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A KAIZEN EVENT ENABLED BY SYSTEM ENGINEERING IN AN INFRASTRUCTURE PROJECT

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ABSTRACT

A Kaizen Event is a well-defined and accepted approach to construction outcome improvement. However, rising project complexity is making this a very involved process if it is to be successful. System Engineering (SE) is an emerging practice that can address project complication. This paper will share a journey of a SE team on how to streamline sophisticated internal processes that manifest in better safety, quality and productivity when improved. SE is a recent innovation emerging as an essential discipline considered state-of-the-art. It crystallises the integrated processes of work and their outcomes on projects and allows constructors to standardise their best practices effectively. This case study of a mega infrastructure rail project in Australia is a relatively brief treatment of a complex process, its factors and its results.

The project work package delivery was improved, including lower cost, as they were sequentially built. For the future, rapid urbanisation and climate change effects are increasing in Australia, and contractors must respond efficaciously for all stakeholders for the greater society to benefit. Mastering Lean principles such as Kaizen Events can help mitigate or minimise long-suffered construction industry problems.

KEYWORDS

Lean construction, SESA, system engineering, kaizen event, continuous improvement

INTRODUCTION

This case study explores and examines the multistep process to significantly improve delivery involving four projects. The paper's research question is, 'Has the application of Kaizen Events improved the SE processes in this megaproject's sequentially scheduled work packages?'

RISING PROJECT COMPLEXITY

A high degree of internal and external complexities has caused many difficulties in construction and hindered the successful delivery of mega-construction projects (Kardes et al., 2013). Common evidence is that significant differences exist in the performance of different types of large construction projects; for example, according to Flyvbjerg (2014). the average cost overrun rate for rail projects is 44.7 per cent, whereas for road projects are 20.4 per cent. Systematic understanding and effective control for complexity are crucial components of project management (Bosch-Rekveldt et al. 2018)

Fast-Berglund et al. (2013) assert that construction complexity positively correlates with installation errors. In mega construction projects, many errors may occur during the construction process due to the complication of multiple technical and management process streams. The accumulation of such errors will lower the overall quality of the project and might even affect the function and operational efficiency of the project. A well-accepted stability theorem (May–Wigner) concludes that increasing system complication inevitably leads to chaos (Sinha, 2005). Aslaksen 2008 concludes that construction project complexity has increased due to several factors such as material science, equipment utility and value (both installation and facility), and design along with increased government regulations.

Increasing Construction Needs

Rapid Urbanisation

Urbanisation is a manifestation of improving human society and economic development; it is critical for social and economic development (Gong 2022). The 21st century is one of urbanisation. Along with this phenomenon, the world's population will increase. White et al. assert (2010) that lifestyles are also changing in the 21st century. As a result, people will demand larger dwellings and other facilities. The three phenomena together point to a need for construction that may outpace contractors' ability to meet it.

Climate Change Effects

The increased consistency, duration, and severity of high-temperature weather have increased recently due to changes in climatic conditions. Australia is highly vulnerable to this hazard. A growing number of studies in Australia have been conducted each year over the last decade related to the heatwave phenomena (Pörtner et al. 2022). Dealing with heat would require upgrading current buildings and other structures, thus, further increasing construction demand. Due to climate change, chaotic weather events such as wildfires, storms and floods will increase the destruction of the built environment. Eingrüber and Korres (2022) assert that the speed and intensity of flooding will accelerate with climate change. There is a high probability of increased and erratic rainfalls accompanied by higher winds in many parts of the world (Moradkhani et al. 2010). Climatic causes play a prominent role in the deterioration of building fabric, and climate change is projected to accelerate the built environment deterioration rate (Johns and Fedeski 2001). The International Panel on Climate Change (IPCC) asserts that costs for maintenance and reconstruction of urban infrastructure, including building, transportation, and energy, will increase with global warming (Pörtner et al. 2022)

Kaizen Event

The factors that guide a Kaizen Event, the continuous improvement of processes, were introduced based on presenting a scientific model for implementing improvements founded on a sequence of questions that enable identification, analysis and problem-solving, called the Scientific Thinking Mechanism (Shingo 2010). Furthermore, Imai (1996) asserts that kaizen implementations to result in practical solutions is based on three general activities: evaluating data, communicating problem-solving methods and keeping the Kaizen Event culture active. Specifically, Kaizen is an intensive Step Change process improvement where the team focuses on improved methods of perfecting execution. It occurs in eight intensive steps enabling this greater efficacy:

1. Choose the theme/focus of the application (determined according to administrative policies according to priority, importance, urgency or economic situation);
2. Analyse the context;
3. Collect and analyse to identify the root cause;
4. Establish countermeasures based on data analysis;
5. Implement countermeasures;
6. Confirm the effects of countermeasures;
7. Establish or revise standards to prevent recurrence;
8. Review the previous processes and start working on the next steps.

System Engineering

The International Council on Systems Engineering (INCOSE) defines SE as "an interdisciplinary approach and means to enable the realisation of successful systems.". Blanchard (2004) more succinctly stated that it is an orderly process that brings a system into being that integrates humans, materials, equipment, tools, information, technology, and money to function in delivering a specific outcome. Johansen and Hoel (2016) define Systematic Engineering as "an assurance that the project fulfils all functional requirements within the set time, cost and quality requirements, planned and verified by a structured process managerially driven from design and planning to handover". However, there is little documentation by the industry and light research by academia to understand the performance of practitioners and the product (Beste 2020).

In the implementation in the construction industry, the need for System Engineering (SE) is becoming greater since construction project complexity is increasing (Aslaksen 2008); its economic value is growing to USD 15.5 trillion worldwide in 2030 (Pacheco-Torgal 2020) and failing to consistently deliver projects to the satisfaction of the project owner and end-user (Boyd and Bentley 2012). Raworth (2017) asserts that all industries need to be "savvy with systems" to succeed in the 21st century. Therefore, the economy's common understanding needs to be updated from its pre-millennium knowledge to one of the complex current systems of many interdependent parts SE can rapidly and reliably integrate business and technological processes that construct infrastructure, building and processing facility projects (Aslaksen 2008).

Constructing the built environment involves many complicated tasks that must be carried out with extreme care while economising on costs. Most construction project functions are costly, and even a minor mistake can cause significant financial liabilities. Therefore, a steady and careful management process is required (Lu et al. 2013). In this case study, SE was executed on an existing process and did not have the luxury of a legacy-free or "green field" operation. Lynghaug et al. (2021) note that manufacturers pursue SE to improve a product or process. Once embedded, the improvement is produced in high volumes. In the construction sector, design and construction efforts are spread across project stakeholders, often one-off actions that result in lessons learnt that are usually minimally captured.

Beste (2020) proposed further studies of SE with more data from an international perspective to complement the existing research and improve the discipline. Furthermore, it is critical to understand many stakeholders' views, such as the design team, contractor and customer, to increase the clarity of the dynamics.

There exists a high conflict level in the construction industry. Reasons for this conflict include delays, cost overruns, and quality problems. The unreliability of multifactor productivity and these factors might be interrelated (Lynghaug et al. 2021). They also note that the implementation of the Systems Engineering methodology is highly dependent on the level of competence among employees in the projects in which the interdependence of tasks is disrupted by a lack of conscientiousness and industriousness by a worker(s)

As the construction effort starts with designing the work of co-dependent but standalone companies (i.e., contractors-main and sub, suppliers and designers), Lynghaug et al. (2021) assert that in practice, SE performs as a Systems-of-Systems improvement process, creating a methodology in which stakeholders work interdependently to accomplish the complex task of delivering better safety, quality, cost, schedule and sustainability. Axelsson et al. argued that the lack of a Systems-of-Systems approach is a significant reason construction productivity has stagnated. The roots cause seems to be a focus primarily invested in the resilient design of the standalone infrastructure constituent parts rather than how infrastructure components can be integrated to comprise a dynamic and valuable system (Vora et al. 2017)

The V-model is well-recognised in Systems Engineering. The approach moves a re-engineering review through design and decomposition subcomponents such as concept analysis, functional analysis, and design synthesis. In the second half of its sequence, satisfying integration, verification and integration, including operation and maintenance requirements of the completed project, is its focus (Elm et al. 2008, Beste 2020). See Figure 1.

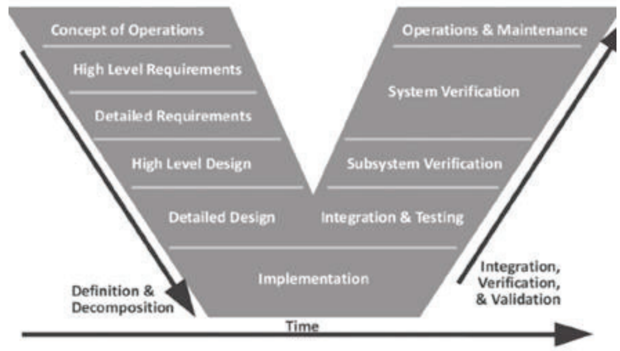

Figure 1: The V-model is the Core Framework Utilised in System Engineering (Elm et al. 2008)

Lynhaug et al. (2021) found problems with verification and verification (V&V) related to ambiguous technical and business specifications. These ill-defined requirements are partly blamed on the lack of budget and time for V&V activities in the early phase—subsequently, this lack of clarity results in imprecise contract language, schedule delays, and verification failures. Cotterman et al. (2005) assert that there are five general factors to consider in system engineering. They are 1) Concept of Operations 2) Business Case 3) Best Practices 4) Standards and Regulations 5) Lessons Learnt.

The term, System of Systems (SoS) was created decades ago to crystallise a definition for an approach to execute complicated projects such as construction infrastructure. Its attractiveness is that it combines disparate functions synergistically towards a common goal. However, SoS engineering has to be customised to individual complex ventures due to their independence, heterogeneity, evolution, and emergence factors. (Nielsen et al. 2015, Lynhaug 2021). Clark (2009) asserts that SE synergises the value of the components when:

1. the elements are integrated (i.e., have interfaces)
2. these elements might be (or not) members of a common domain (such as a product line or rail project)

CASE STUDY

Dozens of highly similar infrastructure projects were procured and scheduled in Australia, starting in 2016 and planned to continue until 2025. Due to their nature and limited resources, they were sequentially constructed, allowing for robust implementation using a continuous improvement approach to spur innovation. This case study is based on similar rail projects – two current and two future states.

MOTIVATION

The stakeholders found that after finishing their first two infrastructure projects as part of this Alliance Contract, the mega project's system engineering and safety assurance processes were inefficient and unreliable. A traditional Kaizen effort could not succeed in several areas without a more sophisticated approach. Upon inspection, they were found to lack communication clarity and process annunciation. Examples include a lack of defined roles and responsibilities, resulting in unpredictability, waste, and program risk. The Project Director stated, "The system engineering and assurance process (system, outputs and definition) is inefficient and lacks defined roles and responsibilities for alliances developing rail infrastructure projects resulting in uncertainty, waste, and program risk."

METHODOLOGY

A re-engineering initiative was started under the System Engineering and Safety Assurance (SESA) team which included the preparation and review of Safety Assurance Reports (SARs) and Safety In Design (SID), risk/hazard identification, mitigation & management throughout the project life cycle. This paper will refer to it as System Engineering or SE. Requirements management, including Requirement Allocation and Analysis Traceability Matrix items (RAATM) for the asset delivery's complete 'V' cycle. System interface and integration management, including Human Factors and other key systems' integration in design development and risk management support.

The focus was on improving the next two projects in the scheduled sequence. To launch the process, a 1-day Kaizen Event workshop was planned and followed by short discussion sessions with the core team to facilitate breakthrough events and manage the transition from the current state to the future. As a result, on multiple projects implemented the desired future state. The stakeholders formed a SE transformation team to examine the performance of two rail infrastructures, labelled Project 1 and Project 2, with explicit instructions to audit practices, analyse results and recommend improvements. Information organisation was critical for the team to effectively and efficiently learn, implement, and monitor the lessons learned from the first cohort of projects analysed. Also, they had to annunciate and discuss their calculations and assumptions to benefit from a discussion.

The V-Model lists many generalised tenets of the projects, such as "Operations" and "Design" factors - See Figure 1. Table 1 contains the ratios to compare these four projects accurately.

- The SE cost is a combination of the Joint Venture, Designer and End-User costs
- Total cost is critical to calculating to form accurate measures, including ratios relating to worker hours, general and administrative expenses and return-on-investment
- The projects initially analysed Project 1 and Project 2 had a similar scope of work for the SE team. It is critical to have similar work packages for a creditable improvement comparison.
- SE team spent more time on Project 1 than Project 2 to set up initial processes and form the team (assumed an add of 30% - the first three months with more management time). Initial set-up is a one-time expense that should be removed from the first project or proportionally expensed to all projects.
- A weighting system was calculated and applied to other work packages to enable the team to compare the SE cost to Project 1 and Project 2 average when the scope of work was different (e.g., Project 3 compared to Project 2 ratio is 1.05; staff room added 5%, set up a time with V/Line (the State-Wide Rail Operator) added 5%, Signalling upgrade added 5%, package value -10% impact)
- The weighted cost of the SE team on Project 3 was 0.749% of the AOC (0.419% less than Project 1 & Project 2 average)
- The weighted cost of the SE team on Project 4 was 0.864% of the AOC (0.303% less than Project 1 & Project 2 average)
- The average weighted cost of the SE team on Project 4 and Project 3 was 0.361% of the AOC, less than Project 2 and Project 1 average

- The designer cost used in the model is based on the invoiced figures. However, the cost of Designer and Asset Owner cost is estimated assuming a $150 hourly rate for managers and $120 for other resources that bill out at 160 hours per month

SE was the chosen approach since changing administrative projects to a more precise (and tedious) one would cause the comparison to be suspect. The project leaders commissioned a group of SMEs to jointly assess the percentage to increase or decrease for variations from the baseline projects. This multi-professional integrated approach has been proven to evaluate differences and estimate impacts more accurately for individuals working alone.

Table 1: Component Coefficients to Compare Projects Against Baseline Determined by the Projects' SMEs

Ratio Criteria	Ratio %	Project
Initial Set up/Team forming	+30%	Project 1
V/Line set up	+5%	Project 3
Not connecting to the existing line	-15%	Project 4
Car park	+15%	Project 4
Staff room	+5%	Project 3
No Line upgrade	-10%	Project 4
Signalling upgrade	+5%	Project 3
Greenfield	0%	Project 3
Scope change	+30%	Project 4

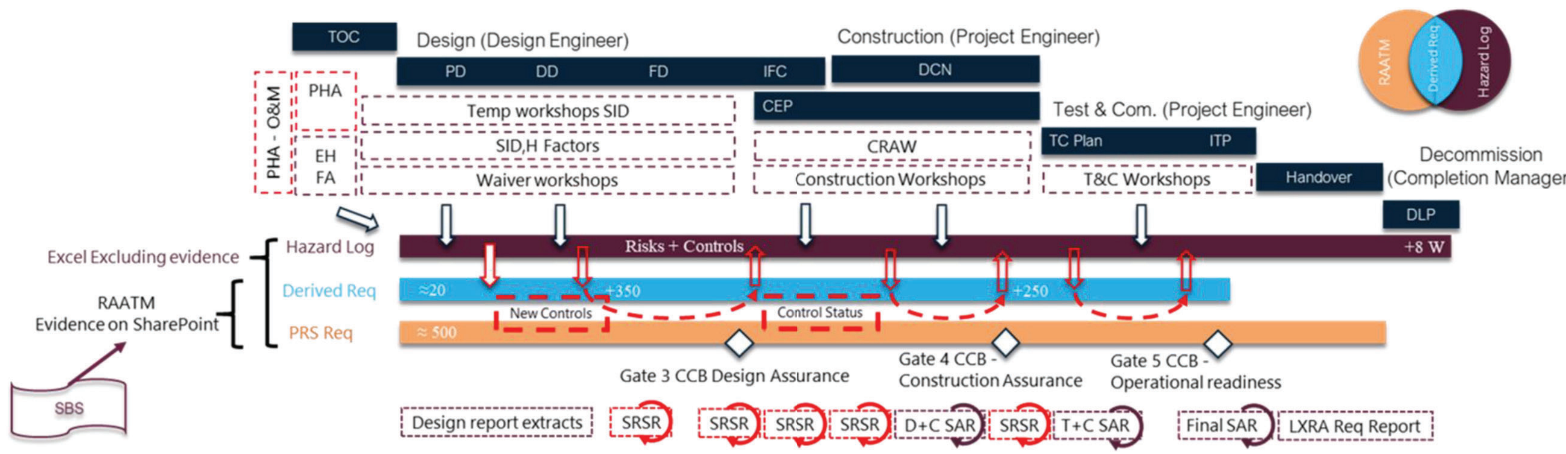

Figure 2: Current State of Projects 1 and 2

Major Issues and Improvements Needed:

- Duplicated effort for evidence reporting and report compilation
- No single source of truth for derived requirements
- Construction Operation &Maintenance risks & controls not tracked in Hazard Log
- Hazard Log can't be amended
- Controls in Hazard Log are unclear
- Hazard Log not consulted when evaluating work packages
- No time/opportunity to act on partially & non-compliant requirements
- Hazard Log management is not continuous across Design & Construction
- Resource burns out

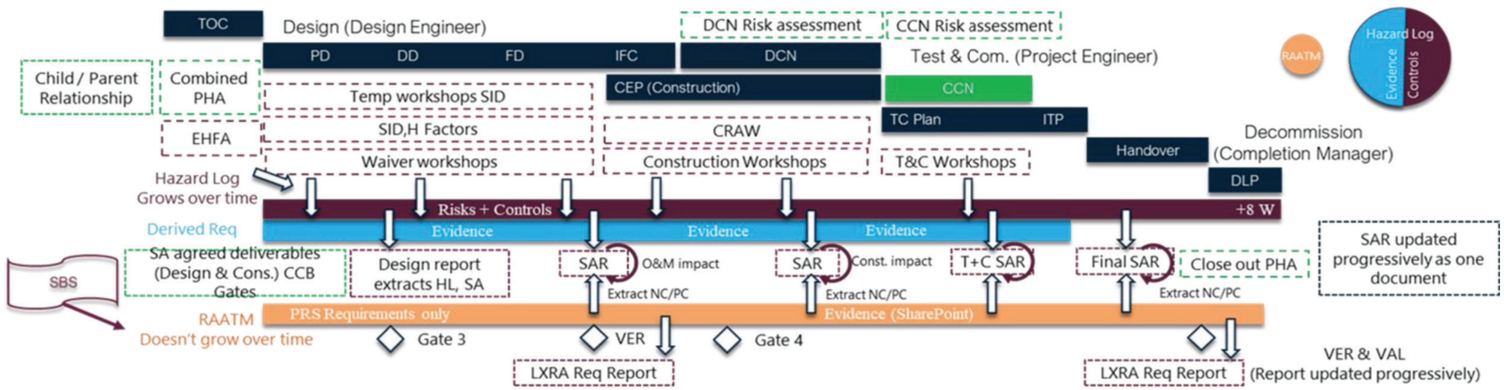

Figure 3: Future State Projects 3 and 4

CHANGES FOR IMPROVED (BEST) PRACTICES:

- Hazard Log, including reference to evidence. Complete information for others to work from – no rework
- Hazard Log progressively updated. Contemporaneous notes thus less error due to memory loss
- RAATM is used only for Project Requirements Specifications (PRS) requirements. A deeper understanding of governing standards for project
- Clear roles & responsibilities using the Responsibility, Accountability, Consultative and Inform (RACI) Matrix. Clear assignment of the lead responsible person who will deliver the task
- Combined Preliminary Hazard Analysis (PHA) workshops & reports. Two activities combined into one – more efficiency
- Visual Management Centre (VMC) for Short Interval Control. "One version of the truth" approach – less confusion and double-checking activity
- Progressive assurance through an extract of Hazard Log (SRSR). Documented quality documented at the time of confirmation.
- Focus on Unique & Novel Assets + Material + Construction Methods. Unfamiliar items and activities need more time upfront to increase cycle time when utilising
- Hazard Log consulted when evaluating projects. History is invaluable to the improvement of safety, quality and productivity

Table 2: Project Cost and Saving Comparison (AUD) – First Two versus Last Two Packages

Package	Actual Outturn Cost (AOC)	SE Cost	% of SE Compared to AOC - Weighted	Achieved Saving Compared to Projects 1 and 2
Project 1	$77,786,146	$1,191,900	1.179%	NA
Project 2	$72,556,966	$839,000	1.156%	NA
Project 3	$127,941,091	$1,006,100	0.749%	$535,527
Project 4	$90,186,517	$919,600	0.864%	$273,609
Total SE Difference Projects 1 & 2 and 3 & 4		**$56,400**		
			Total Saving	**$809,136**

BENEFITS

The alliance team recognised and articulated several benefits to the SE approach that they created and implemented.

- Significant reduction in resources required to manage SE processes once systematised.
- Less staff frustration and potential staff turnover due to the routine and familiarity of a system.
- High-quality safety assurance report (SAR) to improve asset owner's confidence in alliances; thus, the director may spend more time managing their organisation's everyday functions.
- Direct child/parent relationship with Project Hazard Authority making closing hazard list (hl) items easier.
- Eliminate duplication and thus increase process speed, higher asset utilisation and fewer costs.
- Eliminate or reduce project risks minimising schedule disruptions and unbudgeted costs.
- Standardised assurance report template making training, recording and analysis easier.
- Better utilisation of resources (less stressed equipment and safer crews). Since these inputs are always constrained, this can lessen switching between projects, i.e., Fewer inefficient start-ups, closedowns and transfers of people and equipment,

DISCUSSION

An intensive collection of information, including data and observations, is needed at the beginning of a Kaizen Event initiative in construction. In addition, SE requires data (qualitative and quantitative) and other information, such as an existing state process map, to be collected and analysed to transition between current to future states.

Where they exist, construction projects' trade and discipline-oriented silos lead to sub-optimal interfaces accompanied by verification and validation challenges. This was true in this case study. As is well documented, the construction industry differs fundamentally from the manufacturing domain, emphasising the differentiation of the product design – due to the customer need for a unique product due to local conditions such as the project's purpose, location, material availability, equipment selection and local technical mastery - rather than standardising process design in its engineering of systems effort.

The complexity is not only trade sequencing but also structure and services integration. Since products have increased sophistication than the skilled craft to install them, a new system conflict or unintended consequence may appear with the latest design. The process seems to require a review and possible update, just like a firm's strategic plan. The issue is which firms will re-engineer the design and construction process as their stakeholder groups constantly change. Prime contractors and project owners are in the hundreds in most regional markets. This issue suggests that Lean Construction researchers and practitioners must focus on the enterprise rather than the project as a starting point to accomplish the SoS approach that Nielsen et al. (2015), Lynhaug (2021) suggest.

SUMMARY AND CONCLUSION

According to Flyvbjerg (2014), rail construction has twice the risk of budget overrun when compared to road projects. This problem appears to signal the need for a detailed and holistic improvement approach to both. SE fits this requirement. The principle of Kaizen was utilised to streamline the SE process. This can be characterised as SoS. It is essential to point out that practices and insights will stay with the stakeholder firm for use again, while others are unique to the infrastructure project thus, not readily applicable to the next one.

Construction has many barriers to improvement and innovation. This may also be part of the reason that hampered many companies from developing this SoS approach. However, it is clear that an opportunity exists; this case study demonstrates that with the addition of a minimal cost (AUD 56,000) of targeted investment based on a thorough review, a significant saving (AUD 809,000) can be realised. Total savings on the portfolio of ten projects are predicted to be between AUD 5.8 and 7.1 million, due to be completed later this decade. For accurate outcomes, the SE team used the audited cost of the SE process and the resulting AOC after the completion of each package. At the time of publishing, a final result has not been finalised and announced.

Kaizen is a valuable process for long-term and consistent improvement. Tedious and tireless upfront work is needed to ensure a high probability of successful transformation in Mega Projects. Given the low margins and increasing complexity of construction, it appears to be a minimum requirement. With the impending dual crises of rapid urbanisation and climate change effects, it seems crucial to society's future.

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