Benefits and Challenges of Implementing Six Sigma "As a Process Improvement Management Strategy"

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Abstract

Six sigma has long been deemed a quality initiative in the construction industry. There exists a limited use of six sigma within the UK construction industry and there are many reasons for this. Primarily there seems to be a misconception about the capabilities of six sigma in construction-specific context. Very little research has been done for six-sigma as a process improvement initiative for construction. Therefore, in this dissertation, the capability of six sigma to be used as a process improvement management strategy within the UK construction industry is explored in order to better propagate this method and increase its use within the industry. The current stance of six sigma within construction context is explored, drawing out the benefits and challenges of using its principles, further explaining why the UK's construction industry lacks its application. After a detailed literature review, two case studies are presented of UK construction projects and companies which used six sigma to enhance process performance. The case studies were critically analysed to draw out the benefits and the challenges experienced in order to finally provide recommendations which will encourage the industry, whether in research or in practice to further make use of six sigma as a process performance enhancer.

Keywords
UK, Six Sigma, Case studies, Construction Industry

1. Introduction

The construction industry is one of the most influential industries within the United Kingdom's economy. Statistics reveal that the industry contributes more than £100 billion pounds of revenue per annum, approximately 6-7% of the UK's GDP and outputs an average of £6 billion pounds to global construction (Rhodes 2015). The growth of the UK's economy is therefore highly dependent on the health of the construction industry. Efficient construction and effective project management is a major driver for the success, development and growth of the construction industry. Efficient productivity in the construction industry, as defined by Yilmaz (2012), includes a consumer satisfying, sustainable and waste-free final product. Although research and case studies over decades have shown some improvement, achieving this has been a challenge for the construction industry for decades. The construction industry is known to have a major impact on and provides the infrastructure of many other industries. Therefore, any step forward in the construction industry results in a step forward in the associated businesses and industries depending on it. For decades, and as mentioned before, inefficient handling of resources, pragmatic approaches to construction management and lack of systematic quality improvement methodologies specific to construction have continuously caused significant waste of all kinds within the UK's construction industry. Siddiqui et al. (2016) further emphasize that the significant amount of material and human resource wastage within the nature of construction projects has lasted forever solely as a result of insufficient, inefficient and, in many cases, non-existent application of quality and process improvement management procedures. For decades, increasing numbers of construction managers, academics and professionals have been 'storming the ramparts' (Yilmaz 2012) of conventional and traditional construction management methodologies in attempts to construct at a better value of money to owners while simultaneously maintaining profit and customer satisfaction. Countless research efforts in construction management strategies have resulted in many propositions such as just-in-time, lean construction, pull scheduling etc., some more successful than others. Most recently, one specific improvement strategy still undergoing research and relatively still in the concept phase is the integration of Six Sigma Principles as a quality initiative management strategy. Six Sigma-based tools have emerged and have recently been applied to construction projects of varying complexities and sizes successfully. As a general summary of what available literature provides on the benefits of Six Sigma in construction, real case studies show that projects implementing six sigma principles tend to be easier to manage, safer, more sustainable, cost less and most importantly, are of better quality. Research studies tend to focus on six sigma as a quality improvement strategy/methodology. Furthermore, most available literature fails to attract the interest of organisations within the UK's construction industry, i.e. little has been done to effectively 'advertise' the benefits of implementing six sigma principles from an organisational perspective. More efficient propagation is needed to allow for the increase in awareness to the effectiveness of six sigma and to enable construction firms to implement the methodology's principles willingly without worrying about potential risks that come with it. From the perspective of a construction firm, survival in the industry and the potential to grow is not solely based on consumer satisfaction and quality of product delivery, it is actually more important to maintain project process performance and profitability (Ibn-Homaid et al. 2016).

2. Literature Review

2.1. History of Six Sigma

Six sigma was initially ignited by Motorola in 1998 as a six step quality improvement technique and has recently evolved to become a game-changing quality management methodology. Some early research has defined the phenomenon as a business strategy with the goal of enhancing customer satisfaction, increasing productivity and, hence, overall performance of the organisation (Kwak and Anbari 2006). As history records, six sigma can be traced all the way back to Carl Friedrich Gauss in 1809 where the phenomenon of the normal curve was initiated. More than a century later, in the early 1930s, Walter Shewhart proved that "three sigma" from any mean defines a point where a process or processes requires rectification. As mentioned before, by 1998 Motorola was using six sigma as a quality initiative business strategy to change the culture of the business in order to enable higher quality output, expansion of employee's skills and reduce errors and anomalies in work processes (Sandholm and Sorqvist 2002). Six sigma was also used in and is currently still being used in the American, multinational electronic provider corporation, General Electric. Six-sigma executioners can become qualified experts who are specifically trained in applying its principles to multiple disciplines. The eventually become qualified enough to be called six sigma 'black belts'. These experts are knowledgeable to the use of "measurement analysis, analysis of variance, supply chain management and many more" (Stewart and Spencer 2006).

2.2. Statistical Theory Behind Six Sigma

The symmetrical bell shaped normal distribution curve, derived by mathematician Carl Friedrich Gauss is what six sigma is based on. The curve represents the component at measure (product, process etc.), or in statistical terms, represents the whole population by the "infinite series of segments in both directions" (Tehrani 2013). The inflexion point in the curve marks the mean (μ) of the population and each segment is called sigma and represents a deviation from the mean (Tehrani 2013). Although the graph continues to infinity on both sides, usual representations of this graph only show the area between -3σ and +3σ because it covers 99.73% of the data. On the other hand, using 6σ is much more effective as it covers 99.9997% data meaning only 0.0003% of the data are out of range (Goh 2002). Figure 1 shows that with 3σ being customer specification, there is a 31% probability that customer requirements will not be satisfied with a defect rate of 308,000 defects per million defect opportunities (DPMO) whereas with six sigma this percentage is reduced to 0.00033% with only 3.4 DPMO (see section 2.2 for DPMO).

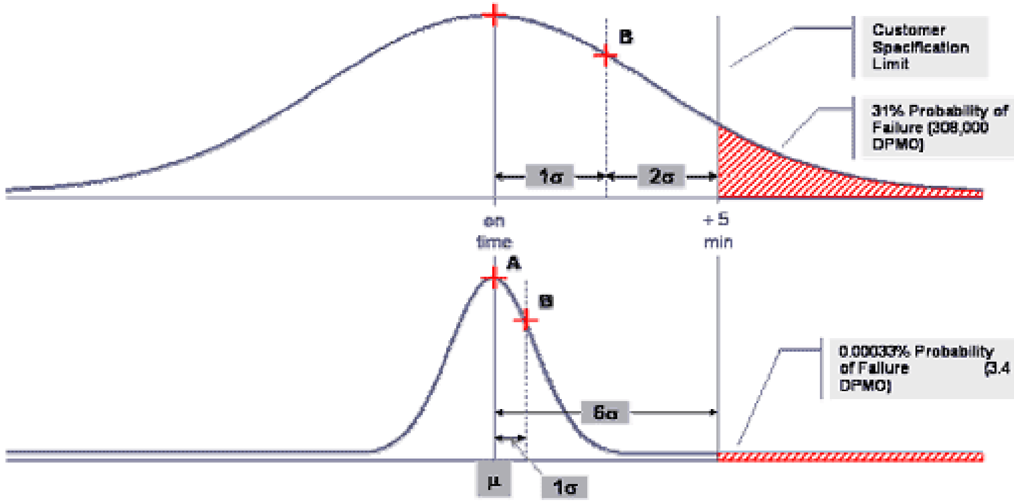

Figure 1. Difference between the use of 3σ and 6σ (Tehrani 2013)

2.3. Six Sigma Principles

Six sigma entitles two different methodologies: Design, Measure, Analyse, Improve, Control (DMAIC) and Design For Six Sigma (DFSS). DMAIC is the most commonly used and is made up of five sequential phases which aim to improve the performance of a current process or a set of processes which are not meeting required specification (Pande, Neumann and Cavanagh 2000). In it's define phase, customer needs, requirements, standards are identified in accordance to the unsatisfactory performance. A few questions are answered in this phase: What is the problem? Who is involved and what are the requirements (Simon 2002). Once the define phase is complete, the measure phase begins and includes measurement of the current performance of the process and the collection of all relevant data for the process. The analyse phase then begins where the root cause of the problem is identified through the creation of cause and effect diagrams. Defects Per Million Opportunities (DPMO) is calculated and the current sigma performance level is revealed

A new target performance level is set and possible solutions are then listed (Yilmaz 2012). In the improve phase, cost/benefit analysis is performed to facilitate a final improvement solution which is then implemented so that the process's performance satisfies the performance requirement (Samman and Graham 2007). The five phase procedure ends in the control phase where the improvement is maintained to ensure the gains in performance remain in the long term (Samman and Graham 2007). As it is popular in the construction industry when adopting six sigma principles, the DMAIC procedure is fully illustrated in detail in section 2.2 below. On a critical note, it is important to note that DMAIC is not used for redesigning a process, it is only to be used to incrementally rectify process performance to meet requirements and/or standards. Unlike DMAIC, DFSS is a method more than a universal methodology and is used for designing and redesigning processes and has no universally acknowledged procedure for implementation (Simon 2002). A logic explanation for this would that nearly every organisation designs and redesigns in a unique way to meet company requirements and follow company policies (Samman and Graham 2007). Alternatively, when deciding to implement DFSS, some companies prefer hiring specialised six sigma consultants to help to redesign a product or service (Kwak and Anbari 2006).

2.4. Six Sigma and the Construction Industry

Six sigma, which is popularly tagged to the manufacturing industry because of its focus on output quality and consumer satisfaction, is becoming an increasingly necessary management methodology for the construction industry. The increase in competition along with the never-ending increase in demand for high quality is reportedly "stressing construction practitioners to think out of the box" (Siddiqui et al. 2016). In light of this, there exists countless research regarding the implementation of six sigma principles within the construction industry. Buggie

(2000), was the first to introduce the six sigma ideology for the construction industry where he proposed that implementing it could allow the organisations within the industry to perform assessments which aid in controlling quality and reduce variability, which are two issues nearly every construction project in the world encounters. Bechtel, one of the largest construction and civil engineering firm in the United States, reported saving eye-watering amounts of money due to the use of a program designed in accordance to six sigma principles which aided in the avoidance of rework, defects and errors from initial design phases to final construction phases (Kwak and Anbari 2006). Linderman et al. (2003) proposes that unlike the manufacturing industry, where six sigma techniques require thoroughness and full adherence to its technicalities in all processes of production, the construction industry needs only to apply six sigma principles where process improvements will see reductions in costs and increased quality. In other words, since the nature of the industry provides for the motive of reducing costs to increase profitability, implementing six sigma principles would be most effective in improving the performance of processes which are cost demanding (Brue 2002; Linderman et al. 2003). Other research observed that in the construction industry, six sigma principles can help reduce wastage in and hence enhance the effectiveness of lean construction (Abdelhamid 2003). In this case, lean construction acts as the standard of work and six sigma plays the role of avoiding and resolving any deviation from this 'lean standard' (Abdelhamid 2003).

2.5. Challenges Implementing Six Sigma in the UK Construction Industry

While it may seem that integrating six sigma principles to construction processes and practices is crucial, research has shown that the UK's construction industry, which comprises thousands of construction enterprises has struggled to effectively adopt its principles. Research has shown that six sigma is: a high investment management initiative which only non SMEs can afford, full-time effort is required and is very resource intensive (Nonthaleerak and Hendry 2008; Sinthavalai 2006). Similarly, Pheng and Hui (2004) concluded, by studying multiple projects within the construction industry of Singapore, that in order for six sigma to be efficiently and successfully implemented in construction, some prerequisites must be satisfied. These included knowledgeable and supportive management, trained specialists in the field of six sigma, the organisational culture to be driven towards quality and customer satisfaction and appropriate employee training in accordance with the six sigma principles to be implemented. While large companies. These perquisites have proven to be problematic to Small and Medium Enterprises (SMEs) in the UK's construction industry who are out there trying to survive and the culture of business is strictly profit driven. Research by Anthony et al. (2005) identified three main reasons why there is a lack of use of six sigma in the construction industry. These reasons were identified as the external environment, six sigma is a quantitative approach to quality management and, most significantly the mode of delivery of construction projects being profit driven (Antony et al. 2005). A study elaborates on this issue by identifying the main reasons why construction SMEs either do not apply six sigma principles or have issues when attempting to implement them. This study performed questionnaires on 30 constructions SMEs in the UK who did not apply six sigma principles in order to identify and rank the main reasons why (Tutesigensi and Pleim 2008). While 30 may seem like a small sample to deem this study reliable, 700 SMEs were originally selected at random from 7967 construction SMEs in the UK. However, only 30 responded to the sent online questionnaires, giving a response rate of approximately 4.28%. Since the questionnaires were sent out online, a 4.28% return rate is normal relative to many other similar studies (Anthony, Kumar and Labib 2007, Banuelas et al. 2006) the results were as follows:

Table 1- Reasons for Not Employing Six Sigma in the UK construction industry (Tutesigensi and Pleim 2008)

Reason	Number of Respondents			
	Great Importance	Some Importance	No Importance	Cannot Say
1. Lack of knowledge of 6σ	12	3	6	9
2. 6σ not required by customers	10	10	1	9
3. Other sufficient quality system in use	10	7	3	10
4. 6σ has no benefits	7	7	4	12
5. Lack of human, time and/or money	2	7	5	16
6. End users don't want pay for	1	-	-	-

Scientists, researchers and project managers have effortlessly attempted to elevate project performance by implementing philosophies such as just-in-time construction, pull scheduling, lean construction etc. (Siddiqui et al. 2016). However, six sigma is relatively low on the knowledge base in comparison with other management approaches. Research has yet to "set definite quantitative goals for performance and process improvement while considering the defect rate involved in the construction operations" (Siddiqui et al. 2016) which is easily attained via the implementation of six sigma principles.

3. Research Method and Data Collection

Primary data is data collected by the researchers themselves and include self-designed interviews, questionnaires, case studies and many more. Secondary data on the other hand is data collected previously by a researcher, organisation, government or any other party which is not involved in the current research. This particular research is aimed at exploring the benefits and challenges of implementing six sigma principles in the UK's construction industry. As this is an exploration study, real life case studies are required on previous construction projects within the UK which used six sigma principles along with previously performed interviews with project managers; this deems the nature of this research to be qualitative. The data collected will aid in the detailed provision of the benefits and challenges of six sigma to the nation's construction industry. Analysing past case studies and interviews will facilitate valid and reliable conclusions and recommendations. In light of this, secondary data was chosen as the most effective way to collect data for this dissertation.

Semi-structured interviews were collected where project managers, site managers, engineer etc. were interviewed from a construction organisation in the UK. These interviews were then analysed against each other to show the extent of knowledge of six sigma and awareness to its benefits and experience with its challenges. The interviews also facilitated the discovery of challenges faced and possible reasons behind the limited use of six sigma within the UK construction industry. Two case studies of construction projects in the UK which implemented six sigma principles were selected based on availability in literature and the six sigma procedures implemented in each case study were presented and analysed to draw out the benefits.

3.1. Case Study 1: Labour Days Lost

This case study, by Samman and Graham (2007) implemented the DMAIC (Define, Measure, Analyse and Control) procedure on a construction organisation within the UK, to reduce the number of working days lost due to work-related injuries. The purpose of the case study was to develop a successful health and safety program for the company through six sigma principles. The organisation was unnamed; however, the data collected consisted of a series of interviews and company health and safety records between the years 2004 and 2006. Data collected between the three years revealed an average of 10 lost workings days per employee per year, amounting to a total of 535 lost days over the three year period (2004, 2005 and 2006). The organization deemed this unsatisfactory and will lead to unnecessary costs and a proposed solution was crucial. As a medium through which to facilitate the discovery of the best appropriate solution, a DMAIC procedure was implemented as follows:

3.1.1. Define

In accordance to the procedure described in section 2.2 the define phase begun by identifying the problem at hand and setting the goals and objectives. In this specific case study, this was done through a project charter which served as a progress report to be constantly updated throughout the next four phases. The goal was set to achieve an amount of lost working days which was 10 times lower than at the start.

3.1.2. Measure

The purpose of this phase was for the organisation to collect all sufficient data and observe current performance and conditions in order to generate a baseline performance to work from. This also facilitated the identification of the cause of the problem. To achieve this, three different tools were used; cause and effect analysis (Figure 4) to aid in the discovery of the root cause(s) of the problem, process capability analysis to locate where and in which process(es) the improvement is needed, and finally time series analysis (Figure 5) was conducted to draw out performance patterns over the three years (2004, 2005 and 2006) for September, December, March and June. According to figure 2, it was observed that the main causes of lost working days were unsafe use of non-motorised equipment, safety policy violations, employee training and experience status and absence of a supervisor at the time of an incident (Samman and Graham 2007).

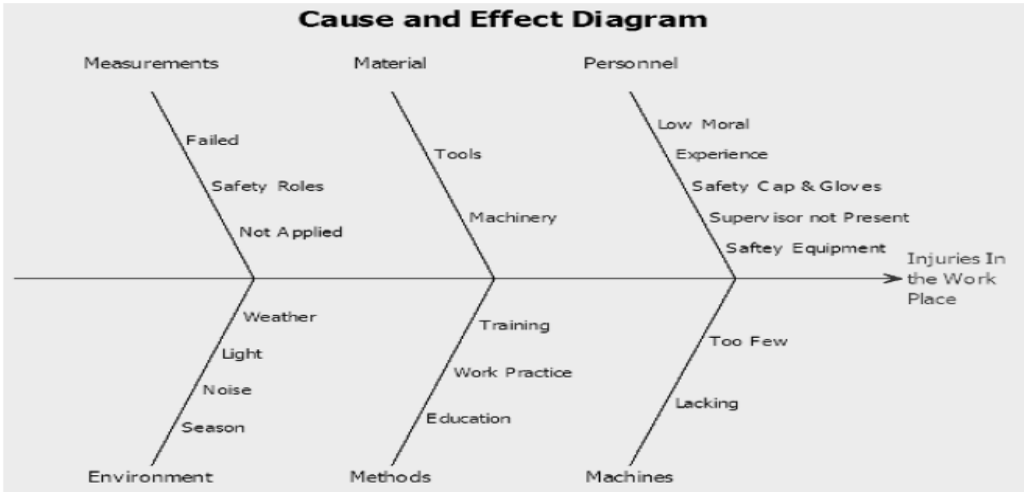

Figure 2. Cause and Effect Analysis for injuries at work place that lead to lost working days (Samman and Graham 2007)

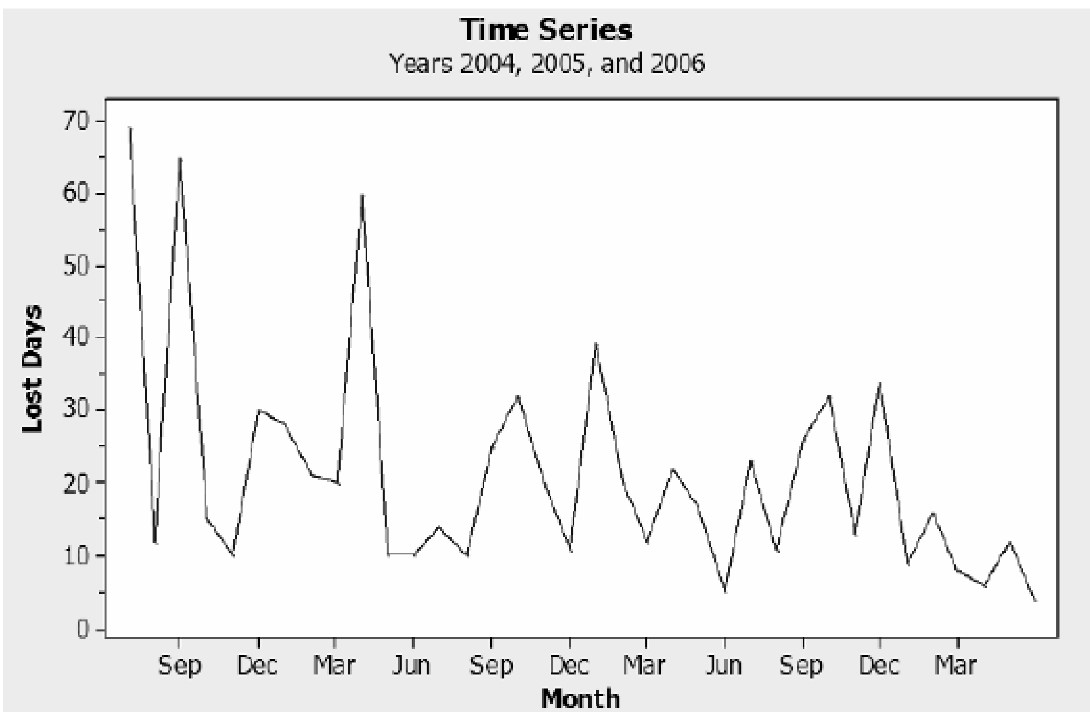

Figure 3. Time Series Chart showing average lost days every month over the a three year period (Samman and Graham 2007)

3.1.3. Analyse

The goal of this phase is to discover alternative solutions and analyse them. To do this, this case study used the Pareto chart (Figure 6), which served as a guideline to know which activities caused most lost days (defects). The Pareto chart revealed that non-motorised equipment was responsible for 165 lost working days, the highest amongst all the other previously identified causes and worker training to be the least at 25 lost days. Additionally, a probability plot was also used to provide a visual overview of the lost days per month and the percentage of occurrence. This chart showed that the collected data on the lost working days over three years was normally distributed.

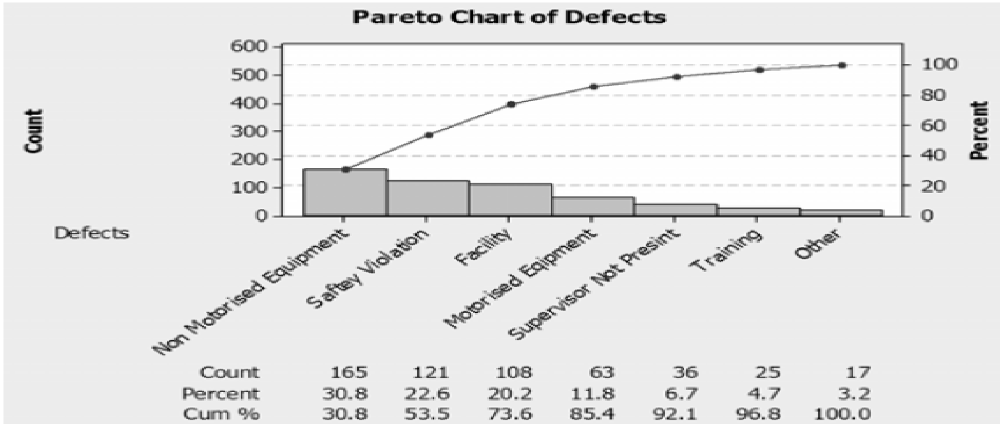

Figure 4. Pareto chart showing ranking of causes of injuries leading to lost working days (Samman and Graham 2007)

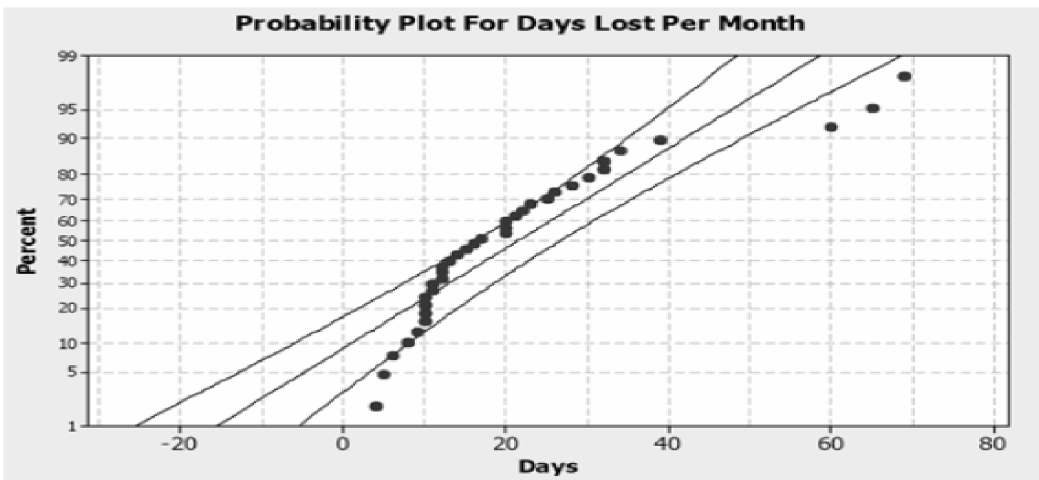

Figure 5. Graph showing distribution of collected data on injuring cause lost working days

The data collected in the measure phase along with the visual representation of data in this phase (Figure 6 and 7) reveal that, as a percentage, the injuries causing lost working days are:

- 30.8% falling from height while using non-motorized equipment (ladders, scaffoldings etc.) inappropriately
- 22.6% from not following safety procedures thoroughly or lack of knowledge of safety rules
- 20.2% from facility, i.e. work location (deep excavations, sharp objects etc.)
- 11.8% from motorized equipment e.g. vehicles, concrete vibrators, man lifts etc.
- 6.7% from a supervisor or project leader not being present at an incident or not enforcing strict adherence to safety rules and regulations
- 4.7 % due to inexperience and low-level training
- 3.2% from other causes such as uneducated labour, employee health and employee awareness.

3.1.4. Improve

The purpose of this phase is to analyse possible solutions and develop a final solution and implement it (see section 2.2 for details). In this case study, the final solution was to provide constant maintenance and monitoring to non-motorised and motorised equipment and place a strict routine inspection program to disallow safety violations and reduce injuries. An addition to the solution was to periodically perform 'safety at work' induction meetings where employees will become more educated and knowledgeable to their surroundings and to the equipment they are using. Analysis of variance of the collected data further revealed a variation of 70.59% where safety violations and non-motorised equipment were responsible for 30.71% and 40.88% of the variation respectively (Samman and Graham 2007). In easier terms, 70.59% of the causes of lost days come from safety violations and the inappropriate use of non-motorised equipment. In light of this, if this 70.59% is rectified, two equations can be derived to calculate the savings incurred with the implementation of this DMAIC procedure:

If 'X' denotes 70.59% of causes of lost working days:

$$X = Number\ Of\ Lost\ Days * Variatio$$

And the savings incurred will be:

$$Savings = Wage\ Per\ Hour * Number\ of\ Working\ Hours\ Per\ Day$$

This means that if the final solution results in a 70.59% decrease in average lost days, 70.59% of the total lost days (535) is 377.7 days ('X') and consequently the savings will then amount to:

$$Savings = Wage\ Per\ Hour * Number\ of\ Working\ Hours\ Per\ Day * 377$$

3.1.5. Control

As described in section 2.2, the main aim of this phase is to maintain any improvements. In this case study, it was done through control charts, flow charts and quality control process charts (Samman and Graham 2007). These charts served the purpose of ensuring that the amount of lost working days does not increase again in the future. Furthermore, all steps carried out in this 5-phase procedure along with improvements which were implemented were documented for the companies' records as a point of reference should the company experience any performance declines in the future.

3.2. Case Study 2: St. Pancras International Station, London

This case study demonstrates the effect of the implementation of a six sigma process improvement protocol on construction activities. This case study was performed in 2006 and was performed for a contract in the United Kingdom. The contract included the construction of a platform extension to the St. Pancras Train Station in London. The organisations involved in this contract were Bechey, Costain O'Rouke and Emcot Rail (Stewart and Spencer 2006). Two decks were included in the construction contracted labelled 'east' and 'west'. This specific case study works on the 'east' part of the construction project. The construction activities involved included; "diversion of underground services (utilities); demolition of existing road and rail infrastructure; construction of piles, pile caps and columns to support the station extension platforms; and construction of beams that will comprise the new station platforms and tracks" (Stewart and Spencer 2006). The main objectives of this case study were to identify the most suitable medium through which to implement six sigma principles on construction projects and to explore and analyse the benefits. To ensure validity of outcomes and effectiveness of implementation, this case study involved a team of 6 members including (six –sigma black belt consultant, foreman, site engineer, design manager, construction coordinator and station extension manager (Stewart and Spencer 2006). As a preliminary stage, all six participants or team members were interviewed with questions regarding the advantages and disadvantages of six sigma in comparison to other total quality management methodologies. Similar to the first case study in section 4.2, the DMAIC procedure was followed and steps taken in each phase were recorded.

3.2.1. Define

The purpose of this process improvement project was to improve the construction of raised beams via the identification of particular construction activities which were causing defects (Stewart and Spencer 2006) which include, for example, late delivery of platform beams. As the construction of beams is obviously not the only construction activity involved in the construction of station platforms, the construction of beams is dependent on a number of other activities which may also hinder its performance. The defined problem and motivation of this case study came from the continuous additional cost incurred due to delays in the completion of the platform beams in this project. The identified costs incurred due to the beam delays were as follows

- The additional cost of equipment and labour needed to accelerate the completion of the beams
- The daily additional cost of keeping the equipment and labour on site beyond the contracted 'planned completion'
- The impact of beam construction delays on other succeeding activities dependant on their completion.
- The contracted £54,000/day penalty for works carrying on passed completion date and delays to opening the station.

A graph was drawn (Figure 8) to illustrate actual vs scheduled performance of beam construction. The graph was drawn when only 32 of the 276 total beams were constructed. Additionally, the researchers behind the study performed a review of past performance which revealed that the contractor was currently able to construct an average of 2.3 beams per week which was lower than the 2.9/week targeted at the contracting stage of this project (Stewart and Spencer 2006). Assuming the performance stayed at 2.3/week, this would incur a time overrun of 8 weeks (Figure 7). Including labour, equipment hire, contracted liquidated damages, and all other cost components, additional costs incurred would have amounted to an eye-watering £3.02 million. In light of this, the aim of this DMAIC procedure was set to reduce the delay by four weeks, effectively saving around £1.5 million.

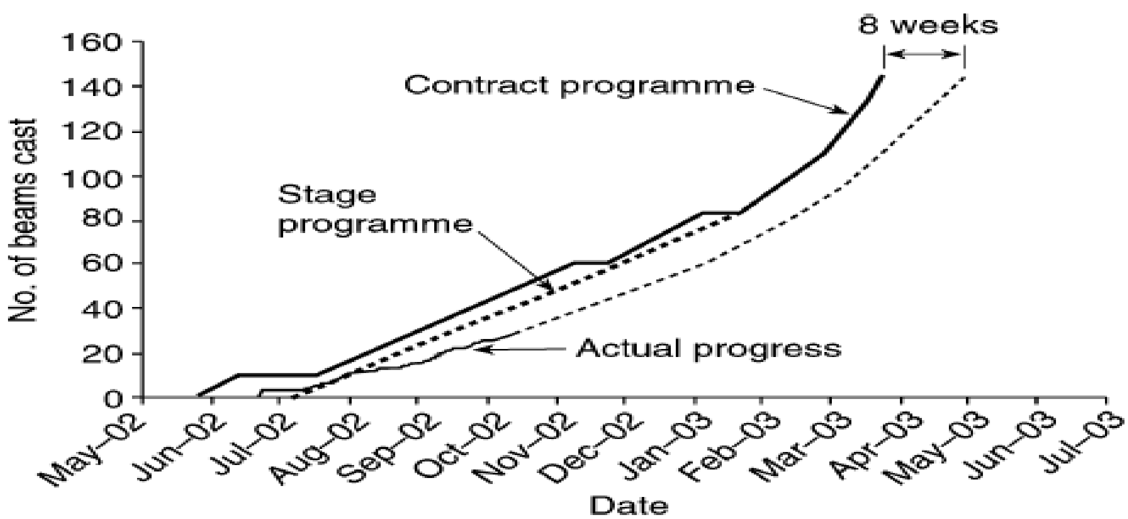

Figure 6. Actual Vs. Scheduled Beam Construction (Stewart and Spencer 2006)

2.3.2. Measure and Analyse

The measure phase was responsible for identifying the potential causes and problem areas behind the delay of beam construction. Similar to the previous case study, a cause and effect analysis was performed whereby the beam construction process was mapped to identify general causes of delay. This revealed that there were some preceding activities which were responsible for some of the delay in constructing the beams (Stewart and Spencer 2006). Furthermore, the cause and effect analysis further showed that the activities which the beam construction's success was depending on were: "site access, utilities and road diversions, demolition, piling, pile caps, and columns" (Stewart and Spencer 2006). Hence, the effective communication and coordination between the teams behind these activities was crucial for on-time delivery of the beams. Numerous events were reported by the contractor whereby miscommunication led to significant delays to beams and preceding activities. The lack of coordination was discovered to be due to the inexistence of a formal handover between the utilities team, demolition and piling team, and the deck team (Stewart and Spencer 2006).
This meant that when work from a specific team was finished, the next team were either not officially notified or a delay in the acknowledgement of activity completion occurred. Although progress reports were published on a weekly basis and given to all project participants, they served more as individual team motivators rather than a medium through which the attainment of common goals is motivated. This meant that, for example, the utilities

team was recognised for successfully excavating to expose water pipes which needed to be diverted for the insertion of the piles instead of being recognised for successfully diverting pipelines with acceptance from the piling team.

2.3.3. Improve

At this stage, three aspects of construction were identified as areas where improvements could see time and cost savings. These aspects were: "pre-beam activities, efficiency of beam construction based on duration and equipment availability (formwork and false work)" (Stewart and Spencer 2006). Pre-beam activities which were causing delay were discovered to be as a result of low coordination between project teams. This was dealt with by creating a coordinated revised programme which assessed productivity based the project as a whole. This minimised the effect of pre-beam activities and hence accelerated the delivery of beams. Furthermore, countless meetings between the six sigma team and the project members emphasized the necessity of maintaining efficient communication between project leaders and labour such that if problems were to arise in the future, they would be rectified efficiently and effectively. As for equipment availability, an analysis produced results which recommended the purchase of additional set of false work and framework to reduce delay by 4 weeks.

2.3.4. Control

It is within the benefit of the contractor to closely monitor performance after improvements have been experienced to prevent roll backs. Similar to the first case study, close supervision, constant reference and adherence to the charts developed in this case study, and training employees to achieve further improvement is key. To ensure this, the six sigma team constantly created performance charts to monitor the construction of the beams, as the project progressed and constantly referred back to the original charts produced in the earlier stages of this DMAIC procedure (Stewart and Spencer 2006). After an unspecified period of time, the six sigma team reported "noticeable" improvements in most of the beam construction activities where the most significant improvement was that there was "less variability in activity durations" (Stewart and Spencer 2006). This meant that more beams were being constructed according to plan, reducing the delay of works. A control/monitoring chart was produced to show this reduction in variability and it shows (Figure 8) visible improvements and the improvement is getting better and better. Figure 8 further shows that the actual progress is now getting closer and closer to the target rate of work, i.e. the target which was set by the contract terms.

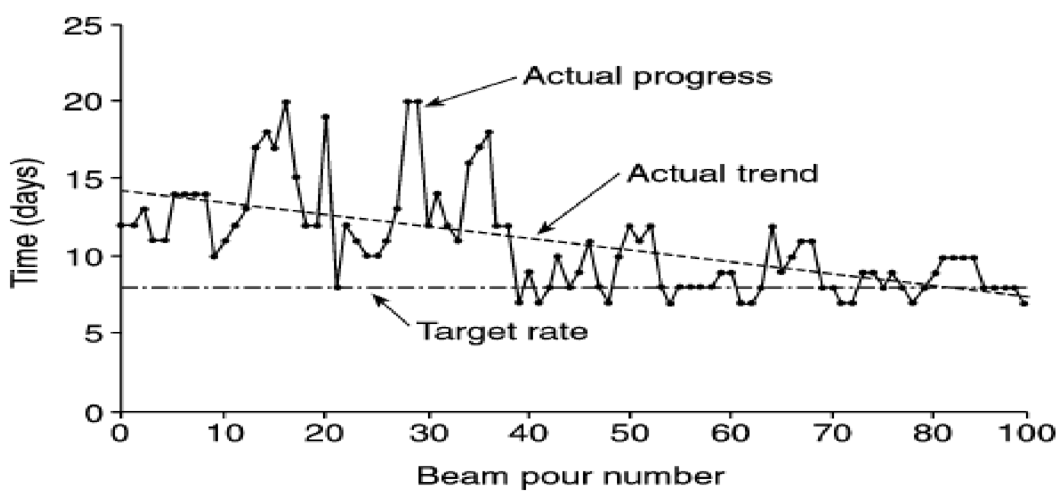

Figure 7. Chart used to monitor and control beam construction improvements

3.3. Interviews

In the previous section, the implementation of a 5-phase DMAIC procedure on the beam construction of St. Pancras Station was successful in rectifying delayed performance by identifying the problems in the process of beam construction. Through the use of various tools to monitor and record performance, the root causes were discovered and acted upon accordingly to deliver on time construction and save eye-watering amounts of money on unnecessary delays. Interestingly, during the measure phase of the DMAIC procedure, the case study found a process within the beam construction process (sub-process) which needed to be rectified before assessing problems with the physical construction of the beams, which was team collaboration and communication. Now, in order to assess the effectiveness of using this six sigma DMAIC procedure, interviews were conducted (N=6) with various project participants (engineers, architects, project manager etc.) on the challenges faced with implementing the DMAIC procedure and general ideas towards the effectiveness of its outcomes and its reliability to improve construction processes.

The results of these interviews revealed that in order to achieve a successful and effective six sigma implementation, some critical success factors (CSFs) must be satisfied. The management needs to be committed, organizational infrastructure to be set in a way which communicates issues and improvements effectively and six sigma to be integrated into the company's business strategy/policies. Initially the interviewees were asked whether six sigma was an efficient process improvement strategy. All participants agreed that six sigma was beneficial to the industry, provided there is a well-designed implementation program which clearly illustrates the processes involved. One person commented "this technique is well structured and lends itself to many processes within construction" (Stewart and Spencer 2006). On a critical note, all interviewees deducted that six sigma is better at improving process efficiency than improving quality in the construction sector which agrees with the earlier work of Linderman et al. (2003) (See section 2.2).

This common view demonstrates a misconception of the definition of quality within construction context. The word 'quality' in construction has been questioned effortlessly in research. Is it aesthetic quality? Is it structural quality? Is it quality of workmanship? Is it a measure of project manager's performance? Or is it a combination of some or all of them? Some research has even defined quality to be based on customer/client requirements. This confusion is most likely responsible for lack of successful, innovative quality initiatives in the construction industry. Six sigma is therefore better perceived as a process improvement strategy which incorporates a better quality output for the construction industry. Coming back to the case study, one interviewee quoted "improved process efficiency [means] less panic [means] better product" (Stewart and Spencer 2006), which further elucidates on this confusion that exists regarding quality.

Table 2- Challenges faced when implementing six sigma principles

Case Study 6σ Challenges (Stewart Spencer 2006)	Agreeing Literature (Pheng and Hui 2004)	Agreeing Literature (Tutesigensi and Pleim 2008)
Employee Ignorance	Employee Education on 6σ	Lack of knowledge about the 6σ programme
Lack of human resources	-	Lack of resources (time, human and money)
Sufficient funding required	-	End users not prepared to pay for 6σ
At least one six sigma trained expert required	Trained specialists in the field of six sigma (black belts) are required.	-
Highly supportive management needed	Supportive management needed	Supportive management needed

4. Conclusion

While there exists a large number of studies addressing six sigma as an effective quality initiative for the construction industry, little has been done to show how six sigma principles can be used as a process improvement initiative. Within the UK, the use of six sigma principles is rare and many companies avoid its use because they are made aware of it in the wrong way, and the knowledge propagated does not suit the needs of a profit hungry industry. Therefore, the main aim of this research was to shed light on the ability of six sigma to improve the performance of construction processes, as a motive to deviate away from most available literature on six sigma within construction context which tends to focus more on six sigma as a quality initiative. This dissertation focuses more on providing the UK's construction organisations with benefits which appeal to the needs of a company. To do this, two real situations where six sigma has been implemented within the UK construction industry have been presented and critically analysed. The first case study presented a six sigma implementation on a process which affected, not only a specific construction project, but the organisation as a whole. The case study realised the amount of labour days being lost due to injuries and accidents on site. After the problem was identified, the DMAIC procedure was followed to collect data on lost working days, propose possible solutions, implement the best solution and control the improvements such that roll backs are avoided. The company involved in the first case study experienced 535 lost working days over a three-year period. Through the 5 step DMAIC procedure, a potential

improvement was suggested whereby lost labour days would be reduced by 377 days. Based on this improvement, formulas were derived to calculate the savings incurred with this significant reduction in lost working days. This case study showed that six sigma can improve organisational process issues, not just physical construction processes. The second case study, saw the implementation of six sigma for the improvement of beam construction process for the St. Pancras International Station in London. Similar to the first case study, the DMAIC procedure was followed and tolls such as Pareto charts, cause and effect diagrams, baseline performance charts and trend charts were used to identify the problem, collect data on current performance, analyse data, propose solutions and implement a final solution to improve the process. Basically, the issue was that beam construction is constantly being delayed and therefor activities which depend upon the completion of the beams are delayed consequently delaying the completion of the project by 8 weeks, which will
cost an additional £3.02 million. The DMAIC procedure resulted to a delay reduction of 4 weeks, effectively enhancing the efficiency of team collaboration, beam construction performance efficiency and saving more than £1.5 million. These 2 case studies showed that six sigma can be effectively used not only to improve physical construction processes, but also enhance organisational processes which may be problematic to the organisation as a whole (lost working days).

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