EXPLORATION OF THE SYNERGIES BETWEEN ACTIVITY THEORY AND THE DMAIC METHOD IN EVALUATING CONSTRUCTION PROCESSES

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Since Taylor advocated the analysis of workflows as a means to improving efficiency and productivity, construction processes have been evaluated using quantitative improvement techniques such as value engineering and Six Sigma. These methods don't account for the effect of stakeholder influences and impacts. In a people-centric sector, such as construction, stakeholder influences may sustain problems in spite of technical improvements. The purpose of this paper is to (1) assess the approaches used for process improvement in evaluating construction problems and (2) determine the potential for combining quantitative and qualitative methods of investigation to extract more precise insights as to the cause of a problem. A case study was investigated using a 2-stage methodology comprising (a) a DMAIC analysis of an identified problem to determine a quantitative solution and (b) Activity Theory analysis to determine the impact of project stakeholders on the problem. It was identified that whilst DMAIC generated technical improvements, Activity Theory analysis identified the underlying root causes of the process failure through qualitative analysis namely lack of professional knowledge, culture and previous experience. The dual-method approach shows how quantitative factors combined with qualitative analysis can provide a cross check to ensure robustness of findings in producing sustainable project outcomes.

Keywords: Activity Theory, DMAIC, worker activity, methodology, process improvement

INTRODUCTION

In an attempt to improve project productivity the construction industry has explored sectors such as manufacturing to examine the effectiveness of adopting improvement tools such as Just in Time, Lean Manufacturing, and Six Sigma (Stewart and Spencer, 2006; Büyüközkan and Öztürkcan, 2010). However increasing evidence has shown that such methods are failing to produce the long-term sustainable benefits required in construction (De Mast and Lokkerbol, 2012; Sin *et al*., 2015). Furthermore, it is suggested that this inefficiency lies in the failure to effectively recognise and make allowance for the influence and impact of project stakeholders when investigating process problems (Stewart and Spencer, 2006; Sunder, 2016). This paper seeks to assess the nature of a quantitative improvement approach, such as Six Sigma, to investigate a construction process problem and the potential value of combining such an approach with stakeholder-focused qualitative analysis, namely Activity Theory, in

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Murphy, M (2016) Exploration of the Synergies between Activity Theory and the DMAIC Method in Evaluating Construction Processes. *In*: P W Chan and C J Neilson (Eds.) *Proceedings of the 32nd Annual ARCOM Conference,* 5-7 September 2016, Manchester, UK, Association of Researchers in Construction Management, Vol 2, 1039-1048.

order to determine more holistic improvements. It is proposed that such a dual-method approach can provide a cross check to ensure robustness of findings in producing sustainable project outcomes.

DMAIC is an acknowledged and respected approach to problem solving from the field of engineering whilst AT has similar deference paid to it from the field of educational psychology. The trans-industry adoption of techniques and theories across seemingly disparate sectors is not uncommon (Tatum, 1987; Pries and Janszen, 1995). However historically there has been more resistance to this from the construction sector than other sectors (Bowley, 1960). The purpose of this paper is to (1) assess the approaches used for process improvement in evaluating construction problems and (2) determine the potential for combining quantitative and qualitative methods of investigation to extract more precise insights as to the cause of a problem.

LITERATURE

One of the earliest theorists of process improvement was Frederick Winslow Taylor. Taylor's work initiated the Scientific Management movement to show how work was performed within his steel company and the impact that it had on work productivity (Taylor, 1914). Taylor hypothesised that making people work as hard as they could was not as efficient as optimising the way the work was done. He proposed that by optimising and simplifying jobs, productivity would increase. In essence, Taylorism breaks down tasks from a large process into more management steps. However, Taylor separated the capability to do 'manual' work from the competence of the workers to undertake 'mental' work to inform or improve their work. In this respect scientific management in its purist form focuses on the mechanics of a process and fails to recognise the potential value or 'mental' contribution of the people implicit in the process.

Modern management practices have sought to incorporate workers ideas, experience and knowledge into practice in order to understand what motivates and drives individuals to perform a task more efficiently and thus improve performance (Mayo, 1924; Maslow, 1943; Herzberg, 1968). Whilst such theories had beneficial impacts for workers experience and workplace conditions they were subject to ongoing criticism that their impact on profit generation was minimal; profit generation being the primary driver of Taylor's original studies. Later studies by Womack on the Japanese car industry in the 1980's proposed that a strategy of optimising flow, minimising waste and continuous improvement can be achieved in conjunction with workers 'mental' involvement and advancement (Womack *et al*., 1990). This promoted a plethora of industry reports which stimulated the widespread and uncritical adoption of manufacturing techniques into the construction industry (Egan, 1998; Latham, 1994). Whilst this approach was challenged (Winch, 2003) there still sustains the notion that systematic and quantitative analysis is the optimum approach to evaluating construction problems (Dainty, 2008).

Seymour questioned the perceived traditional dominance of the rationalist position to investigating construction (Seymour *et al*., 1997). Seymour suggested an overreliance on the scientific theorising, associated with quantitative methods, had developed within the field of construction to the detriment of more interpretive approaches. A key element of Seymour's argument was that the 'object' of most construction management research is people and hence investigatory methods should be aimed at understanding the social structure and patterns of interaction between those working within, and affected by, the built environment.

Dainty investigated the extent to which construction is investigated using alternative research paradigms (Dainty, 2008). He found that the research community has largely continued to adopt a rationalist paradigm in evaluating construction and suggested that no single methodology can provide a holistic picture of industry practice. Also that mixing paradigms advances the research community towards a "more balanced methodological outlook" to understand the industry's complex nature which informs its process problems. The use of both qualitative and quantitative methods constitutes a valid approach either separately or combined (Knight and Ruddock, 2008).

More recently, studies have exhibited an increasing tendency to address these concerns. Leicht explored the use of observational studies as a valid and insightful approach to investigate the process (Leicht *et al*., 2009). Hartmann and Bresnen cite a lack of multiple perspectives on the concept of partnering in construction projects (Hartmann and Bresnen, 2011). They examined collaborative practice from an Activity Theory perspective in order to extract deeper insights into the evolution of partnering relationships. In adopting an Activity Theory approach, Hartmann and Bresnen confirmed Dainty's earlier concerns regarding the importance of reflexivity in the execution of a qualitative approach, more specifically, in evaluating behavioural patterns and identifying accurate sources of divergent perceptions and meanings (Hartmann and Bresnen, 2011). Gluch and Räisänen have used Activity Theory to examine the problems between project practice and environmental management. They focused on tensions that occur between human agents and material objects within a complex Activity System, namely that of managing environmental issues in projects (Gluch and Räisänen, 2012). Similarly, Fetais (2010) applied Activity Theory to investigate the interactions of people and project management systems at the conceptual cost estimate stage of the construction procurement process. He argued that in management research new insights require creative yet academically robust approaches that address multiple dimensions and perspectives of the complex and often ambiguous socio-cultural contexts situations they seek to analyse.

Six Sigma is defined by Linderman *et al*., (2003) as an organized and systematic method for strategic process improvement. It is delivered by means of the DMAIC process (Su and Chou, 2008). DMAIC is an acronym for five interconnected phases: Define, Measure, Analyse, Improve, and Control and is a process of continuous improvement through these five phases (Linderman *et al*., 2006; Pande and Holpp, 2002; Schroeder *et al*., 2008; Kumar and Sharma, 2012). It is a systematic and evidence based approach which uses a set of tools to provide a framework of results.

Activity Theory (AT)

Activity Theory (AT) is a qualitative observational approach to determine how an action of an individual or group is embedded in a context of collective practice (Kaptelinin and Nardi, 1997). According to Redmiles (2002), AT offers a means of examining a phenomenon through deconstruction and analysis of the relationships. It encompasses, relationships of objectives, communities, rules and division of labour. The underlying principles of AT are: hierarchical structure of activity, object-orientedness, mediation, continuous development and distinction between internal and external activities. The core element of AT is the Activity System (AS); a collective human construction that cannot be reduced to discrete individual actions (Engeström *et al*., 1999). The basic model of an Activity System is shown in Figure 1.

In explaining the AS the term 'subject' describes the person or people carrying out the activity. Activities are directed towards an 'object-oriented' goal. Achievement of

goals ('objects') is mediated by 'artefacts' which together with human beings make up the socio-cultural matrix. Artefacts can be both mental and physical such as software or lack of understanding. The same artefact can be used in different ways, depending on the rules for using it, rules which can be influenced by the community in the Activity System. Additionally boundary objects are information, such as specimens, field notes, and maps, used in different ways by different communities (Star, 1989). Boundary objects exist at the point where knowledge domains meet which makes it possible to explore differences in language that can facilitate knowledge sharing.

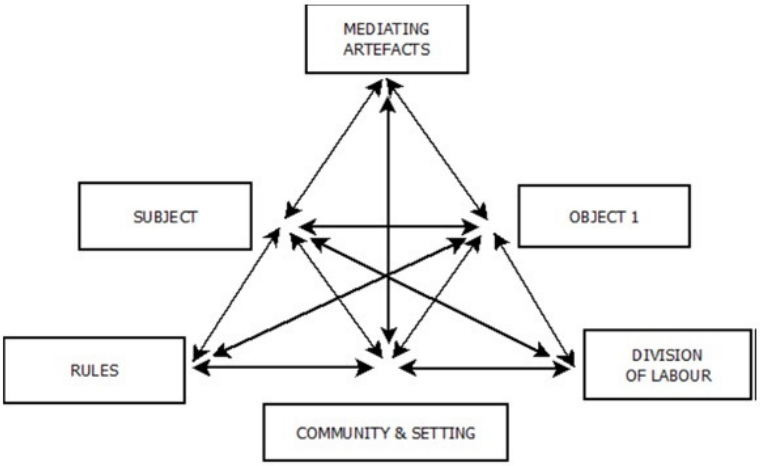

Fig 1 Activity Theory: The Activity System. Source: Adopted from Engeström, 1999)

'Rules' can be both explicit and implicit to ensure the project is carried out correctly. Different 'communities and settings' may apply different rules to the same tools. This also illustrates the 'division of labour', the way in which authority, tasks and benefits are allocated among participants, also influences the activity and subsequent Activity System. In a project delay situation, there will have been disturbances to the system in the past, perhaps in the division of labour (such as a change of project manager) or the tools (different submission techniques or software programmes) which will have resulted in changes to the structure of the Activity System. The output from one typically becomes the input to another system or combines with one or more to generate further Activity Systems or a Chain of Activity Systems. Any disturbance in one Activity will have an impact on adjacent Activity Systems in the Chain.

METHOD

A case study was identified which had a documented problem relating to its Reviewable Design Data (RDD) process which required resolution. It was initially determined to resolve the problem using DMAIC however following consultation with the project stakeholders it was agreed to pilot the dual-method approach of investigation to address the problem. The case study was a large multi-build PPP (Public Private Partnership) project for an Education Authority in the UK. The project involved the design and build of 11 schools in Scotland to meet government targets for the education provision in the Scottish Borders area. The total value of the works was £180 million with duration of 114 weeks. As part of the D&B contract an RDD process was programmed into the main works programme.

Reviewable Design Data (RDD) process is the iterative process of review and sign-off by a client of contractor-designed work packages in a D&B (Design and Build)

project towards final approval of the completed design. The work packages include design data which could not be fixed during the initial tender stage.

In the RDD process a design proposal is presented by the D&B Contractor to the Client at staged intervals during the project, and the Client is required to either reject or issue notices granting approval to proceed either with or without comments within a contractually defined timescale. It is implicit on the Contractor to ensure that there is a clear audit trail of comments and responses and that any additional stakeholder required to provide an input, such as an FM contractor, is included within the approvals process. The result is an interactive process of ever decreasing concerns or queries towards an agreed design solution.

The RDD process as a case study is an optimum investigatory tool for this study for two reasons. Firstly it facilitates application of the DMAIC technique of investigation by virtue of its sequential nature and fixed durations and secondly it lends itself to Activity Theory approach in having a cross-section of diverse stakeholders with traditionally adversarial attitudes with potentially polarising viewpoints.

DATA COLLECTION AND ANALYSIS

The investigation was undertaken using the DMAIC phases as a framework. Three teams were formed namely the Contractor, Client and Designers and each team was appointed a person trained in the DMAIC technique and each team was inducted in the AT protocol for data collection which involved iterative series of interviews combined with document collection and analysis.

Phase 1 - Definition

The first phase on DMAIC required the definition of the problem. A Process Map of the 'current state' of the problem was developed and a Pareto Analysis undertaken. This showed that there were increasingly unsustainable delays being caused to the overall project programme due to the requirement to resubmit iterations of work packages to achieve Status A to close out the RDD process.

The Pareto analysis evidenced that'Inadequate information provided' was evidenced as the primary reason which produced significant overall effect (20%) on the problem against 11 other factors which had proportionally minimal significant impact.

In conjunction with the DMAIC interventions a series of semi-structured AT interviews were undertaken with key stakeholders. Initial observations identified strongly held professional allegiances amongst participants which evidenced in a reluctance to fully engage in a procurement method i.e. Design and Build, which, it was perceived, challenged their professional positions in the industry. Such reticence is considered to be a constraint in the DMAIC method and is considered an obstacle to be overcome whereas in AT such allegiances are considered 'contradictions' and are considered valuable determinants to understand an individual's actions. This understanding is key in developing concise and holistic improvements for construction process problems.

Phase 2 - Measurement

Using DMAIC Value Stream mapping was carried out to analyse the current state and a Fishbone diagram was developed to categorise the potential causes of the problem in order to identify the root causes. Results revealed that the problem was two-fold. Firstly, the Client was required to return the approved design data through various iterations within the allocated 2 week period. However the Client was providing a

status decision of B or C by the end of the agreed period which then triggered an additional period of internal review before re-submission for another 2 week period. This was making the RDD process a possible 6 week process with no assurance that a Status A. Whilst the Client was within their contractual rights to extend the review period it was becoming increasingly problematic for the Contractor to maintain project programme and additionally was becoming a drain on administrative and human resources.

As part of the AT approach, a second iteration of structured interviews was undertaken to allow participants the opportunity to respond to the results of the root cause analysis according to their role and experience (Fellows and Liu, 2015). Participants were asked about their involvement in the RDD process, methods and software used, involvement of other people in related activities, experience of problems caused by the process, their own skills, knowledge and experience and their ideas for improvement. The interviews were recorded and transcribed.

Phase 3 - Analysis

Data from the DMAIC method was evaluated by reductive analysis using Failure Mode and Effect Analysis (FMEA). Qualitative cross-factor analysis from the AT interviews was undertaken and results were correlated using SPSS techniques. The resultant Activity System is shown in Figure 2.

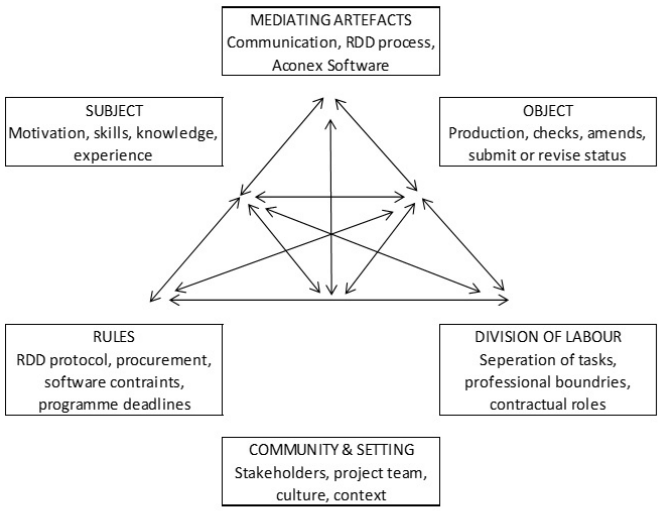

Fig 2. Resultant activity system

Phase 4 - Improvement

Results showed that a significant risk to the process was caused by an overreliance on electronic communication to manage discussions about the RDD submissions. The key improvement identified using DMAIC was the scheduled use of face-to-face meetings prior to and during submissions. This would be monitored and controlled using an RDD Tracker; an electronic tracking system managed by the Contractor's Design Manager. However in AT, improvements are defined as continuous learning through negotiation of knowledge. Negotiated knowledge is knowledge created through a process of negotiating meaning while expertise is being shared. Whilst a practical solution is developed using DMAIC this is sustained by opening up the channels of communication through an on-going conversation and sharing of knowledge experiences and expertise. For example, one stakeholder will communicate their evaluation of the risk whilst another will moderate his suspicions

in line with these 'negotiations'. In this way, knowledge is constructed collaboratively and solutions are sustained.

Phase 5 - Control

As a result of the DMAIC outcomes, training, benchmarking and tracking was established in the project to facilitate opportunities for face-to-face communication. AT outcomes was the generation of 'conversations' or discussions within a culture of continuous improvement. This was facilitated through the newly established communication routes resulting from the DMAIC improvements.

FINDINGS AND CONCLUSIONS

Prior observations suggest that both DMAIC and AT methods are significantly opposing in their approach and outputs. DMAIC is quantitative method providing concise findings derived from a series of proven tools whilst AT is a qualitative approach facilitating a forum for representation of opinions from a range of sources. Theoretically both methods are not seemingly conducive to alignment however it is proposed that there is potential in combining these methods, or similar, to extract more precise insights as to the holistic causes of construction problems.

DMAIC operates through a sequential set of stages which examined the problem through reductive analysis. Its purpose was to strip away anomalies to produce a singular action for implementation. The DMAIC analysis revealed an increased risk to the process caused by an overreliance on electronic communication to manage discussions around the RDD submissions. AT examined the problem through deconstructive analysis of relationships through the subjective engagement with boundary objects and mediating artefacts. In this study the project used ACONEX, a powerful project management software (boundary object) which had been used previously by the contractor but was new to the other stakeholders. This could potentially have been used as a mediating artefact across stakeholders. However, the lack of experience of stakeholders in the use of the software compromised knowledge management. This adversely impacted the communication process which failed to be addressed timely by the contractor. Activity Theory seeks to understand a problem by determining the context through evaluating individual responses. The interviews showed that participants understood the problem under investigation but sought acknowledgement of their differences before being coerced into effecting systematic improvements.

Constraints identified using the DMAIC method were considered obstacles to be overcome whereas these were termed ‘contradictions’ within the AT system and were considered valuable determinants to understanding an individual’s actions. This was borne out in the observation that whilst DMAIC occurs through the generation of solutions AT learning occurs through negotiation of knowledge. Negotiated knowledge is knowledge created through a process of negotiating meaning whilst sharing knowledge. In this study when construction professionals discussed risks encountered in similar projects, one highlighted contractual risks and the other emphasised technical risks, then both individuals considered how these might apply to this project and both revised their knowledge accordingly. In order to reach agreement about a problem, stakeholders needed to share information about their experience and views so that they could share understanding and hence knowledge through a process of argument, listening to, and then challenging, each other’s

viewpoints. One stakeholder looked at risks differently, whilst the other moderated his suspicions. In this way, knowledge was constructed collaboratively.

Culture and context is vital to determining the sustainability of a solution. In a complex human network such as construction it is imperative to be cognisant of the impacts of external influences on a construction process. In this study AT showed that the D&B procurement structure was problematic for the architect. It promoted an enforced separation from the client which impacted attitudes and placed blame on the contractor as the intermediary party and hence actions i.e. the submission of incomplete drawing packages. This was also compounded by contractor failure to proactively engage with the problem well as the client's lack of knowledge which exhibited itself as uncertainty. This may also have its cultural roots in the historical separation of the professional bodies and trade representatives of the respective stakeholders.

In summary both methods reached the same conclusions i.e. the need for increased face-to-face collaboration within a context and culture of increased understanding. The difference being that whilst DMAIC facilitated the findings in practical outcomes AT exposed the rationale and drivers for these improvements. This form of improvement sustains as long as the impetus is present to drive it namely the key stakeholders. It is imprecise to assume that one approach can fully determine the final solution to a construction problem. However whilst this study represents initial investigation of this the hypothesis it suggests that there is potential to undertaking dual-method analysis to examine construction process problems. It is proposed that further research is required to extend the study findings and include a range of construction processes and input from diverse stakeholders.

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