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THE ROLE OF LEAN IN DIGITAL PROJECT DELIVERY

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ABSTRACT

The role of digitalization in delivering construction projects is ever increasing as digital tools and processes are pervading the entire construction lifecycle. Lean processes have a proven track record in improving construction project delivery while playing a positive and important role in the deployment of digital processes.

This paper discusses the key lean drivers for introducing digital production management systems to support efficient production planning, monitoring and controls. The paper also highlights the role of Last Planner System® (LPS) in the development of centralized digital command rooms to integrate disperse project teams. The research methodology was action research using a case study of a data centre.

The use of digital tools to support the last planner system can affect the behaviours of the participants. Improved transparency with an increased understanding from using digital platforms can improve the understanding between project stakeholders. It was found that the lean collaborative processes based on the LPS, especially the lookahead and commitment planning processes contributed significantly to the successful deployment of the digital platform and improvement of the control cycle.

To manage global networks and integrate fragmented project teams, Lean construction methodology supported using digital tools can enhance the collaborative environment. Digital construction can enhance the knowledge sharing that in turn improves social networks that can increase innovation.

KEYWORDS

Lean Construction, Digitization, Project Management, Last Planner System®

INTRODUCTION

Lean thinking and lean processes have proven to be successful and to positively influence major operations and improve productivity. Using digital tools to support lean concepts by providing near real time information that can be formatted and displayed can support multi stakeholder engagement and increase the effectiveness of collaborations (Sepasgozar et al. 2021). This information should underpin lean social collaborative production planning, where information is used to understand productivity rather than direct operational decisions using data alone (McHugh, et al., 2021). The correct management of digital platforms can support and increase the effectiveness of lean construction methods for project teams. The use of cloud based platforms and organized data, project teams can share a single source of truth that can improve communication to avoid delays and minimize reworks (Quiso et al. 2020).

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LITERATURE REVIEW

The international construction industry is vast, according to the Confederation of International Contractors' Association (2022), global construction industry represents a global turnover of US$14 trillion and employs around 120m people. The industry relies on specialized contractors and designers who work with international clients. Standardized delivery methods for projects are desired to manage productivity. Productivity loss is experienced when a contractor has not accomplished anticipated achievable or planned rate of production (Gibson and Edwards 2015). Lean Construction (LC) methods have been identified as a possible improvement to construction project management. Technology has been identified as key element to support LC, however barriers to implementation include technical barriers, organizational fragmentation, and organizations unwilling or prepared to make the necessary changes to adopt LC (Hamzeh et al., 2021).

The availability of skilled workers is an issue for the industry with the current global growth (Ceric & Ivic, 2020). This deficit of skilled operatives effects the quality and overall project performance resulting in higher costs (Karimi et al., 2018). Utilizing key staff and bringing the required expertise is a challenge to the construction industry. The availability of skilled staff and underutilization of staff hinders construction productivity.

There is an increased focus on the adaption of construction 4.0 technologies and methodologies (Bolpagni et al., 2022). The digitalization of the construction industry and the advancement of Building Information Modelling (BIM) have highlighted opportunities for projects to harness construction 4.0 technologies (Kunz & Fischer, 2020; Sacks et al., 2010). The Internet of Things (IoT) can seamlessly interconnect components and improve the quality of performance and output of information systems. While Industry 4.0 is the bedrock of technological change through an adaptable tool to ensure desirable change and automation occur in the process of adopting IoT and Lean concepts, which was supported in (Ballard & Howell, 2003; Dave et al., 2013, Dave et al., 2016). Digitalization can potentially prove beneficial for large scale projects where project teams are fragmented and where project scope is vast. Effective and immediate access to information minimizes the time and labour needed for retrieving information and reduces the occurrence of ineffective decisions that are made in the absence of information (Ergen et al. 2007).

The adaption of digital technology and platforms can assist lean construction where production networks can be deployed for all stakeholders that can improve productivity both on and off site. This can improve efficiency, accountability, sustainability and scalability where dispersed project teams can collaborate (Frazzon et al. 2013). These processes can further be supported by providing digital collaboration spaces where teams can join collaborative meetings in digital operation rooms. This improves the effectiveness of collaborations as the correct stakeholders and decision makers are available to participate in the sessions. With live digital information at hand stakeholders are prepared for collaborative meetings where the project information available on the cloud for interrogation which increases the value of the meeting (McHugh, 2021).

LEAN BASED MANAGEMENT

Lean thinking, tools and methodology can influence major operations and improve productivity. Continuous innovation and supporting a learning environment are core elements of lean construction (Zhang and Chen 2016). As construction projects become more complex, specialization of specific functions has introduced complex project organizational structures and interfaces that require integration to complete the project. How a project performs is linked to how efficient the bounded activities are planned, managed, and how permeable the boundaries are to support information flow, share knowledge and learnings (Hobday, 1998).

The use of digital tools supporting lean concepts of management can provide innovative solutions to maximize the availability of near real time information. This information should underpin lean social collaborative production planning, where information is used to understand productivity rather than direct operational decisions using data alone (McHugh, et al., 2021). Construction research theories provide insights, but it is the nature of the markets—notably, the diverse objectives of stakeholders and the procedures and their practices in pursuit of self-oriented benefits—which are the main impediments to achieving greater coordination and collaboration (Fellows & Liu, 2012).

Digital platforms can support the generation and sharing of knowledge and will need to be adapted and improved as construction management progresses. Hamzeh et al., 2021 introduced the concept of Lean Construction 4.0 which recognizes the advancement of digitization in the industry with the need for a human centric rather than a technologically centric philosophy to advance the industry. Using cloud platforms and organized data, project teams can develop an information system where all stakeholders can commit and also be held accountable (Hicks 2007). This also provides a collective collaborative platform where the project interests are highlighted rather than interest of just individual stakeholders. This reinforces positive behaviors where project constraints can be identified and shared clearly, and project commits can be shared and validated using acquired data.

RESEARCH METHOD

Action Research (AR) has expanded over the years across varied disciplines as a means for improving the quality of interactions and understanding among people in social situations (Burns, 2005). In this study some of the authors were participant in the study. The results and actions outlined were created collaboratively with the project participants. The study focuses on generation of public sphere where participants can engage. This participation is relevant in critical participatory action research. However, authors have emphasized that the key form of participation in this kind of research is participation in a public sphere and participation with others in communicative action. This approach is analogous to a conversation in which people strive for intersubjective agreement about the ideas and the language they use, mutual understanding of one an - other's perspectives, and unforced consensus about what to do (Kemmis et al., 2013).

A case study was developed to represent the research where a "case study" can be defined an intensive study about a person, a group of people or a unit, which is aimed to generalize over several units (Heale & Twycross, 2018). Case studies by their nature, are more concerned with depth of analysis than with generalization (Borgman, 2015). This study follows on from previous research developing digital social environments (McHugh et al., 2019; McHugh, et al., 2021). Case studies provide a deeper understanding, for example, causal relationships than controlled experiments do (Host et al., 2012).

The research will be led by one of the authors who is an industry practitioner of lean construction. Action research is participant research that comprises of taking actions while studying a problem whilst also producing knowledge accumulating experience and contributing to the discussion of problems (Collatto et al. 2018). This research will support the development of an information system to support the efficient phased handover process that is essential for commissioning stage of the project.

CASE STUDY

The case study is on a €1.2bn data centre project where lean project management systems have been used during the construction phase. The project was based in Ireland and had initially started in 2016. This facility is an 86,000 m² structure consisting of 8 single storey data halls

with associated electrical rooms and external backup generator systems. The facility also consisted of an administration block and external security centre. This study was carried out on the third phase of construction on the campus. For this phase there was a fundamental change of the design where a First of a Kind (FoK) cooling system was designed for the client. This required significant equipment changes along with layout and build sequence alterations.

This study will focus on the final phase of construction the Commissioning (Cx) phase. The (Cx) phase of data centre projects have traditionally proven to be more difficult to execute as there are more stakeholders involved. Since they are highly dependent on each other, developing schedules in parallel without adequate coordination can lead to misconceptions and, therefore, a great deal of rework (Garcia et al., 2004). It has been identified that the Cx phase requires a greater level of collaboration with an increased integration of project stakeholders. The problem posed was how to gather, share and use information acquired to integrate construction, commissioning, and quality functions for all stakeholders.

Digitized LPS was use on previous project phases on the site where they were completed and handed over to the client defect free. The resultant predictable and reliable phase handovers enabled the client to challenge the team to construct and commission a FoK construction project. This case study documents how digitization supported the process and assisted the integration of teams and it supported the execution of complex tasks.

Preparation for Digital Collaboration

The Production manager, Cx manager and programme manager developed a high-level work breakdown structure. Early engagement from the project vendors and design team highlighted project constraints. The Cx phase of the project started with a pull planning session where all stakeholders developed a commissioning plan. There were approximately 20 different organizations ranging from designers, specialist vendors, quality assurance and trade contractor teams. This exercise identified and exposed issues with the construction and Cx sequencing and provided the team with a greater understanding to complete the Cx programme. Figure 1 illustrates the progression from reviewing the proposed master schedule to development of an actionable commissioning programme,

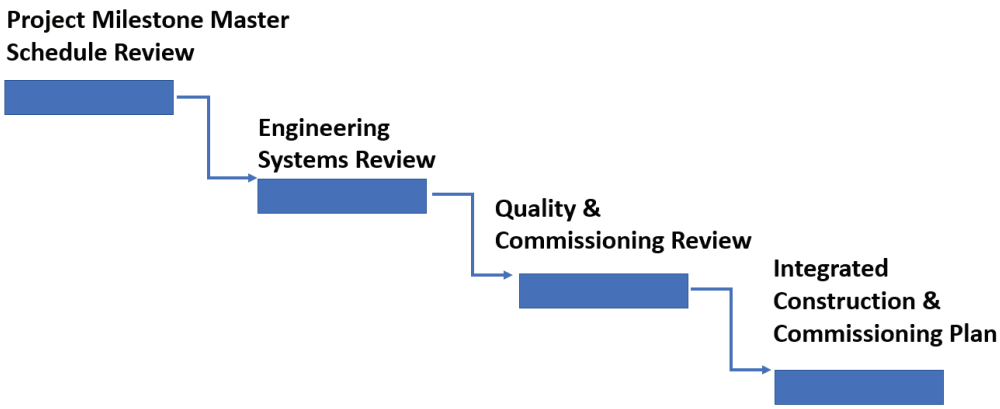

Figure 1: Cx Framework development phase

This was then cascaded to the trade contractors to review and resource in advance of a pull planning digital mapping day. A digital hybrid method of mapping was used for the first time instead of using 'post-it' notes in the room. Project resequencing and constraints were highlighted in the collaborative session. A dedicated digital hub (Figure 2) was used with

technology to virtually interact using web cameras, mist microphone room pick up and high-definition touch screens and sound bars. This room was designed to improve interactions between site-based teams and virtual remote teams. The use of touch screens and smart microphone functions improved collaboration between team members.

The use of this technology allowed interaction between professionals connected remotely and the ones in presence. The command room has been present on the project since the first phase. The digitization of the room began early in the project and has evolved and improved on each phase where new available and affordable technology has been introduced. The room was designed with collaboration in mind where interaction is key to good communication and collaboration.

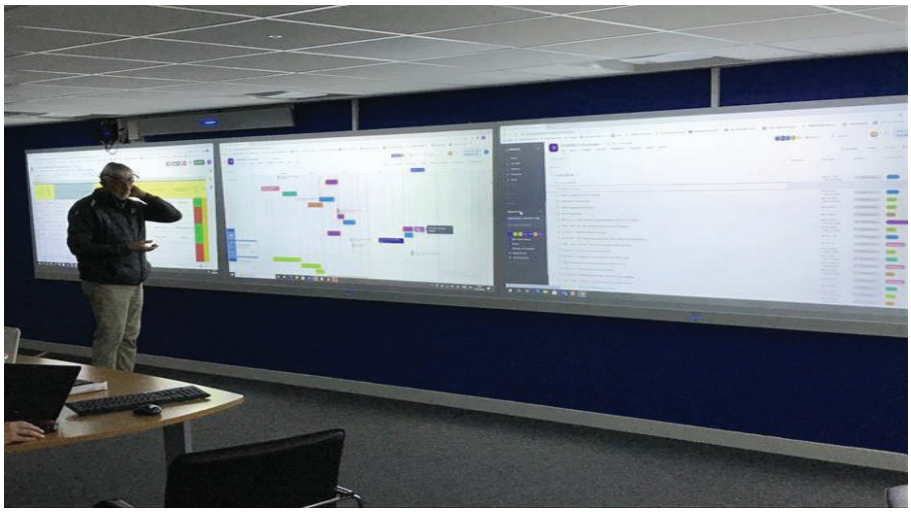

Figure 2: Digital hub with Digital Pull Planning sequence

DAILY OPERATIONS PREPARATION

The quality of collaborative meetings observed relied on participants being informed and prepared. Information quality is key to the success, shared information platforms aided the acquisition and validation of key project information. The identification and tracking of key activities were important to successfully achieving defined targets. Therefore, the more extensive and balanced the inputs of information (i.e., options, alternatives, predictions, and criteria, which we call collectively decision contents), the more informed the decision basis becomes (Kam and Fischer 2004). Following the initial mapping day there was a series of targeted workshops to map the critical air, water & electrical systems. Visilean (Dave, B., 2013) was used to prepare these plans and it was used to highlight and manage constraints raised.

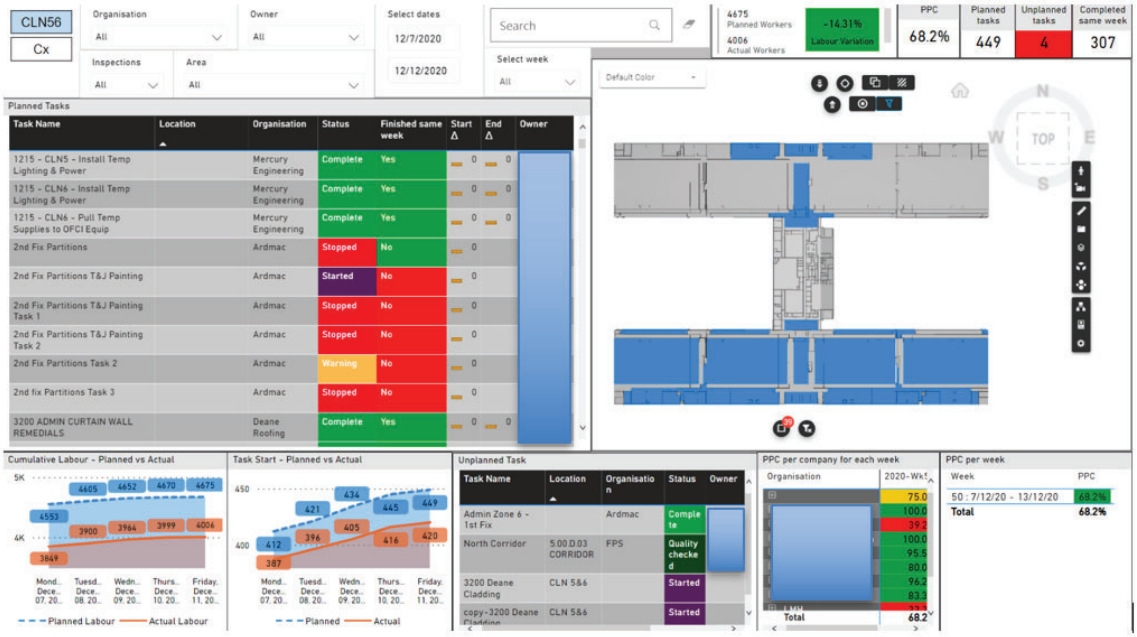

Figure 3: Weekly Work Plan PPC live dashboard

This plan was then further broken down to develop look ahead planning and weekly work plans using the Last planner System ® (LPS). Digital platforms were identified to gather information and share the status of the project as shown in (Figure 3). BIM 360 Field was used to prepare and manage the quality check sheets which are necessary for the Cx stage. There are limited mitigation measures at Cx phase for not completing the preceding Cx activities, therefore it is necessary to have an accurate picture of the current activity status. This allowed project teams to develop and manage the required check sheets collaboratively. This provides the Conditions of Satisfaction (CoS) necessary for seamless staged handovers. Daily morning huddles previously held on site were relocated to the digital command room. Digital white- boards were prepared by each trade contractor and vender. This board was designed to include client issues, design issues, quality issues and commissioning status of activities.

A Cx dashboard was developed to capture the project status and improve communication between project stakeholders. Constraints were raised and incorporated into daily meetings where the team removed constraints and improved the delivery process. The status of each piece of equipment was managed for installation. The status of each piece of equipment tracking was essential to map the critical Integrated system test (IST). IST can begin when all equipment has passed the required testing and initial commissioning.

Daily huddle meetings are an important meeting in the production control system cycle. This is where daily commitments are reinforced and where the team members collaborate to execute defined assignments, this is where the quality of the planning and preparation is validated. It is important that commitments can be communicated effectively and trade to trade handovers are delivered efficiently. These meetings are the foundation for all future planning and ensure that the quality of the installations is validated and ready for the next stage of commissioning. Dashboards were an effective way of managing commitments as shown in figure 4.

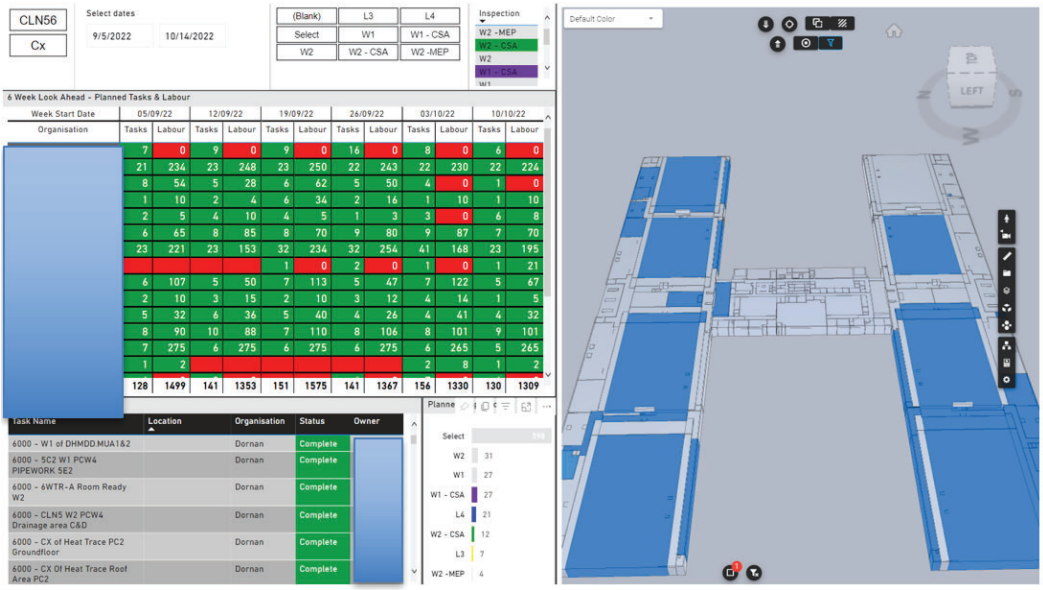

Figure 4: Cx Dashboard

Reporting & Communication

Project data was collected using multiple digital platforms. This information was integrated by developing Business Intelligence (BI) dashboards. Dashboards played an important role for communication between project stakeholders. PowerBi® platforms were used to gather information from different sources to integrate into a single visualisation platform. Data was collected from multiple platforms that were used for daily works planning, material delivery, safety documents, quality documents, design, with laser and scanning/reality capture sources. This data was formatted and sorted by area and by utility and then by trade contractor.

It was important to code and identify all assets and functional areas correctly to allow data from different formats to be integrated correctly. There were over twenty different organizations imputing information daily into the system from daily activity reporting to quality check status and BIM coordination and scanning. This form of bottom-up communication really meant that there were over one hundred individuals managing the Cx programme between site teams and planning teams. It was important that all teams could work effectively and the ability to report accurately on daily Cx activities was important. This allowed teams to work effectively together with a shared understanding of the project.

The purpose of developing of digital dashboards was that they could be used in a digital control room to support allowed project teams' ability to communicate effectively. The dashboards were configured to be used at the different stages of the LPS. Short term forecasting and PPC dashboards were primarily used for site supervision collaborative meetings. Weekly work plan dashboards were used at daily huddle meetings. The information collected from the field fed directly into operational and planning dashboards.

Figure 5: Quality Dashboard

The project team focused on improving the sequencing and trade to trade handovers of this FoK project. Quality trade to trade handovers are an important gateway for the Cx stage of the project. The status of equipment was visually displayed on the quality dashboard (Figure 5). There are multiple stakeholders involved in this quality function. Defining what the correct parameters and requirements for each stage is important. Communicating this and measuring adherence to the defined parameters is also required. Firstly, in design the quality of the documentation and design modelling is a make ready need for construction. Procurement of materials and the validation of installation by construction teams is then required. The demonstration of how to present the soundness of installations to the project quality teams is required. The development of a detailed quality plan ensured that all stakeholders understood the steps to handover installed works. The sign off for the equipment and associated services before the Integrated Service Test (IST) is the focus of the Cx phase of the programme. In terms of planning, each sequence of work is directly linked to the next.

Forecasting and ensuring quality inspections passed first time was a key focus for delivery. Scheduling quality walks and confirming commitments were ready is an important process for accurate look ahead planning. This ensured that all project stakeholders could schedule and utilize their resources effectively (Figure 6). The raising of issues was promoted to provide learnings and to support developing a plan to execute the works to complete each phase of the project. The importance of the quality dashboard ensured that when handover of a section of works was panned, it was possible to demonstrate in advance that the works were completed to the correct standard.

Figure 6: Progress Dashboard

FINDINGS

The use of digital tools was integral to the success of developing the Cx phase plan for a first of a kind mechanical cooling process. The construction and commissioning processes were integrated to achieve a successful project delivery. The ability to collaborate and generate near live data to track the elements of the project efficiently provided project teams the resource to make informed decisions.

Presenting complex project data in a form that allowed all stakeholders to engage effectively improved communication between project stakeholders. Near real time information increased the accountability of all stakeholders and increased the quality of commitments.

The use of collected field information provides certainty of the quality of the works. At each stage of the process the conditions of satisfaction were communicated, and the overall project performance was measured and displayed digitally. This provided the correct environment where transparency created trust and the digital information provided accountability against commitments. It was clear as the project developed that the complex nature of the Cx phase required greater co-ordination and involved multiple stakeholders to collaborate to complete.

This was particularly important in this phase as often specialist personnel would be required to be scheduled to be available weeks in advance of attending the project. This also gave assurances to all parties that the works were available and could be coordinated effectively. This was crucial to the success of this phase of the project. Specialist commissioning teams could be booked in to attend the project well in advance. The visibility and execution of make ready tasks increased the certainty of work being available for these teams when they arrived on site. This increase of resource utilization increased the productivity of the Cx phase of the project as commissioning could only continue when the preceding phase was completed. The use of near-live information and production dashboards allowed remote teams to collaborate effectively.

DISCUSSION

The forming of temporary alliances is typical in construction and the parties to these alliances change from the various stages from design to handover of construction projects. The social technical element provided by lean construction can develop the capabilities of the project by the process of continuous improvement.

New roles and responsibilities have been identified to support lean construction. Process facilitators assist collaborative meetings and now with increased digitization data management roles are important to manage the acquired data. Digital dashboarding were manged daily using technology syncing of acquired information for the digital control room and collaboration rooms. This support structure maintained the quality of the information that was increasingly relied upon for project status reporting and planning. It was important to the success of the project that all project teams could report information and communicate effectively.

The importance of using a single source of production and planning data positively influenced behaviours on the project. The quality of information collected from the field was high because it was used daily to inform operational meetings. The bottom-up communication stream integrated site teams and office teams which increased trust. The transparency of using shared dashboards improved accountability and allowed the teams to communicate effectively. The design and development of digital platforms and digital collaboration areas need to be considered to allow innovation and adaption of digital technology to support project production.

CONCLUSION

It is recognized that the adaption of Lean Construction 4.0 is driving innovation in the construction industry. This paper shows that building a digital environment to work effectively and interact with digital media virtually and in person promotes the adoption of digital tools. This in turn stimulates innovation and increases the use of digital tools to support construction management activities. The recognition of the role of digital in lean construction is important to note when identifying digital hardware and software to support construction management. Digital tools however cannot take the place of skilled workers and managers.

The creation of a lean production management system where tools and practices are supported by digital tools improves LC. The digital platforms were transparent, and the project status is visible to all stakeholders which in turn increases the collaboration and focus the deliver the project holistically.

There is an importance to ensure the quality of the data is correct. This requires multiple tools and constant maintenance of data. The coordination and collection of data to support managers is vital to the success of clarity of collaborative sessions both virtually and in person. The amount of information that can be collected is enormous. It is important to understand where the value is in the information and avoid overproduction of information that can over complicate and undermine the production control system.

The use of digital tools and platforms to effectively communicate and to demonstrate honoured commitments positively influences behaviours on the project. The flexibility provided by using digital tools, allows all stakeholders to engage and influence the workflow on the project. This improves the quality of engagement between project stakeholders where the acquired data forms the basis of the argument rather than a perception of how the project is progressing. This also encourages a holistic project continuous improvement process where stakeholders can continuously improve delivery and increases predictability of the project schedule.

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