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MODELLING CONSTRUCTION INNOVATION CONSTRAINTS: A TOOL FOR SUSTAINING INNOVATION IN PROJECTS

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Abstract

There is concern that the construction industry lacks the ability to effectively sustain product innovation through the project process. A review of literature identifies lost opportunities where product innovations were introduced into construction projects but poorly managed, thus not fully implemented. Whilst literature points to project constraints for this failure it is proposed that the problem lies rather in the failure of stakeholders to adequately manage the constraints.

Previous construction innovation research has failed to substantially evaluate and priortise constraints in implementing innovations into projects thus leading to a gap in knowledge of how Project Managers might manage these constraints to ensure successful adoption of the innovation. This paper presents a methodology for quantifying and modelling innovation constraints using FMEA and Perceptual Mapping techniques.

An iterative grounded theory approach was used to identify constraint data from 30 case studies of construction projects where a product innovation was introduced. Constraint data was extracted and quantified from the case studies using content analysis and Failure Mode and Effect Analysis (FMEA). The resultant data was subject to manipulation using perceptual mapping techniques to formulate an Innovation Management Flowchart (IMF) and Constraint Classification Matrix (CCM). These outputs map the critical management tasks with the appropriate stakeholder responses to determine the optimum workflow sequence required to successfully implement an innovation into a construction project.

A key attribute of Perceptual Mapping is that it can communicate both qualitative as well as quantitative information thereby enabling the outputs to be used by non-academic beneficiaries. The benefit of this research is an established methodology and communication framework which can be used by Project Managers to inform the risk management strategy for their projects.

Keywords: FMEA, innovation constraints, perceptual mapping, procurement, product innovation.

1. BACKGROUND

Currently the accepted means of adopting and managing innovation in construction projects relies largely on project management techniques (Bresnen and Marshall, 2001; Walker, 2007). However an over-reliance on strict project controls and evaluation methods, around which project management operates often stifles innovation (Koskela and Vrijhoef, 2001). Whilst literature points to project constraints for this failure it is proposed that the problem lies rather in the failure of stakeholder competencies to adequately manage the constraints (Murphy et al, 2011).

Rosenberg (1982) proposed that since most innovations turn out as failures more attention needs to be paid to the evaluation of innovation constraint risk. Constraints can produce a blockage in the overall project process and premature rejection of an innovation (Koskela and Vrijhoef, 2001). Constraints which act upon the project process are well documented in literature but those which act on an innovation are less well investigated (Zou, et al., 2007). Identification and prioritisation of constraint risk is therefore critical to a study on construction innovation in projects.

This paper proposes a new approach to evaluating the source of innovation constraints and presents a methodology for quantifying and modelling these constraints using FMEA and perceptual mapping techniques to develop a risk management strategy for use by Project Managers (Zou, *et al*., 2007; Dulaimi, *et al.,* 2002; Gann and Salter, 2000a; Edum-Fotwe and McCaffer, 2000).

2. METHODOLOGY

In construction-related research there are historical difficulties in investigating construction projects over a short space of time. For this reason case studies were the primary source of data for this study (Tatum, 1989). 30 case studies were identified which represented both successful and failed attempts to implement an innovation into a construction project. The cases comprised a primary group of four cases (Group A) and a secondary group of 20 cases (Group C) in which innovation was successfully implemented. A third group (Group B) was used as a control and comprised 6 cases of failed innovation. The case study selection criterion was evidence of an attempt to adopt and implement an innovation into a project based on 5 key criteria as established from the literature: (1) Newness and uniqueness of concept (Rothwell, et al., 1976); (2) First use within the industry (Laborde and Sanvido, 1994; Harkola and Greve, 1995; Slaughter, 2000); (3) Ability to effect change to standard practice (Afuah and Bahram, 1995); (4) Derived benefits for all stakeholders (Ling, 2003); (5) Associated risk (Winch, 1998; Dodgson, 2000; Ling, 2003).

To investigate innovation in construction projects it was proposed that by mapping the investigation with the project procurement stages it would be possible to identify a common framework within which to structure construction innovation research (Murphy, et al., 2006; 2006a). Whilst studies have been carried out to link procurement systems with successful innovation, there had been scant work done to map the procurement process with the innovation process (Caerteling, et al., 2006). Murphy (2011) established a Concept Model which mapped the project procurement process with the process of innovation. The model correlated two established areas of literature: The Generic Design and Construction Process Protocol (Hughes, 1991; Cooper, *et al*., 1998; 2005) and two seminal models of innovation literature; Marquis, 1968 and Slaughter, 2000. It was proposed that by mapping the case study data with the Concept Model it would be possible to identify a systematic strategy for managing innovation in construction projects.

Case study data was collected from interviews and project documentation. Interviews were carried out with key project stakeholders namely Client, Project Manager, Designer (Consultant) and Supplier (Contractor). Structured interviews lasted between 1 to 2 hours and were recorded and transcribed. There were 96 stakeholders interviewed in total across the 30 case studies. Participants were questioned about their role, responsibility and activities relating to the adoption, implementation and management of the innovation during the project. From management literature a list of relevant documentation was compiled which comprised both written and drawing documentation: Minutes of Meetings; Product specifications; Feasibility reports; Concept sketches; Production drawings and As-built drawings. The key selection criterion for documentation was that it should include direct reference to the innovation[1]. From the documentation, evidence of innovation activity was mapped against the Concept Model to provide an accurate and chronological sequence of recorded events about the 'life' of the innovation. As constraints were identified so were the stakeholder responses to each constraint.

3. DATA ANALYSIS AND MANIPULATION

Content analysis was used to analyse the volume of raw data from the documentation and the interview transcriptions. To facilitate this, the software programmes NVIVO™ and SPSS™ were used. The resultant analysis reduced the overall data content and identified emerging and common themes. Through use of cross-matching of outcomes and internal validation the analysis produced a total of 131 verifiable constraints.

From the resultant constraints there was no indication whether one constraint was more critical to the success or failure of the innovation than another. Prioritisation of constraints was necessary particularly where there were numerous project stakeholders. To do this the extracted constraint data was subject to Failure Mode and Effect Analysis (FMEA). FMEA can evaluate the *criticality* of a potential risk. By identifying the differing constraint risks the Project Manager can modify stakeholder competencies to more effectively manage the innovation.

In FMEA analysis, probability is assessed by ranking the data according to probability of Occurrence (O), Severity of effect (S) and probability of non-Detection (D). The multiplied sum of these figures generates the Risk Priority Number (RPN). By identifying the 'risk priority' of a constraint, actions can then be prioritised based on the RPN value; the higher the RPN the more urgent the action required; the lower the RPN the least urgent. An RPN was assigned to each constraint identifying it as a High, Medium or Low constraint risk (Murphy et al., 2011). FMEA was applied to all 30 case studies.

3.2. Perceptual Mapping

Perceptual Mapping is a communication tool used to convey information at a number of levels. A key attribute of Perceptual Mapping is that it can communicate both qualitative as well as quantitative information simultaneously. Hence it can communicate the relationship between the quantitative data of constraint risks (RPN) with the qualitative date on the stakeholder's response to those constraint risks (Stakeholder competency). The application

[1] For example, a drawing that showed the connection detail between the glazing and the roof structure, or a set of minutes, which directly addressed the delay to delivery of the glazing, from the supplier.

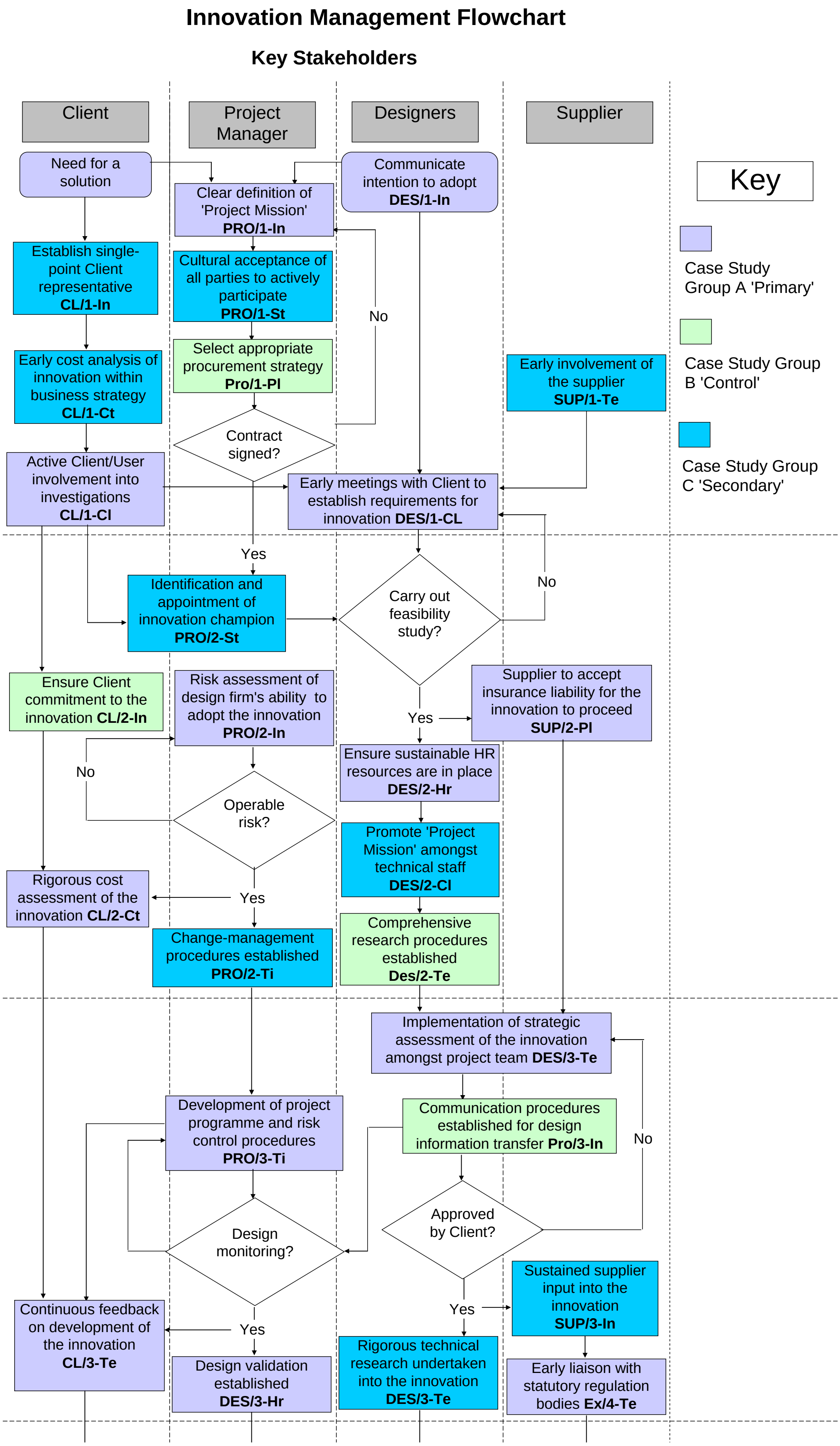
of Perceptual Mapping was a key consideration in this type of applied research where the outputs will be used by non-academic beneficiaries.

The Perceptual Mapping techniques used for manipulating the data in this study comprised Process Flowcharts and Matrices. A Process Flowchart is a workflow management system that coordinates the execution of numerous tasks to achieve project objectives (Sadiq and Orlowska, 2000). Rolland (1998) described a flowchart as a "rough anticipation of what the management process will look like". A Process Flowchart was formulated which mapped the Project Stakeholders (Axis X) with the Stages of Procurement (Axis Y). At the intersection of the two axes was the constraint and the stakeholder response used to manage that constraint.

The Process Flowchart data was those constraints extracted from the Groups A and C which represented projects with successful innovation. The flowchart therefore defined a skeleton of workflow tasks which could be used to successfully manage an innovation and was subsequently labelled Flowchart XZ. A second Process Flowchart was formulated using the data from Case study Group B which represented projects with failed innovation; Flowchart Y. It was observed that whilst Flowchart Y exhibited largely similar processes to Flowchart XY they were identified at later stages in the procurement process. This suggested that possible 'firefighting' or defensive management responses by stakeholders were implemented too late in the project to mitigate failure of the innovation. It was proposed that by combining Flowchart XZ and Flowchart Y it would be possible to identify those management activities which require high prioritisation at an early stage in the procurement process and those which are more effectively managed later in the process. The combined flowchart produced the Innovation Management Flowchart (IMF) (Fig. 1).

3.4. Innovation Management Flowchart

The Innovation Management Flowchart (IMF) established a workflow process which mapped stakeholders and their management tasks with the procurement stages of a project, to deliver a successful innovation. Initial findings from the IMF evidenced that many of the activities used to manage an innovation was drawn from the Group A data (Primary data) and this was validated by Group C data (Secondary data). These same activities are evidenced by the Control data (Group B) however they are concentrated in the mid to later stages of the procurement process. This would indicate that whilst the correct management activities took place in the failed case studies they occurred too late in the project to redress the imminent failure of the innovation.


Innovation Management Flowchart
Key Stakeholders
Client
Project Manager
Designers
Supplier
Key
Case Study Group A 'Primary'
Case Study Group B 'Control'
Case Study Group C 'Secondary'
Need for a solution
Clear definition of 'Project Mission' PRO/1-In
Communicate intention to adopt DES/1-In
Establish single-point Client representative CL/1-In
Cultural acceptance of all parties to actively participate PRO/1-St
No
Select appropriate procurement strategy Pro/1-Pl
Early involvement of the supplier SUP/1-Te
Early cost analysis of innovation within business strategy CL/1-Ct
Contract signed?
Active Client/User involvement into investigations CL/1-Cl
Early meetings with Client to establish requirements for innovation DES/1-CL
Yes
No
Identification and appointment of innovation champion PRO/2-St
Carry out feasibility study?
Ensure Client commitment to the innovation CL/2-In
Risk assessment of design firm's ability to adopt the innovation PRO/2-In
Yes
Supplier to accept insurance liability for the innovation to proceed SUP/2-Pl
Ensure sustainable HR resources are in place DES/2-Hr
No
Operable risk?
Promote 'Project Mission' amongst technical staff DES/2-Cl
Rigorous cost assessment of the innovation CL/2-Ct
Yes
Change-management procedures established PRO/2-Ti
Comprehensive research procedures established Des/2-Te
Implementation of strategic assessment of the innovation amongst project team DES/3-Te
Development of project programme and risk control procedures PRO/3-Ti
Communication procedures established for design information transfer Pro/3-In
No
Design monitoring?
Approved by Client?
Sustained supplier input into the innovation SUP/3-In
Yes
Continuous feedback on development of the innovation CL/3-Te
Yes
Rigorous technical research undertaken into the innovation DES/3-Te
Design validation established DES/3-Hr
Early liaison with statutory regulation bodies Ex/4-Te

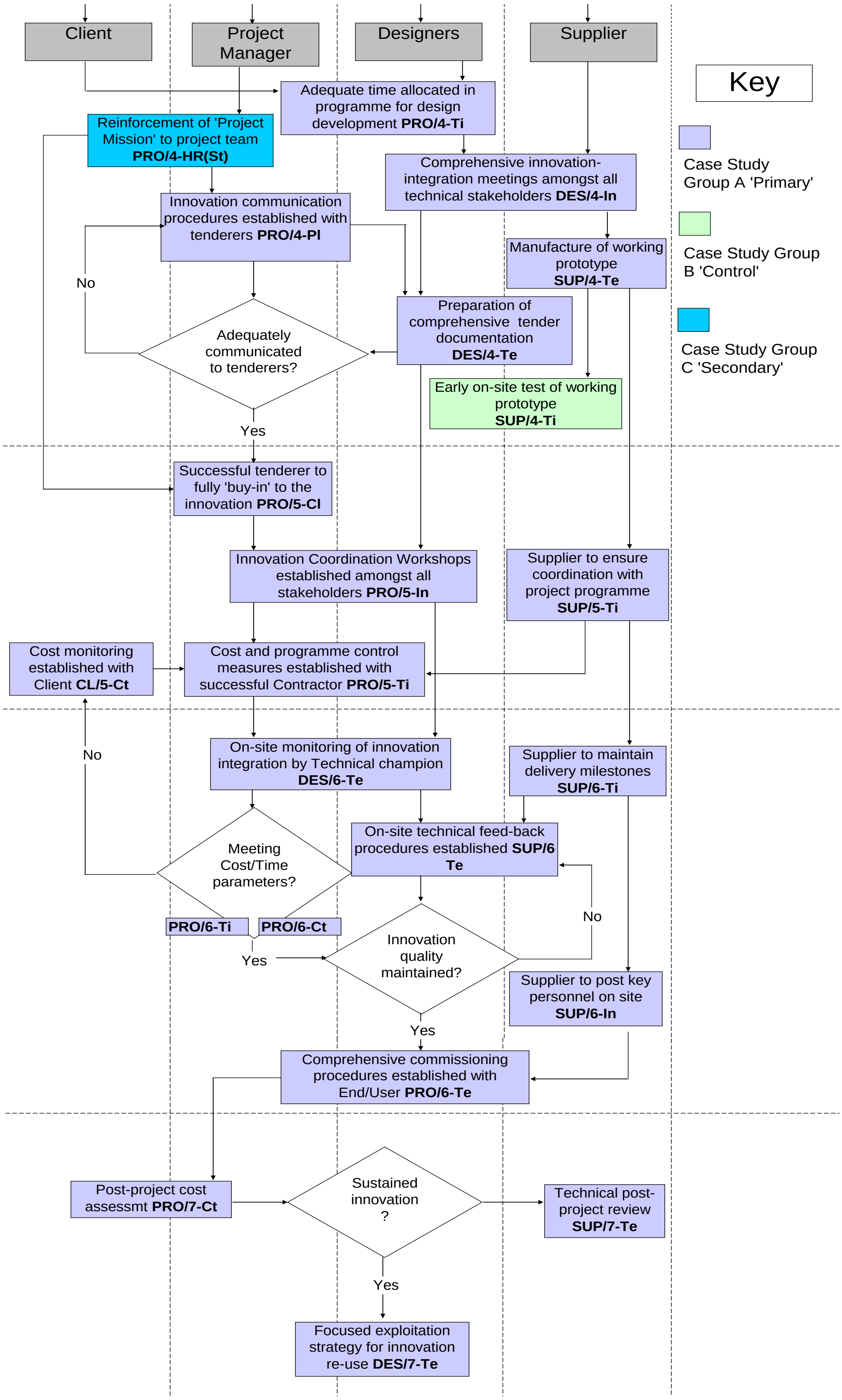


Figure 1: Innovation Management Flowchart

However, it was not possible from the IMF to determine which tasks were more critical to the success of an innovation than another. The disproportionate emphasis on one particular management response at any stage may adversely impact the success of an innovation. It was proposed that the tasks identified in the workflow process needed to be weighted relative to their importance in the workflow process and to map this back to the relevant stakeholder implicit in its management. To do this a form of matrix modelling was introduced as part of the Perceptual Mapping process.

3.5. Constraint Classification Matrix

A matrix is more often associated with concepts of linear algebra and mathematical theory. It is a tri-variable communication tool in which there is an X and Y variable and where the two variables intersect there is a third variable i.e.: Z. This third variable is more often an empirical value which quantifies the relationship between the intersecting X and Y variables.

In this study a matrix was formulated in which the X Axis represented the Stakeholders and the Stages of Procurement at which they were active and the Y Axis represented the competencies of those stakeholders implicit in the management of the innovation. The Z variable represented the RPN of the constraint encountered by that stakeholder at that stage. To graphically represent the intersecting data the RPN values were displayed in the form of a bubble marker. Bubble Graphs are a form of Perceptual Mapping and provide a 3-way representation of data so that three sets of values can be compared graphically. The size of the bubble marker was scaled proportionately to the constraint risk and colour coded thus: Low constraint risk (green); Medium constraint risk (blue); High constraint risk (orange); Severe constraint risk (red). The resultant Constraint Classification Matrix (CCM) is a collective series of bubble graphs which represent the empirical constraint data across all the procurement stages and the implicit stakeholder competencies (Fig. 2).

4. CONCLUSIONS

The study established a methodology for the analysis and modelling of innovation constraints extracted from 30 construction projects and their stakeholder responses. FMEA was used to identify the criticality of constraints and Perceptual Mapping techniques were used to manipulate the data and formulate a structured workflow process.

The study was based on the hypothesis that successful innovation in projects is largely determined by effective stakeholder management and effective stakeholder management is determined by having the right stakeholder competencies in place at the appropriate procurement stage in the project process.

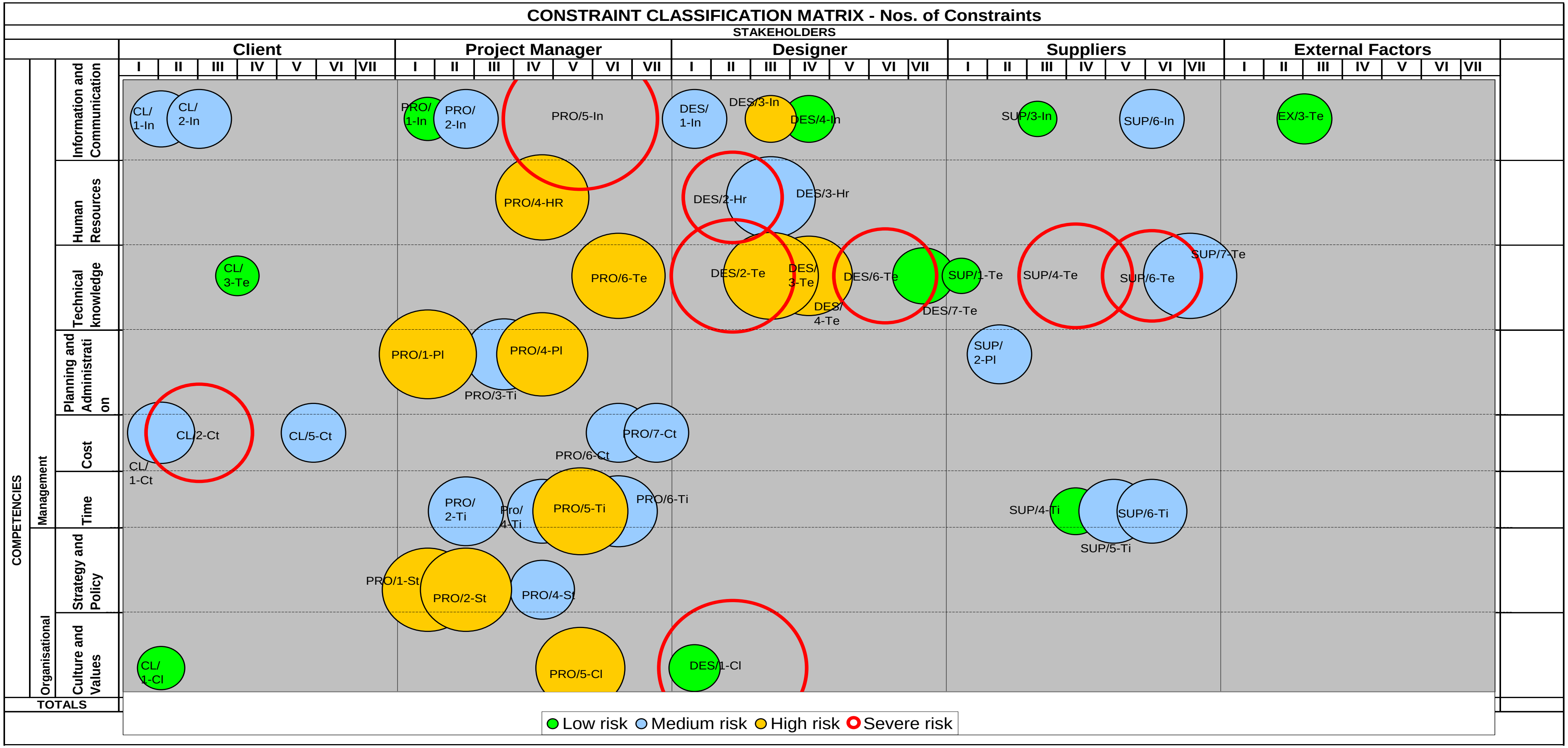
From the overall study of innovation from 30 case studies of construction projects a total of 131 constraints were identified. The primary constraints evidenced were: (1) Inappropriate culture and context; (2) Poor communication between project participants; (3) Lack of technical competency of innovation champion. Whilst these constraints have been variously confirmed in previous literature, this study ranked their criticality, using FMEA, against the project procurement stages in which they occurred and identified the failure in stakeholder competency which generated the constraint.

The study used Perceptual Mapping techniques to manipulate this constraint data and generated two inter-related study outputs; the Innovation Management Flowchart (IMF) and the Constraint Classification Matrix (CCM). The IMF established a systematic workflow process for the successful management of an innovation and the CCM established the appropriate stakeholder competencies required during the process.

Previous research into construction innovation had focused on the use of established project management techniques to manage innovation (Slaughter, 2000; Bossink, 2004; Winch, 2010). This study identified that a stakeholder-centred approach is required where successful innovation delivery is incumbent on the right stakeholder competencies being in place at the appropriate stage of the procurement process. It was evidenced that stakeholder competencies which successfully addressed issues of cultural context, team communication and technical competency in adopting an innovation were most likely to succeed. Furthermore, it evidenced that stakeholder responses to failing innovation were often employed belatedly *in response to* increased constraint activity rather than *as a means to* prevent constraints occurring. This validated the hypothesis that it is not innovation constraints which require management but rather the failures in stakeholder competencies.

Previous literature had documented constraints which act upon the project process but had failed to adequately quantify differing risk weightings. This study identified that prioritisation of constraints was critical to a study on construction innovation particularly where there were numerous stakeholders within the project process. The design risk assessment tool, Failure Mode and Effect Analysis was used to identify and evaluate a risk weighting for each constraint. The benefit of this study is an analysis methodology which can be used by Project Managers in construction projects to profile constraint risk in adoptive innovations and inform a stakeholder competency-based risk management strategy for their projects.

Figure 2: Constraint Classification Matrix



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