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Benefits of Visual Management in Construction: Cases from the Transportation Sector in England

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Abstract

Purpose
The purpose of this paper is to explore the benefits of Visual Management (VM) systems in transportation construction projects in England.

Design/methodology/approach
Following a comprehensive literature review, the benefits of VM were investigated through action and case study research executed within two construction projects in England.

Findings
The main findings are; VM can contribute to (i) increased self-management, (ii) better team coordination, (iii) better promises or an increasing Plan Percent Complete (PPC), (iv) easier control for the management, and (v) improved workplace conditions in the transportation sector. It is important for the management to obtain the engagement of their workforce for VM through increased participation and demonstrating the actual benefits. However, managerial monitoring and control on the systems should not be underestimated.

Originality/value
The transportation sector in England has been systematically deploying lean construction techniques in its operations for a while. One of those lean techniques is a close-range visual communication strategy called Visual Management (VM). The literature on the VM implementation in construction is scarce and generally limited to the building construction context. This paper documents the benefits of VM systems for the transportation sector by using data captured through both qualitative and quantitative data collection methods. The paper also identifies a set of recommendations for similar research efforts in the transportation context in the future.

Keywords: Lean construction, Visual Management, benefits, transportation sector, England, process transparency

Paper type: Technical paper

Introduction
The deployment of lean construction has recently gained momentum in England's transportation construction and maintenance supply chain with ambitious efficiency targets (Ansell *et al*., 2007; Network Rail, 2010; Chen *et al*., 2012; HMT, 2012; Drysdale, 2013; Fullalove, 2013). Lean construction is an umbrella term referencing to a combination of operational practices that take their roots from the lean production system developed at Japanese automobile manufacturers and are tailored to the architecture, engineering and construction (AEC) industry (Koskela, 1997; Green, 1999; Howell, 1999; London and Kenley, 2001; Salem *et al*., 2006). Since the 1990s, 'lean' has become increasingly prominent in construction, a development strongly influenced by the broader production and management debate, where 'lean' has been a leading production management fashion for around two decades (Jørgensen and Emmitt, 2009). The broad gamut of lean construction implementations includes Visual Management (VM) as an information management strategy based on the effectiveness of close-range sensory communication and increased process

transparency (Antony *et al*., 2003; Achanga *et al*., 2006; Bhasin and Burcher, 2006; Parry and Turner, 2006; Salem *et al*., 2006).

Forming the basis for lean improvement programs, the VM strategy advises an extensive information share in work operations and removal of information blockages at the points where information needs might occur (Galsworth, 1997; Liker and Morgan, 2006). In production management, VM and its associated visual systems (e.g. visual controls) have long been cited as a fundamental part of the lean production system (Ohno, 1988; Lewis, 2000; Liker, 2004; Parry and Turner, 2006; Wee and Wu, 2009; Hodge *et al.*, 2011; Ortiz and Park, 2011; Belekoukias, 2014). The amount of discussions on VM and its benefits for the AEC industry has also been increasing (Formoso *et al*., 2002; Picchi and Granja, 2004; Sacks *et al.*, 2010a; Brady, 2014; Emuze and Saurin, 2015; Tezel *et al*., 2015; Tjell and Bosch-Sijtsema, 2015). However, those discussions are mostly centred around the building construction context. Hence, there is a paucity of literature illustrating the application of VM and its benefits at the workface of transportation construction projects. Specifically, for the transportation construction context in England, the current VM discourse in the literature is mostly limited to the use of visual performance boards (visual indicators), with little empirical study on the practical application characteristics and benefits of VM (e.g. Ansell *et al*., 2007; Highways Agency, 2010; Drysdale, 2013). Also, the existing VM literature in construction is either conceptual (theoretical) emphasising the qualitative benefits of VM systems or explores the VM strategy limitedly over one or two specific visual systems. No comprehensive empirical study aiming at displaying a wider picture of the subject over a set of VM tools with their both quantitative (hard) and qualitative (soft) benefits has been identified. This can possibly be due to the challenges (i.e. extensive access to live-project settings, longitudinal study requirements etc.) associated with capturing the benefits in a real-life context. The VM discussions for the transportation sector is even more scarce in that sense. However, with lean construction gaining momentum in the sector, more organisations operating in the sector have been adopting those practical visualisation systems.

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At the workface, transportation projects are frequently executed over large areas in short work windows by many work teams of different, specialised sub-contractors. Alongside time and quality pressure, the work teams are often subject to live traffic conditions with the presence of heavy construction plant, which gives raise to additional safety concerns. Also, there is a clear expectation by the large public transportation clients in England for their contractors to cut down on their operational wastes through innovative management strategies (Network Rail, 2010; Chen *et al*., 2012; Drysdale, 2013; Fullalove, 2013). Under these circumstances, effective communication and coordination induced by process transparency come to fore for operational waste reduction, timely project execution and worker/ passenger safety. Therefore, the VM strategy and its visual systems have been resorted to as a viable solution that does not necessitate significant investment to practical coordination and communication issues.

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There are two main contributions of this paper; (i) exploring both the qualitative and quantitative benefits of four practical visual systems developed through the VM strategy within two construction projects from England's transportation context and (ii) discussing the characteristics of those implementations for future lean construction and VM adoptions. Understanding the benefits of VM, as a fundamental part of the lean production system, is important to further improve and justify lean construction deployments. The efficacy of VM and the conditions of the current VM realisation within the transportation sector still need to be determined. The paper is organised as such; following a comprehensive literature review on the VM concept from the production management domain and its associated benefits in construction, the research methodology and research findings are presented. The research methodology of the study is action and case study research. The research findings include a

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detailed description of the characteristics and benefits of four visual systems developed within two transportation construction projects. The findings are also discussed to further clarify the captured benefits, implementation characteristics, research limitations and opportunities for future research efforts.

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Visual Management in production management

There are different views in the literature as to what VM is; (i) it is defined as a sensory communication strategy for increased process transparency (Tezel *et al*., 2015), (ii) simple and attractive communication approach with some distinctive visual tools and systems (Ho, 1993), (iii) a managerial approach that creates communication and information centres for all employees (Tomkinson and Smith, 1998) and (iv) an information sharing vision that facilitates continuous improvement (Imai, 1997). Fillingham (2007) suggests designing VM aids so that managers can simply go-and-see what is happening and anticipate future problems. According to Maskell and Kennedy (2007), VM provides information when it is needed in a simple and easy to understand fashion, which in return creates transparency, meaning everyone is working with the same information.

Three characteristics distinguish information displayed in visual systems from other forms of communication, such as verbal and written: (i) the information in VM is entirely determined ahead of time (pre-emptive), (ii) it relies little on written communication, and (iii) information is displayed openly for the workforce to see (Galsworth, 1997). In VM, an information field from which groups or work teams can pull information is created, extending the access to information to a large number of people (Greif, 1991). The main motive of VM is to increase the communication ability of process elements, or process transparency, and self-management capabilities of the workforce (Greif, 1991; Formoso *et al.*, 2002; Liff and Posey, 2004).

Process transparency can be achieved by making the main process flows visible and comprehensible by using a combination of different visual tools as visual systems (Saurin *et al.,* 2005). With created information fields, this visibility gives way to seeing as a group (e.g. production status and inventory levels), acting as a group (i.e. consensus on objectives and involvement in improvement activities) and knowing as a group (i.e. delivery commitments, rules and schedules and management rules) (Greif, 1991; Dennis, 2015). Also, VM tools facilitate managerial control (Suzaki, 1993; Parry and Turner, 2006). Galsworth (1997) proposed a general classification of the basic visual tools that are used to realise the VM strategy; (i) information giving (e.g. signboards), (ii) signalling (e.g. *andon* quality boards); (iii) response limiting /guiding (e.g. *kanban* production control cards) and (iv) response guaranteeing (*poka-yoke* systems) visual systems.

In practice, the initial step to realise the VM strategy is visual workplace order or the 5S housekeeping programme (Mastroianni and Abdelhamid, 2003; Kobayashi *et al*., 2008; Hodge *et al*., 2011). The 5S programme consists of those steps (Hirano 1995; Ho, 1999); sorting (disposing of unnecessary items), setting-in-order (visually standardising necessary items in terms of location and quantity), shining (systematic cleaning and maintenance checking for space and equipment), standardising and sustaining the first three steps. The main benefits of the 5S in a workplace are a decrease in the non-value adding activities (e.g. searching), excess inventory, and a increase in the usable workspace, overall health and safety condition and machine/equipment reliability (Hirano, 1995; Galsworth, 1997; Gapp *et al*., 2008; Ikuma and Nahmens, 2014; Jaca *et al*., 2014).

Another aspect to VM is visual specifications and indicators that are used to communicate standard operational practices, planned future work tasks and managerial expectations (Galsworth, 2004; Dennis, 2015). Those visual systems act as coordination tools for work teams to understand their current and future work scopes (Liker and Balle, 2013;

Bateman and Lethbridge, 2014). Announcements, desired behaviours, best practice examples, visual aids, process charts, end-product samples and A3 sheets summarising the continuous improvement process or important quality practices are integrated into the workplace (Shook, 2008).

Within the VM strategy, performance figures of teams are shown openly on visual performance boards and team meetings are organised regularly around those performance boards to ensure understanding of the actual performance by the teams, to trigger group discussions and to facilitate continuous improvement (Greif, 1991; Suzaki, 1993; Parry and Turner, 2006; Radnor, 2010). In some cases, condensed and essential visual information (e.g. key performance indicators, quality and safety issues, standards etc.) are consciously displayed together in the same area to focus and trigger the discussions in regular team or managerial meetings, in what is called *obeya* rooms or "large rooms" (Aasland and Blankenburg, 2012).

Visual control systems are used to limit, to track and to regulate work processes through simple visual clues (e.g. cards, tokens, signs, signals) (Motwani, 2003; Otiz and Park, 2011; Kattman *et al.*, 2012; Mann, 2014). The renowned *kanban* system in the lean production system is essentially a visual control that is operated mostly by the exchange of a specific amount of cards among work units to harmonise pull-production and to realise the just-in-time (JIT) logistics (Ohno, 1988; Otiz and Park, 2011). Finally, visual guarantees (*poka-yokes*) are mistake-proofing systems that enable only the right outcome by imposing physical or electro-mechanical constraints or warning systems on work processes. They have been mostly used to increase process quality, safety and to reduce process set-up durations (Shingo, 1986; NKS, 1988; Fisher, 1999).

Those visual systems often work in connection with each other and take roles in different managerial practices (e.g. performance management, logistics management, production management, quality management) (Greif, 1991; Galsworth, 1997; Liff and Posey, 2004; Bateman and Lethbridge, 2014). Although many of those VM systems were developed in manufacturing environments, they have been successfully implemented in other industries (Liff and Posey, 2004). In recent years, the construction industry has also started to consciously exploit the benefits of the VM strategy in its operations, often within some lean construction deployment efforts.

Visual Management and process transparency in construction

Theoretically, process transparency in construction can be increased by (i) keeping a clear and orderly workplace, possibly through the 5S, for better information flow, (ii) incorporating information into processes, (iii) using visual systems to enable immediate recognition of process status, (iv) having a more visible site layout, (v) improving project drawings and (vi) reducing task interdependencies with better sequencing (Koskela, 1992; Heineck *et al.*, 2002). According to Moser and Dos Santos (2003) and Emmitt *et al.* (2012), increased process transparency induced by visual systems in construction leads to (i) simplification and greater coherence in decision making and production control, (ii) stimulation of informal contacts throughout different hierarchical levels, (iii) contribution to introduction of decentralisation policies, (iv) broadened employee engagement and autonomy in management, (v) increased on-site coordination and awareness, and (vi) rapid comprehension of and response to problems. Construction sites, by their nature, present also specific barriers for increased process transparency; (i) they are constantly changing environments where large number of teams move continuously, (ii) the site layout suffers several modifications throughout a project, demanding an intense effort to update and relocate the necessary set of visual devices, (iii) construction sites are relatively large places where different teams spread out, and (iv) non-removable visual barriers are incorporated into the working environment as the facility is being constructed (Formoso *et al*., 2002).

Following on those earlier discussions on VM and process transparency, a plethora of works demonstrating the application of various VM tools/ techniques originated from the manufacturing industry in construction can be seen. One of those discussions is on the 5S housekeeping methodology. Empirical studies on the 5S in construction are actually scarce. In an investigation on the penetration of lean construction among German contractors, Johansen and Walter (2007) determined that the 5S had been employed by only 16% of the contractors. Mastroianni and Abdelhamid (2003) reported a pilot implementation of the 5S in an industrial building construction project. According to the authors, the real challenge for the 5S for construction lies in sustaining a 5S effort.

One of the most frequently discussed elements of those visual systems is the card based visual production control system or the *kanban* system that is used to optimise the work-in-progress and realise the just-in-time production system (Monden, 1998). Arbulu (2009) described the benefits of using *kanban* for managing the supply of a large number of non-task specific materials in a large airport construction project. Khalfan *et al.* (2008) reported a successful use of the *kanban* system in delivering selected products from suppliers and off-site manufacturers on a just-in-time basis. The applicability of visual production controls (i.e. *kanban* system), visual production leveling boards (i.e. *heijunka* boards) and visual quality signals (i.e. *andon* system) has been widely discussed with positive results for building construction projects (Tommelein and Weissenberger, 1999; Alves *et al*. 2009; Burgos and Costa, 2012; Barbosa *et al*. 2013; Emuze and Saurin, 2015). Ko and Kuo (2015) demonstrated the implementation of visual production control cards (i.e. *kanban* cards) and visual quality signals (i.e. *andon* system) in formwork operations for building projects. Visual control systems can also be used to connect the Last Planner System's look-ahead plans (Ballard and Howell, 1994) with site teams (Jang and Kim, 2007; Brady, 2014). Tezel *et al.* (2015) illustrated a comprehensive VM tools taxonomy and identified the implementation characteristics of the VM strategy for building construction projects.

Developing information technologies such as Building Information Modelling (BIM), mobile and wearable computing, Virtual and Augmented Reality and the Internet of Things (IoT) hold the potential to support VM and help overcome some of the construction specific barriers identified by Formoso *et al*. (2002). BIM based systems can provide a data-driven visual background to replace conventional VM systems with digitalised systems (Sacks *et al.,* 2009; Sacks *et al.* 2010a,b). Tjell and Bosch-Sijtsema (2015) reported that a combined use of BIM models and conventional visual systems increased the self-management capacity of design teams. The IoT (sensor networks) integrated with BIM models can enrich process information collating and presentation for large construction sites (Dave *et al.,* 2016). Augmented construction field visualisation (Kamat *et al.,* 2011) and virtual prototyping (Guo *et al.,* 2010) also contributed to increased construction process transparency.

Despite the growing body of research, in the lean construction research community, VM is one of the least reported research themes (Daniel *et al.,* 2015). Furthermore, the discussion presented above indicates that the main directions of the VM discourse in construction have been either on the process transparency concept or application of some manufacturing based visual systems, often within building construction projects. However, the characteristics of VM systems and their benefits can be highly context dependant (Liff and Posey, 2004), which necessitates an in-depth understanding of the deployment of VM in the transportation context. Also, when learning from the manufacturing industry, the strategies and techniques introduced in the construction industry should be accepted with appropriate modification as the large number of participants in a construction supply chain and its complexity make it difficult to facilitate information sharing (Titus and Bröchner, 2005). For the transportation

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construction context specifically, the scarcity of empirical research on VM becomes even more apparent. Apart from mostly taking the building sector into its focus, the existing VM research in construction is frequently based on conceptual benefit discussions over one or two specific VM system(s) with a greater emphasis on the strategy's qualitative benefits of implicit nature. Therefore, a comprehensive benefit analysis of the real-life application of VM in construction projects with its both directly observable (explicit/quantitative) and implicit (qualitative) benefits was found necessary. Although it is a fundamental part of the lean production system, VM has often found itself a brief secondary place as a visual communication strategy within other lean construction discussions (Picchi and Granja, 2004). Also, the accounts on the use of VM in the transportation sector in England has mostly been limited to a single visual system (e.g. visual performance boards). Considering the increasing adoption of lean construction and VM in the transportation sector, it can be inferred that there is a need to further understand what benefits different VM systems could yield in the transportation context. In summary, the presented study differentiates itself from the existing VM in construction literature over the following points; (i) it focuses specifically on the VM strategy in the transportation sector, (ii) it presents a set of real-life benefits of both explicit and implicit nature, captured in relatively longer time-windows, (iii) it covers four main VM systems identified in the literature as opposed to one or two systems frequently investigated in the existing accounts, and (iv) it also discusses the VM systems' associated implementation characteristics and challenges in detail for future applications and modifications.

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Research methodology

In order to explore the benefits of VM in the transportation sector, a mixed research approach, which is comprised of the action and case study research methodology with mixed data collection methods (both qualitative and quantitative), was adopted. The explorative research question is how the benefits of VM manifest themselves at the workface of transportation projects. The authors are part of a research alliance with the main public organisation responsible for the construction, maintenance and operation of the strategic highways network in England. That alliance enabled the researchers to implement a VM system (the 5S in this case) as an action research effort and to study three existing VM systems as case studies in the transportation sector. The implemented and studied four types VM systems include; one visual workplace order or the 5S effort (action research), one visual performance system (case study), one visual specification/indicator system (case study) and one visual control system (case study). Thereby, the study covered all the main types of VM systems classified in the literature except for mistake proofing (*poka-yoke*) systems.

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Action research is used in real situations, rather than in contrived, experimental studies, since its primary focus is on solving real problems (Brydon-Miller *et al.,* 2003). It is a participatory process concerned with developing practical knowing seeking to bring together action and reflection, theory and practice, in participation with others (Reason and Bradbury, 2001). It is also a powerful research strategy to advance both science and practice as it may provide rich insights on real-life applications, taking its roots from grounded theories (Whyte, 1991). In management research, the value of action research can be seen to be in developing and elaborating theory from practice (action) with pragmatic methods, tools and approaches developed in real-life situations (Eden and Huxham, 1996; Kaplan, 1998). For operations management, action research presents three distinctive advantages over 'traditional research topics and methods' (Coughlan and Coghlan, 2002); (i) it has broad relevance to practitioners and applicability to unstructured or integrative issues, (ii) it can contribute to theory, and (iii) for explorative research efforts, researcher as an actor, agent of change and immersed, has closeness to the full range of variables in settings where those variables may not emerge at all. Some issues related to action research are finding's generalisability, trustworthiness of data, ethical issues and judging of success (Eden and Huxham, 1996; Kaplan, 1998). The main reasons why the 5S was implemented are; (i) the 5S is a scarcely researched methodology in construction, (ii) it is often referred to as a fundamental step in adopting VM, (iii) the management of the project in which the 5S was implemented showed an explicit interest and support to the methodology to improve their operations with the researchers' support, (iv) the storehouse of the project presented a suitable ground for the 5S implementation.

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Case studies, on the other hand, are more suitable when a phenomenon is studied in its real-life context and the researchers' control over the phenomenon is limited (Yin, 2003). As three of the studied VM systems had already been in place when the researchers started the research effort, the case study methodology was found appropriate. The unit of study of the case studies is the VM systems with a focus on their benefits, implementation challenges and implementation characteristics. The critical point for increasing the validity of a case study and action research is to triangulate the findings. To achieve this triangulation, both qualitative and quantitative data were collected from different resources. Also, for research objectivity, challenges associated with those VM systems were investigated and discussed. Research reliability was tried to achieve by collecting first-hand data as much as possible through a data collection protocol. The generalisability of the findings should be limited to construction production settings. Additionally, maintaining the anonymity of the data resources and research partners were paid attention to for research ethics. The illustrated visual systems were studied within two construction projects from the transportation sector in England; Project 1 and Project 2. The projects were chosen in cooperation with the public organisation on the following basis; (i) the projects had had comparatively more advanced VM practices in place that the researchers could study, (ii) one of the projects (Project 1) was keen for the researchers to implement the 5S, presenting an action research opportunity, and (iii) the projects were willing to be the subjects of this study with their extensive managerial cooperation with the research team. The details of the research methodology can be seen in Table 1.

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Project 1

Project 1 is located in Northern England. It is one of the major improvement projects in England's strategic highways network to be delivered by 2020. The work is needed as the route is used by over 180,000 vehicles per day (one of the busiest in the UK) and suffers from heavy congestion and unpredictable journey times, especially during peak periods. The project is comprised of 3 individual sections and it will cover a corridor approximately 27 kilometers long with 11 junctions and 2, 3 and 4 lane carriageways along the route. A number of cameras, information signs, signals on gantries and additional lighting columns have been installed on the route as part of the project to relieve the congestion. The estimated cost of the project is 202 million GB £. The works commenced in July 2014 with a planned completion of September 2017. To avoid traffic disruptions in peak hours, night shifts have been given importance by the project management team. Project 1 has been driving its lean construction and VM efforts through a process improvement manager.

Project 2

Project 2 was completed in Southern England as a part of an ambitious plan for upgrading 72 underground stations over a 7-year period from 2013 within an estimated budget of 350 million GB £. Project 2's scope covered the upgrade of 5 stations of the total 72 with a cost of circa 25 million GB £. The site works included replacement of the life expired mechanical, electrical, fire and communication systems as well as failing roofs, walls and floor finishes and defective staircases. The project had to be executed at night when the stations were closed, in confined areas and with constrained access. The actual site works were completed between February 2014 and January 2015. Project 2 drove its lean construction and VM efforts through a process improvement manager.

Benefits of the Visual Management systems

The 5S

A 5S pilot project was implemented at the storehouse in a warehouse of Project 1. The most frequently used equipment (i.e. safety items), materials and hand tools are stored in the storehouse with a cumulative of 42 item transactions on average between the storehouse personnel and the rest of the project personnel per day. In line with the project's lean construction and better housekeeping vision, the management had had a 5S implementation intention for a while. Also, due to lack of ownership, the management had previously failed with completing another 5S pilot in the warehouse. The pilot project was commenced with a kick-off meeting with the warehouse personnel by outlining the aims and objectives of the project in general. The personnel then were given a comprehensive introduction to the 5S and an implementation plan was agreed on.

The initial step in the implementation plan was to observe, identify and document the as-is situation in the storehouse (see Figure 1a). Bearing inefficiencies in the storage area use with motion blockages and 3 possible tripping and skin piercing health and safety hazards, the storehouse floor and racks were cramped with various materials and equipment scattered around. There was no visual identification of the items clearly showing the item locations, item types and item replenishment levels in the storehouse. Locating the correct safety gears was particularly problematic as there were many types of the same item with different sizes (i.e. jackets, vests, trousers and boots) or made with different materials (i.e. safety goggles) or colors (i.e. colored safety helmets for different construction trades). The arrangement of the items had been done haphazardly to a great extent without much thought to systematically organising the item locations as per the demand by the site personnel. The item record books were casually placed among the materials on the shelving. To better capture and compare the benefits, a time-motion study was executed before and after the 5S implementation on the transactions of some of the most frequently requested items in the storehouse.

A typical item transaction process starts with an item demand by the project personnel from the warehouse personnel at the storehouse counter. The warehouse personnel then locate the correct item in the storehouse, bring it to the counter, find the relevant record book and take note of the given item, the demanding personnel's name and personnel number in the record books. For the initial step in the 5S plan, to better reflect the reality, a time-motion study of the item transactions, from the start of the item demand to the completion of the item handover, of one experienced warehouse personnel with more than 5 years of experience and one inexperienced warehouse personnel with less than 5 years of experience with equal chances of serving an item request were recorded separately.

As the first S (sort) in the 5S, the warehouse personnel were asked to evaluate the items in the storehouse in terms of their short-term and long-term necessity. The less needed items that would not be possibly requested in a 6-month period or more were removed from the storehouse. As a result, the storehouse floor was cleared of the scattered materials and equipment, which saved around 30% of the total floor area. By the introduction of pigeonholes and portable drawers, vertical and horizontal space savings were achieved on the storage racks. In the second S (set-in-order), the locations of the items were rearranged as per their use and demand. The more frequently requested items were located closer to the storehouse counter in an easier reach. The items were regrouped and rearranged by their types. The item names, item types, item locations and replenishment levels were clearly marked by highlighted visual clues. A particular attention was given to the safety gears for their better identification. The record books were collected in the same location, just over the storehouse desk by the counter, and better organised. For the third S (shine), standard instructions for cleaning and health and safety checks for the storehouse were discussed and issued to the warehouse personnel. For the last two S (standardise and sustain), the project management regularly control the progress and sustaining the created 5S condition in the storehouse with their internal auditing practices. As the storehouse is small, the control practice is relatively quick and simpler. The general condition of the storehouse after the 5S can be seen in Figure 1b.

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The item transaction process times for the same, most frequently requested items were recorded again within the same configuration with one inexperienced and one experienced personnel after the 5S pilot to compare the benefits (see Table 2). In summary, the 5S pilot in the storehouse led to significant time and work savings in the item transactions, reduced the standard deviations in the item transactions, increased the usable floor area, raised the horizontal and vertical storage rack space utilisation, and the overall neatness, cleanliness, and health and safety condition (all potential hazards were removed) in the storehouse. See Table 2 for the details of the recorded 5S benefits.
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The pilot 5S project implementation in the storehouse lasted for 3 months between October and December 2015. The warehouse personnel's approach to the implementation process in terms of their cooperation and compliance with the requirements from the authors was positive in general. They also stated their content with the improved layout, health safety condition and shorter item transactions in the storehouse. The personnel assured they would continue experimenting with the 5S steps in the warehouse during the implementation repeatedly; yet the authors' drive, leadership and impulse had been constantly necessary during the implementation process. Being mostly a top-down effort, the 5S implementation at the storehouse would have come to a halt without the presence and monitoring of at least one of the authors. Although the warehouse personnel were mostly left to decide on the new layout of the storehouse and what items to keep or remove in the first and second S as per the instructions from the authors (their ideas and preferences were included), obtaining the real acceptance or willingness of the personnel for the 5S was observed to be challenging. The warehouse personnel had been sceptical of the expected benefits from the changes in their work routines and work environment throughout the implementation. Moreover, although the project has an internal training mechanism, the personnel were unaware of many 'lean' concepts. It was observed from the interaction with the workforce and some managers that the view to the 5S was generally narrow. The 5S was often confused for good housekeeping, which is actually just a part of the methodology (Hirano, 1995).

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It is particularly challenging to sustain a 5S effort for a long term; even for manufacturing organisations where the production environment is generally more controlled than construction (Hirano, 1995). In dynamic and constantly changing construction sites, close managerial support, supervision and workforce ownership should be in place in order to sustain the 5S (Mastroianni and Abdelhamid, 2003). Along with in-project 5S team champions, it can be also useful to create a constructive competition and incentivisation mechanism for the 5S among construction teams. 5S workshops and site visits could be organised to raise the awareness and the ownership. Another apparent issue is to make the 5S a standard approach across different projects. As identified by Johansen and Walter (2007), 5S initiatives often take place in small, isolated pockets in some specific projects in the construction industry. More empirical research exploring the 5S in construction seems necessary to advance the understanding about and to help justify the business case for the methodology. In line with this proposition, the benefits documented from the 5S pilot prompted the project management to disseminate the 5S to the rest of the construction site as a future step.

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Team performance visual boards

In Project 1, the management wanted to have an integrated visual system to monitor and coordinate their project teams' performance, which are comprised of 140 permanent staff split into 15 teams (i.e. design, technology, engineering, health and safety etc). Also, the management found that the project's meeting routines within their teams were inefficient in identifying and solving problems and needed more focusing. Therefore, an integrated visual performance board and a team meeting system were developed. The management's ultimate aspirations was that the senior management team could walk around the office every day and observe or participate in each and every teams stand up meetings where they would discuss the day's tasks and existing performance.

The initial process for engaging with the teams was via a standard 2-hour weekly meeting without any systematic meeting and follow-up structure. Actions and minutes would be taken and then typed, and circulated 3 to 5 days later. The meetings gave no clear indication as to how the teams were performing and what key issues were. As a result, many problems raised by the teams during their meetings had lingered unsolved. Also, It was a challenge for the teams to understand what other teams are engaged with and how they are performing as sharing of key information was difficult.

The management organised a series of workshops with the teams to mitigate the problem. As the result of the workshops, a generic visual performance board template around which daily meetings of the teams are held was shaped. The generic template includes a task promise part (made in public with owner, date and status), ownership of the task part, what needs to be done by when part and a team continuous improvement part along with each team's past performance figures (Figure 2). Each team stops work daily at 8 a.m. to update their visual boards. The boards are publicly open for everyone to see and a summary of the information extracted from the team boards is distributed to all of the staff on a weekly basis providing a wider understanding of the performance among the teams. Persisting or more critical issues from each team board are transferred to a specific management summary board for special attention of the senior management.

{Please insert Figure 2 around here}

The first benefit recorded after the implementation of the boards is a reduction in the average duration of the team meetings. Previously, the meetings would take around 2 hours (120 minutes) on average per week with minor deviations (approximately 13 minutes from the past records) for each team. With a more focused and systematic daily meeting approach via the visual boards, the total weekly meeting duration was calculated to take approximately 50 minutes on average with a standard deviation of 6.3 minutes for the teams (calculated over a 10 week period after the implementation of the visual boards), representing a 59% reduction in meeting durations on average with a lesser deviation.

Comment [MOU17]: For Reviewer 2 comments.

The Planned Percept Complete (PPC) indicator, which is the percentage of all actual on-time task completions to all promises (plans) made for task completion for a certain time period, is generally used with the Last Planner System and a good indicator of the consistency of promises made, and an effective performance control tool (Ballard, 1997; Sacks *et al.,* 2010b). After the implementation of the visual boards in May 2015, the overall PPC of the teams has shown a general upward trend in time with an average PPC of 76% (see Figure 3). The upward trend indicates a gradual improvement in the actualisation of the promises made by the teams after the implementation of the boards and the meeting system. In other words, the teams started to make more attainable promises or started to pay more attention to the realisation of their promises. Also, the systematic meetings with the visual boards enabled a better identification and quantification of the root causes of performance variances of the project teams for future actions, which was mostly lacking in the previous meeting system. Those causes and PPC values have been distributed to the project personnel on a weekly basis for increased transparency. To capture insights from the team members on the boards, an open-ended, semi-structured questionnaire about the visual performance boards was distributed online among the teams for improved anonymity. The results obtained from the questionnaire can be seen in Table 3.

{Please insert Figure 3 around here}

{Please insert Table 3 around here}

Table 3 suggests that alongside presenting a structured and focused meeting mechanism, the team performance boards help facilitate the inter-team communication, engagement and a better work requirement seeing for the project teams. The process improvement manager stated that it could become challenging to drive the teams to regularly use the boards. Also, it was observed that it can be easy for the teams to cancel the meetings around the boards due to other priorities so it is integral for the management to continuously underline that the boards and meetings are important priorities. The management allowed the teams to continuously improve their boards through trial and error. Therefore, no board looks the same but they all share a common base structure. It was also observed that interactive handwriting practices and simple physical artifacts such as post-its or magnetic pins positively contributed to the teams' engagement with the boards. Rather than taking time consuming minutes or notes during the stand-up meetings, which are also open to mistakes or omissions, the teams would simply take photos of the updated boards for the records. As a future step, cross-functional teams from the members of different project teams can be brought together to form continuous improvement (CI) cells to improve some of the recurring, more significant problems identified during the meetings (Bhuiyan and Baghel, 2005).

Comment [MOU18]: For Reviewer 2 comments to summarise the key findings in the qualitative tables

Traffic management coordination boards

While improving a busy highways network in a live traffic situation, permanent and temporary traffic management, varying from slip road closure, lane closures and full carriageway closures, become highly critical issues. Most of the time, contractors face serious monetary penalties by their contracts for the number of closures they incurred. Therefore, maximising the utilisation of the working window with value adding actives during a closure is of primary importance to contractors. To cause less disruption, closures are generally imposed during night time. Ideally, closures should be utilised as much as possible until it has to be safely removed, in time for morning traffic. Consequently, if the overall utilisation of closures is not efficient, construction teams require visibly more than expected closures during a project.

Suggesting a higher amount of waste in the utilisation of working windows during closures, it came to Project 1 management's attention that the amount of closures they were using was above what was expected and they began to look into this internally with their construction teams. After discussing with the construction teams and analysing the closure utilisation sheets, the management identified the following points as the main reasons for the lower closure utilisations; (i) lack of communication between different disciplines, (ii) a clearer high-level night time briefing for supervisors and managers. (iii) lack of VM to increase the closure transparency and help the construction teams coordinate their efforts and (iv) a more structured handover process from nights to days.

To improve the coordination and transparency in the utilisation of the project's closures, two visual boards were adopted between March-April, 2015. The first board is for the night-time traffic management that was created to allow all construction teams to view 2 week look-ahead traffic management program in order to maximise the use of each closure (see Figure 4a). The board is located close to the point where the construction teams have their daily meetings. The second board, which is basically a large project drawing with magnetic traffic management related pins, was put in use for the coordination meetings of the night-time traffic management personnel in the office (see Figure 4b). The traffic management personnel have been visualising their traffic management plans and coordination on the board. The board was mainly developed by the traffic management personnel as per their needs and instructions from the management through trial and error. The construction teams and traffic management personnel execute the boards with a systematic daily coordination meeting structured around them.

{Please insert Figure 4 around here}

The main benefit identified from the implementation of the traffic management visual boards is in the downward trend after March-April, 2015 (implementation of the boards) in the percentage of the project's closure working window waste, which corresponds to the total percentage of the work wastes or the unnecessary non-value adding activities against the value adding or the necessary non-value adding activities during the closures in the corresponding month (see Figure 5). Even though the total number closures for works has dramatically increased in time as the project has progressed, both the percentage of the process waste decreased, and the number of cancelled closures due to the errors or mistakes by the project personnel remained low (relative to the total number of closures). Naturally, the aim of the management is to consistently eliminate or to keep the cancelled closures reasonably low. The figures suggest a positive contribution of the boards to the coordination issues identified by the management. To capture insights from the traffic management personnel and construction teams on the coordination boards and validate the quantitative findings, an open-ended, semi-structured questionnaire about the visual coordination boards was distributed online among the teams. Even though asked, no significant input regarding the problematic points or improvement opportunities for the boards was captured. The results obtained from the questionnaire can be seen in Table 4.

Comment [MOU19]: For Reviewer 2 comments.

Comment [MOU20]: For Reviewer 2 comments.

{Please insert Figure 5 around here}

{Please insert Table 4 around here}

Table 4 suggests that the traffic management teams mainly use the boards to increase the work visibility between their personnel working on different shifts to identify various bottlenecks, clashes, and to facilitate the work control and coordination.

Comment [MOU21]: For Reviewer 2 comments to summarise the key findings in the qualitative tables

Visual project control board

To improve the planning reliability, to increase collaboration and to be more proactive in a constrained environment, Project 2 management had decided to deploy the Last Planner System. After the start of the project, the project management realised that they needed a way to manage and control the site at an activity level. Moreover, the PPC figures of the project were initially at around 55% to 60%, which the project management wanted to increase. The main problem was identified in the coordination between the project management team and different subcontractors. To tackle this issue, a 3-week look-ahead card type board was introduced on site to connect the Last Planner System to different site teams (see Figure 6).

{Please insert Figure 6 around here}

The left hand side column of the board was color-coded as per the project areas. The columns represent shifts and weeks. Bespoke cards were designed for each contractor to write down and record their activities for the first 3 weeks on site. Each card was again color coded to match the main schedule. These cards then populated the 3-week look-ahead boards. Therefore, before the start of a shift on site, one could easily see clashes where multiple contractors were planning to work in the same area. New opportunities to bring work forward were also identified through the boards. At the end of every shift, the construction manager reviewed progress during the shift and confirmed whether the activity was completed or not. If it was completed, the construction manager would 'turn over' that activities card, revealing the green back of the card. If the activity was not completed, the activity card would stay as it was and allowed the project team on the days to follow up and re-plan. This helped the handover process from the construction manager directing work on nights, to the project team on days. Once the first week was complete and all unachieved activities were re- planned, the boards were then shuffled down and Week 1 became Week 3. The subcontractor's activity cards included information like the working area, date, activity, man power and the duration. Few other cards for the subcontractors to use, such as, the 'Ready for Inspection' card and the 'Issue Card' were given.

A weekly progress meeting system was put in place, in which the board was re-populated with the activity cards at the end of every week. The project planner would run this meeting and examine the board; in particular, re-planning work site clashes and trying to exploit opportunities. The issue cards would also be logged with agreed actions and owners to resolve. After the implementation of the boards in May, 2014, except for a short-downfall during the learning period of the subcontractors, the project enjoyed a steady increase in its PPC values up to 85% at the end with an on-time project completion, which indicates a better-coordinated and proactive site management at the task level (see Figure 7). This trend also indicates improved planning realisation reliability from the subcontractors. To further analyse the benefits, a semi-structured interview with the project management team about the board was conducted. The managers were asked to evaluate the identified benefits of the board on a five-point Likert scale (Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree) with its related challenges and their improvement suggestions (see Table 5).

Comment [MOU22]: For Reviewer 2 comments.

{Please insert Figure 7 around here}

{Please insert Table 5 around here}

Table 5 suggests that the visual control board mainly contributed to maintaining the coordination among different sub-contractors, reducing the work and space clashes, triggering discussions for improved work planning and increasing the PPC level of the project.

Comment [MOU23]: For Reviewer 2 comments to summarise the key findings in the qualitative tables

Discussion

Improved work coordination, triggered project team discussions and better root-cause identification of problems, which translate to an upward trend in the PPC figures, and decreased waste in limited work-windows or in regular team meetings, come to the fore as the important benefits of the visual systems for transportation projects. The associated benefits of the 5S in item transaction times and floor area savings could be more clearly calculated in that sense. Another commonality in the implementations is in the identified importance of obtaining buy-ins or engagements of the people that are going to use those systems. A degree of scepticism can be expected particularly in the initial implementation phases, as the visual systems often require some sort of a change in people's accustomed work routines. Demonstrating the identified benefits and involving people into the implementation process can be of use to overcome those barriers.

The main concern of the research is discussing the benefits of the VM systems in detail while maintaining the research objectivity. Particularly with the implementations involving a trend analysis over a period of time (i.e. team performance visual boards, traffic management coordination boards and project control visual board), it is hard to isolate the quantified benefit of a particular visual system to the overall performance from the rest of the other factors that might potentially play a role in the performance improvements. The trend analyses show the tendency towards a positive contribution to the overall performance after the implementation of a specific visual system. An experimental or quasi-experimental research design can be pursued for better benefit isolation in future research efforts. This experimentation for the benefit demonstration intent was only partially achieved with the 5S pilot study. In order to maintain the research validity, the quantitative findings were supported and elaborated by the in-depth qualitative findings obtained from the people actually involved in the use of those visual systems, as initially planned. Along with helping to mitigate any positive bias that may be present, the qualitative findings and observations of the authors also illustrate a wider picture of the benefits and implementation characteristics of the visual systems. To further increase the research objectivity, data on the challenges associated with the VM systems were also collected. The authors' main role with the 5S was facilitating the implementation process by providing the necessary guidance and theoretical know-how. For the other three VM systems, the authors remained as observers to capture the benefits and challenges associated with those systems.

Comment [MOU24]: For Reviewer 1

Comment [MOU25]: For Reviewer 1 & Reviewer 2 & Reviewer 4 comments.

Comment [MOU26]: For Reviewer 1 comments & Reviewer 4 comments.

Comment [MOU27]: For Reviewer 1 comments

It should be noted that all those successful implementations outlined were firmly supported by the senior management of the projects with a lean construction and VM vision. The senior management made it clear to their teams that they wanted those visual systems to be developed and used in their daily work routines. Even though people were left to decide on and experiment with the implementations to a degree, the implementations were essentially top-down, starting with the identification of a need by the management and developing with constant monitoring. The visual systems were devised to counter an existing problematic situation or to improve the overall performance. Also, the visual systems were executed with a meeting and follow-up mechanism (except for the 5S, which needs constant managerial monitoring for sustaining by its definition), the outcomes of which were openly shared with the people involved. Without a systematic managerial mechanism in place, the visual systems would not be as effective. That is to say, solely creating visuals without any systematic managerial backbone is not enough to attain the expected gains from increased process transparency.

The presented VM systems are particularly in line with four process-transparency increasing propositions for construction by Koskela (1992) and Heineck *et al.* (2002): (i) keeping a clear and orderly workplace through the 5S, (ii) incorporating information into processes, (iii) using visual systems to enable immediate recognition of process status and (iv) having a more visible site layout. Except for mistake-proofing systems, the studied visual systems cover all the VM system types classified by Galsworth (1997). The findings also empirically confirm some of the generic, conceptual benefits of VM and process transparency proposed by Formoso *et al.,* (2002), Moser and Dos Santos (2003), and Emmitt *et al.* (2012) specifically for transportation projects, which is one of the contributions of the paper: (i) simplification in production control, (ii) stimulation of contacts throughout different hierarchical levels, (iii) broadened employee engagement and autonomy in management, (iv) increased on-site coordination and awareness, and (v) rapid comprehension of problems. Additionally, it was shown that the 5S can contribute to reduction in total item transaction durations through motion economy and transaction deviations, and improved health and safe with better space utilisation in construction projects. On the other hand, some challenges or problematic points related to the VM systems were also identified. A detailed summary of the captured benefits and challenges for each VM system can be seen in Table 6.

Comment [MOU29]: For Reviewer 1 & Reviewer 3 comments to link the findings to the lieterature review

Comment [MOU28]: For Reviewer 1, Reviewer 3 & Reviwer 4 comments.

{Please insert Table 6 around here}

Alongside empirically confirming those generic benefits of VM, the findings suggest some more transportation sector-specific contributions of VM as well; (i) VM can facilitate the coordination among transportation teams working on different shifts and in disparate geographic locations away from each other for a better short-work window productivity, (ii) with the existence of many work teams of different sub-contractors, VM systems can help impose a focused meeting mechanism for performance-reviews, better task visualisation for the teams and peer pressure for more reliable work related promises, (iii) problem and clash identification, work control and coordination of different sub-contractors working in a live traffic situation can also be facilitated for management under high scheduling and quality expectations, (iv) as transportation work teams often keep many mobile and static on-site material/component storages in different locations (i.e. along a road, railway track or around stations), the study suggests that a more extensive, standardised adoption of the 5S holds the potential to yield significant benefits in the sector.

Comment [MOU30]: For Reviewer 1, Reviewer 3 & Reviwer 4 comments.

Comment [MOU31]: For Reviewer 1, Reviewer 3 & Reviwer 4 comments.

VM offers highly practical solutions to the situations that can be improved through increased process transparency. The form and content of those visual solutions can change as per specific project conditions, project needs and people involved. Therefore, different visual solutions can be adopted even for the same problem in the transportation construction context in the future. Also, innovative visual systems can be developed to address a VM need. In line with future research efforts, experimental researches, comparing similar projects or work teams with and without specific visual systems on similar indicators, can be executed to better reflect and even isolate some VM benefits, which this research effort mainly lacks. Also, future research may put forward more varied quantitative indicators for capturing VM benefits. However, qualitative benefits of visual systems, which are hard to translate in numerical figures, should not be overlooked in those discussions.

Conclusion

With a clear support from large public agencies, lean construction and correspondingly VM have been increasingly finding a place in the agendas of the transportation construction supply chain in England. In parallel with this, more lean construction related research and implementation narratives will be seen from the same context in the future. As one of the initial examples of those works, this paper presents the documented benefits of four practical VM systems; visual workplace structuring (the 5S), visual measures (team performance visual boards), visual specifications/indicators (traffic coordination boards) and visual controls (project control visual board), with their implementation characteristics.

The findings confirm the VM benefits identified from the literature for the transportation sector; (i) increased self-management, (ii) better team coordination, (iii) better promises or an increasing PPC, (iv) easier control for the management, and (v) with the 5S, an improved workplace condition with decreased item transaction process times (non-value adding activities or motion economy), savings in work spaces and a better health and safety condition. It is important for the management to obtain the engagement of their workforce for VM through increased participation and demonstrating the actual benefits. However, managerial monitoring and control on the systems should not be underestimated. Additionally, the challenges identified in Table 6 should be paid attention to and taken as improvement opportunities while implementing similar VM systems.

Comment [MOU32]: For Reviewer 1.

Beyond the generic and conceptual benefits proposed in the literature for VM, the findings indicate that the deployment of VM in the transportation sector holds the potential to bring about some operational benefits that can address the sector's distinctive characteristics and work limitations. It is argued that the conceptual benefits of VM can manifest themselves in different forms in the transportation sector (i.e. increased efficiency in short-work windows through better coordination, early bottleneck and problem identification of teams working for different sub-contractors in disparate locations etc.). This argument is also in line with the proposition that the benefits of VM could be context-specific. The manifestation of those benefits supports the need for developing VM systems in cooperation with the transportation sector professionals for greater relevance. In this sense, action and design science research will enable researchers' experimentation with (i.e. testing IT based replacement of some conventional VM systems) and involvement in the deployment of VM in real-life transportation work contexts to a greater extent. In line with this, innovative and more operational VM control system at the direct interface between manpower-machine/ plant and manpower-soil/land on transportation construction sites can be devised.

Comment [MOU33]: For Reviewer 1, Reviewer 2 and Reviewer 4's comments to extend the conclusion section with more discussions.

VM in construction, particularly in the transportation sector, generally lacks empirical research with a holistic emphasis on VM's both quantitative and qualitative benefits. In that sense, future research can present new parameters for VM's quantitative benefits for managers to evaluate and justify their VM efforts in a more varied way. Also, qualitatively, the perspectives of different organisational roles (i.e. managers, engineers, construction workers) on the same visual system can be recorded for richer insights. Empirical studies comparing team or project performances with and without some specific VM systems can be executed over an experimental or quasi-experimental research design. The 5S can also be implemented in the transportation supply chain on a larger scale to spaces like offices, depots, lay-down areas, construction sites, laboratories, maintenance vans and warehouses. The use of emerging information technologies to replace or support conventional VM systems in the transportation sector can present another research opportunity. Also, a detailed analysis of the condition of and the opportunities for VM in Small and Medium sized Enterprises (SMEs), which constitute the largest portion of the organisations in the transportation supply chain, can present another research opportunity. A systematic continuous improvement process linked to those visual systems possibly with continuous improvement (CI) cells can also be tried. The potential of *poka-yoke* (mistake proofing) systems in source inspection (quality) and for worker safety can be investigated for the sector. To better understand the business case for VM in transportation, return on investment focused studies can also be conducted.

Comment [MOU34]: For Reviewer 1 & Reviewer 2 & Reviwer 4 comments.

Comment [MOU35]: Additional future resarch opportunities to expand the conclusion section a little more as required by the Reviewers

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(a) (b)

Fig 1. The storehouse before (a) and after (b) the 5S

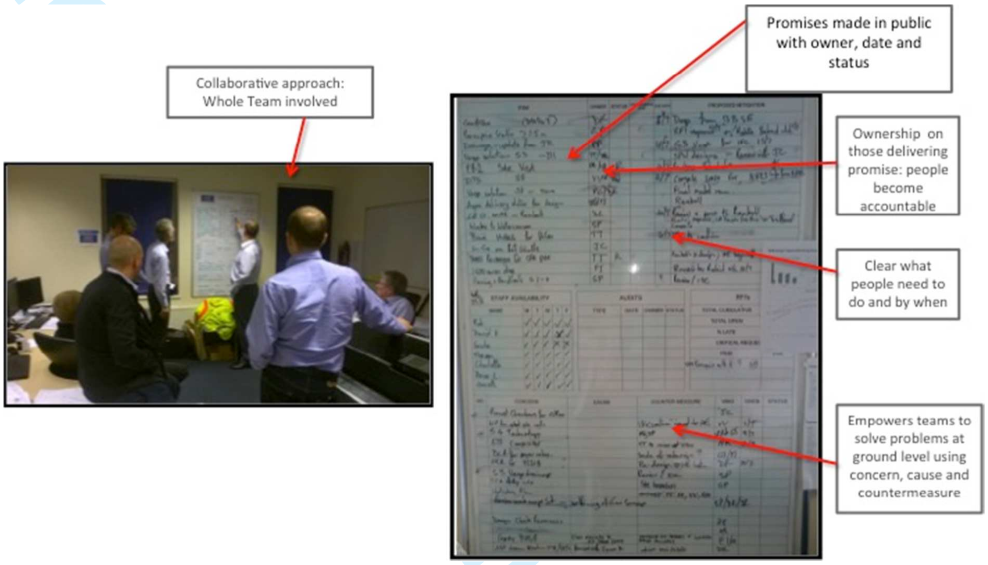

Fig 2. Visual performance board of the engineering team with the generic template

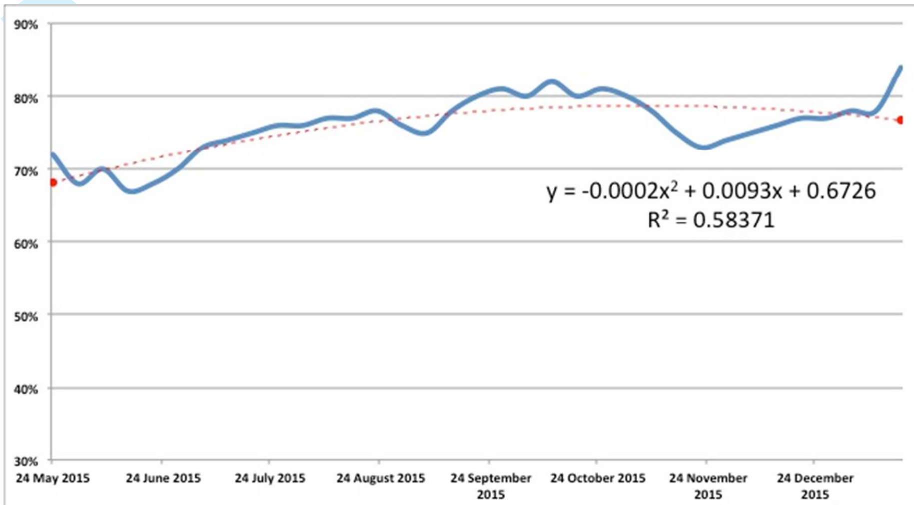

Fig 3. Gradual increase in the teams' PPC after the performance boards.

(a) (b)

Fig 4. Traffic management two week look ahead board (a) and the night-shift meeting coordination board with the magnetic stickers (b)

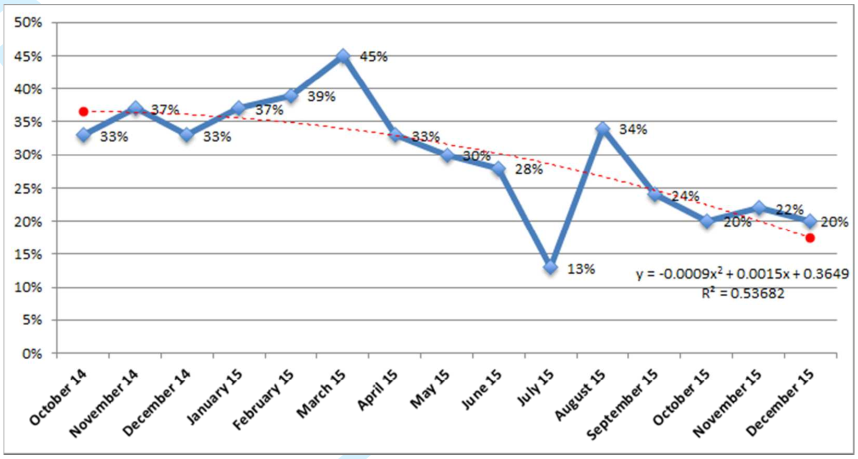

Fig 5. Decreasing percentage of the non-value adding activities during the closures

Fig 6. The visual control board

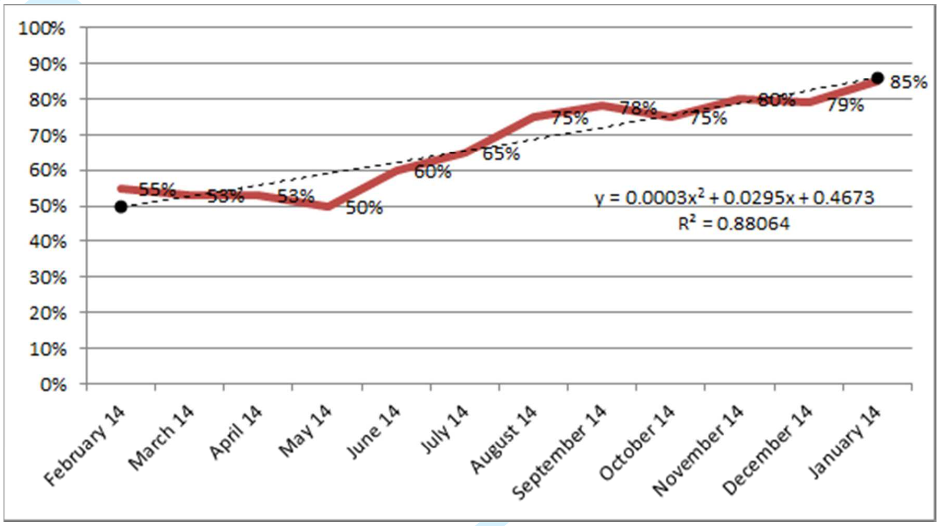

Fig 7. Steady increase in the overall project PPC after the implementation of the visual control board

Table 1. Details of the research methodology

No	Visual systems	Project	Research methodology	Quantitative data collection methods	Qualitative data collection methods	Study time-frame
1	Visual workplace structuring system (the 5S)	Project 1	Action research	• Time-motion study in item transactions before and after the 5S • Comparing number of health and safety hazards before and after the 5S • Calculating saved floor area before and after the 5S	• Unstructured discussions with the process improvement manager • Unstructured discussions with the warehouse personnel	October 2015 - January 2016
2	Visual performance system (team performance boards)	Project 1	Case study research	• Comparing average meeting durations before and after the system • Time series and trend analysis and regression	• Semi-structured questionnaire with the project teams • Unstructured discussions with the process improvement manager	May 2015 – January 2016
3	Visual indicator system (traffic management coordination boards)	Project 1	Case study research	• Time series, and trend analysis and regression	• Semi-structured questionnaire with the traffic management team • Unstructured discussions with the process improvement manager	May 2015 – January 2016
4	Visual control system	Project 2	Case study research	• Time series, and trend analysis and regression	• Semi-structured interviews with the project management team	October 2015 - January 2016

Table 2. Benefits of the 5S implementation project

Comment [MOU36]: Table 2 changed as per Reviewer 2's comments

Benefit		Number of observations (N) before and after the 5S	Before the 5S				After the 5S				Time savings after the 5S		Reduction in standard deviations after the 5S	
	Item		Inexperienced Pers. (Aver. Sec.)	Experienced Pers. (Aver. Sec)	Inexperienced Pers. (St. Dev. Sec.)	Experienced Pers. (St. Dev. Sec.)	Inexperienced Pers. (Aver. Sec)	Experienced Pers. (Aver. Sec)	Inexperienced Pers. (St. Dev. Sec.)	Experienced Pers. (St. Dev. Sec.)	Inexperienced Pers. (Aver. Sec)	Experienced Pers. (Aver. Sec)	Inexperienced Pers. (%)	Experienced Pers. (%)
Reduction in item transaction times	Batteries	5	67	57	4.60	3.63	37	29	3.67	3.06	30	28	20.30	15.80
	Hammer	5	48	70	3.40	2.83	35	27	2.81	2.48	13	43	17.50	12.30
	Oil	5	111	80	9.40	5.83	40	27	6.62	4.69	71	53	29.60	19.60
	Paint brush	5	87	67	5.70	3.85	63	26	4.38	3.24	24	41	23.10	15.80
	Safety gloves	5	146	86	15.30	9.05	63	38	9.58	7.13	83	48	37.40	21.30
	Safety googles	5	75	80	8.58	5.96	55	38	5.90	4.48	20	42	31.30	24.90
	Safety vest	5	136	60	29.22	14.69	60	42	14.11	10.20	76	18	51.70	30.50
	Safety helmet	5	203	85	34.26	19.50	50	40	18.0	12.74	153	45	47.50	34.60
Space savings	Floor Space	2	Available Floor Space (m2)				Available Floor Space (m2)				Floor space saving (m2)			
			15				19				4			
Health and Safety improvements	Trip and Fall Hazard	2	Number of hazards				Number of hazards				Number of cleared hazards			
			3				0				3			

Table 3. Project 1's team members' views on the visual performance boards

Response No	What is your work team?	What are the benefits of the visual performance boards you have in your office?	Is there any negative sides or improvement opportunities for the visual performance boards?	How those visual boards help you with your meetings?	How did the boards affect the task completion in your teams?
1	Commercial	Gives awareness of what other members of the team are doing Gives reminders of priorities for the week	It's become a little bit of a 'going through the motions' exercise	We've chosen specific headings so we can keep the meetings brief and to the point - less opportunity for waffle	We have started to take our promises more seriously.
2	Technology	See what other members are working on. Tracking actions. Highlighting risk. Tracking people's movements People started to give themselves smarter objectives (better promises)	Difficult to get a daily routine/meeting suitable to all members.	Enables meeting focus/structure and makes them more efficient.	People started to think more carefully before making any promises
3	Operational Support/Communications	They are engaging and give a solid understanding as to where each of our individual team members are up to with tasks. We can refer to the vis board if a team member is not in the office and we need some information. The boards display dates for upcoming works and act as a simplified programme.	No negative. The only thing I would say for improvement is that there isn't much room for our board in the office, so when we have our meeting it is a little cramped and we have to lean over to reach the board. However, this is only a minor issue.	They are a great platform for the team to engage in conversation and communicate with each other.	
4	Health and Safety	Allowing people to know what you are up to and what you have not managed to do and why	No. It is a benefit bar the time taken to go through it on a daily basis.	It allows people to be open and know what everyone is doing and reasons for not doing things	As the boards help us see the bottlenecks and unsolved issues with their responsible, they provide an urge to take our actions seriously.

					I sometimes feel though It just shows the time we are being reactive to others poor planning
5	Health and Safety	Communication about what is being achieved, identifying what needs to be changed.	The board could be improved	Focus the discussions	
6	Health and Safety	We can see what tasks the team members are carrying out, also we can prioritise tasks which involve input from multiple team members	It is difficult to keep up the momentum daily and ensure attendance from all the team.	It helps us see the whole picture. Improves the team's coordination.	
7	Health and Safety	Visibility of what team members are doing and "Heads Up" information sharing of pressures influencing decisions making.	Members of the team would not always make themselves available for the meeting but were quick to complain that they had not been made aware of what was happening. Not enough was done identify external influences on the failure to complete objectives such as common trends and patterns.	Facilitates team discussions and early identification of the problems.	
8	Traffic Management	It focuses attention on the board and the benefits that can be derived from their use and briefing out of the results	o	Focuses our discussions.	Helps us complete the tasks on-time
9	Traffic Management	It allows people to know what is happening on a daily/weekly basis	People can easily get away from the meeting around the board	It keeps people on the course	Better promises are made now
10	Project Management	Clear, visual management so everyone can see the actions and discussion points	Since they replace formal written minutes, there is an emphasis for the individuals to	They provide a focus for the teams, and accountability for the owners of the actions.	Affected positively.

			complete their actions in a timely manner. This needs sufficient challenge at follow up meetings.		

Table 4. Project 1 traffic management team's views on the traffic management boards

Team Member No	What are the benefits of the large, plastic covered project board with magnetic pins that you use for the night-shift meetings?	What are the benefits of the traffic management two-week look-ahead board around the warehouse?
1	Solve problems before they arrive with better coordination, visibility for all.	Solve problems before they arrive, visibility for all.
2	It enables all the foreman and supervisors to avoid clashes, the location of the next nights work and all are aware of he times get of e traffic management and when they can access their work location and when they need to complete works and leave site	Better coordinate and harmonise the teams' works.
3	Enables better communication and coordination for the teams in nigh-shifts	It is good for planning the efforts beforehand. Raises awareness of what other traffic management teams do.
4	Triggers coordination and discussion. The night and day shift people can see what is going on any time without asking	The teams can do better forward planning.
5	Increases visibility for us	Helps to link the night and day shift teams

Table 5. Project 2 managers' views on the visual control board

Job Title	Increased the coordination among different subcontractors? (night and day)	Reduced the work and space clashes among different teams?	Helped the management to identify the bottlenecks in advance?	Triggered discussions among the subcontractors?	Linked the Last Planner schedules with the field personnel?	Challenges faced during the implementation?
Project Manager	Strongly agree	Strongly agree	Strongly agree	Strongly agree	Strongly agree	Writing the cards was labor intensive. Anticipate the increased level of management needed (but it's worth it)
Business Improvement Manager	Strongly agree	Strongly agree	Strongly agree	Strongly agree	Strongly agree	Selling the benefits to the project team - and then down the chain to the subcontractors
Construction Manager (day)	Strongly agree	Strongly agree	Disagree	Strongly agree	Strongly agree	Trends were not identified early enough. We could have better continuous improvement efforts linked with the board.
Construction Manager (night)	Strongly agree	Strongly agree	Strongly agree	Strongly agree	Strongly agree	Minimal continuous improvement for the problems identified through the board

Table 6. Summary of the captured benefits and challanges by each VM system

Comment [MOU37]: For Reviewer 1, Reviewer 2, Reviewer 3 and Reviewer 4's comments

VM system	Captured benefits	Main Challenges
5S	• Decrease in the item transaction times (motion economy), • Decrease in the variation (standard deviation) in the item transaction times, • Increase in the space utilization and • Increase in the overall health and safety condition.	• Narrow view to the 5S, • Skeptical approach of the workforce, • Need for constant monitoring, control and guidance throughout, the implementation and • Hardships in sustaining the 5S
Team performance boards	• Decrease in the meeting durations, • Prompting the teams to make better promises (increase in the overall PPC), • Improved transparency among different work teams/individuals for better coordination and • Presenting a visual information recording mechanism for planned work tasks.	• Maintaining the regularity of the team meetings and • Need for better identification and recording of the external problem sources and patterns.
Traffic management boards	• Contributing to the decrease in the percentage of the non-value adding activities during closures, • Increase in the coordination among the night and day teams and • Presenting a visual planning and discussion background (interface) for the traffic management.	
Project control board	• Increase in the coordination among different subcontractors, • Reduction in the work and space clashes among different teams, • Helping the managers identify bottlenecks in advance (facilitated project control), • Triggering discussions among the work teams and • Linking the Last Planner with the field personnel through self-management, contributing to a gradual increase in the overall PPC.	• Hardships in maintaining the continuous improvement cycle, • Writing on the cards on a daily basis can be laborious and • Obtaining the engagement and buy-in of people at the beginning.