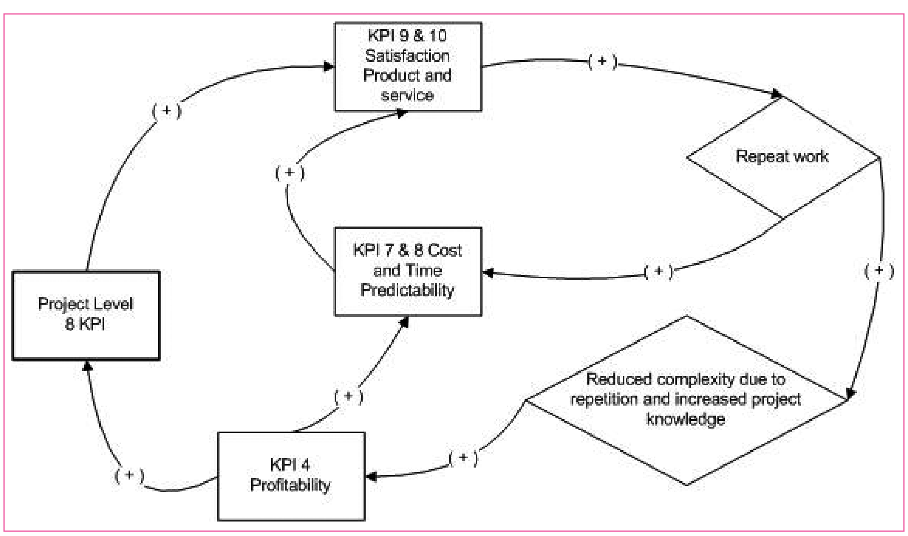

Figure 5
Company Level 5-KPI CLD

1. As a means for project teams to consider which KPIs should have a priority over other KPIs. In different types of construction projects the order of priority of KPI changes. For example in chemical plants, safety is critical, for defense services, client confidence in security is critical and for highway contracts, time is critical. The KPI with the highest priority can be given a weighting to reflect its priority. All other KPIs can be weighted similarly. By working around the model loops an assessment of the impact of increasing or decreasing initiatives on a particular process can be made. This information can be reflected precisely in the computer simulations, which could follow the CLD model.
2. The project team can discover the process(es) requiring increased initiatives. The analysis of the results of the performance indicators demanded in the eight KPI project model will allow the project team to identify which of the KPIs is the weakest link, relative to the project objectives, that is constraining the system. This is an important part of the benchmarking process and is a core tenet of the theory of constraints. This KPI can receive focused attention and enable decisions on how to improve it can be made by the team.
3. To identify critical KPIs; these are those Project Level KPIs that must be identified as critical and important to achieving the company level KPIs and as such must receive the maximum of the inevitably limited project resources. The KPIs will also receive the most attention in terms of management effort and resource.
4. The identification of "critical factor KPIs" will enable company level decision making to maximise its support on these KPIs rather than those that are not critical. This will then improve company level support to individual projects, as relevant to each unique project.

The dynamics of changes to the system, such as initiatives employed or unexpected design changes can be evaluated in virtual time using the CLD feedback mechanism. The long and short-term effects of the proposed solution to a problem can be observed by the parties concerned prior to implementation. CLD also can contribute to the project performance measuring system by taking into consideration the influence of one KPI on the other KPIs.

Conclusion

This paper has explained the need for increased efficiency in the construction industry and the role that Key Performance Indicators (KPIs) have in driving these required efficiencies.

The ten key KPIs derived by Egan (1998) have been examined to assess their value to construction project managers and from this analysis a theoretical two level hierarchical model was derived. Causal Loop diagrams were used to define the relationships and influence that the ten KPIs have to each other. At the site or project level six KPIs were identified as being within this system level, these being: Cost, Time, Defects, Safety,

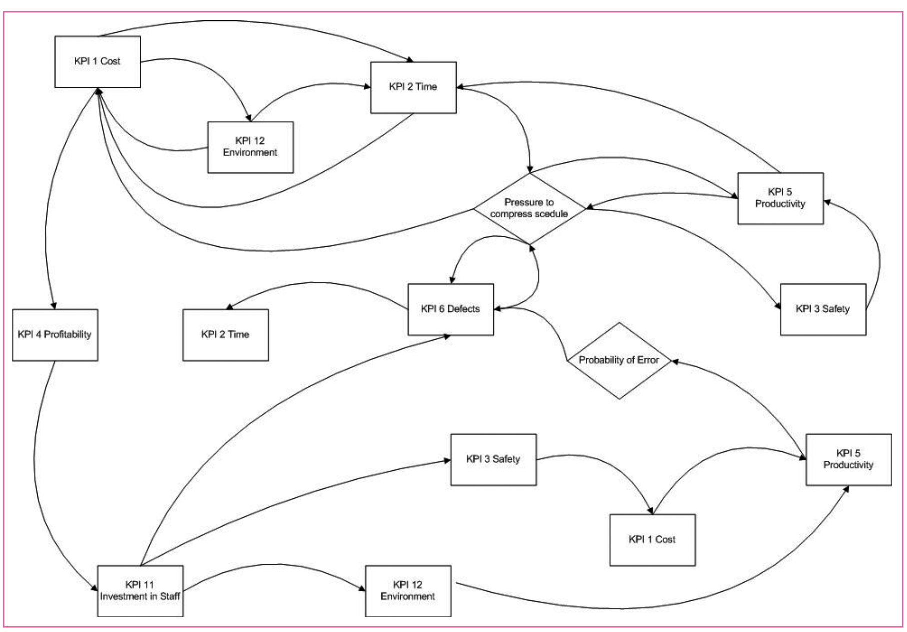

Figure 6
Project Level 8-KPI CLD

Productivity and Profitability. This system level then feeds data into the higher company system level; there are four KPIs at the level are this Company level being: Client satisfaction product, client satisfaction service, cost predictability, time predictability. The correctness of this theoretical model , represented by the KPI Hierarchy Model and the KPI CLD Models (Project and Company Level), was tested by using questionnaires and interviews put to experienced construction project managers. Data so derived enabled an improved working KPI model to be developed. This revised model has a company hierarchy level with five KPIs: client satisfaction product, client satisfaction service, cost predictability, time predictability and profitability. The project level has eight KPIs: cost, time, defects, safety, productivity, profitability, investment in staff, environmental.

This improved working KPI model enables project managers to model the impacts that the various KPIs have on the goals of the project. The model also permits the project manager to manage and focus on the various influences the changes in the weight of each KPI. The use of this model will lead to increase in efficiency of the construction process.

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