EnPress Publisher

Journal of Infrastructure, Policy and Development 2024, 8(9), 7386.
https://doi.org/10.24294/jipd.v8i9.7386

Article

Effectivity analysis of the scrum framework adaptation in safety performance improvement: A system dynamics approach

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CITATION

Sudiarno A, Abdillah O, Yusdin HD, et al. (2024). Effectivity analysis of the scrum framework adaptation in safety performance improvement: A system dynamics approach. Journal of Infrastructure, Policy and Development. 8(9): 7386. https://doi.org/10.24294/jipd.v8i9.7386

ARTICLE INFO

Received: 25 June 2024
Accepted: 9 July 2024
Available online: 4 September 2024

Abstract: The rapidly growing construction industry often deals with complex and dynamic projects that pose significant safety risks. One of the state-owned companies in Indonesia is engaged in large-scale toll road construction projects with a high incidence of workplace accidents. This study aims to improve safety performance in toll road construction by implementing the Scrum framework. The study uses a System Dynamics approach to model interactions between the Scrum framework, project management, and work safety subsystems. Various scenarios were designed by modifying controlled variables and system structures, including introducing a punishment entity. These scenarios were evaluated based on their impact on reducing incidents and the incident rate over the project period. The results indicate that the combined scenario significantly reduces incidents and incident rates in different conditions. The study also finds a strong relationship between Scrum framework implementation and improved safety performance, demonstrating a reduction in incidents and incident rates by over 50% compared to existing conditions. This research underlines the effectiveness of the Scrum framework in enhancing safety in construction projects.

Keywords: safety performance; scrum framework; construction projects; system dynamics simulation

1. Introduction

The construction Industry commonly complies with the complex and dynamic nature it needs for effective management strategies to navigate (Shen, 1996; Son, 2022). A complex project can be defined as one with multiple systems corresponding to each other. Thus, the project's dynamicity means that the system's condition changes over time (Taylor and Ford, 2006). The construction industry is sensitive to time and cost. Contractor companies often forget the safety aspect while accelerating the project to achieve the minimum price and time needed to accomplish the project (Chan et al., 2023). According to the Indonesian Ministry of Public Works and Housing, construction is one of the industrial sectors with the highest accident risk (Ramdan and Handoko, 2016). This case study analyses explicitly the safety aspect of the toll road construction project. The project recorded seven high-risk incidents from 1 February 2020 to 15 April, indicating a high incident rate. This problem suggests that a toll road construction project requires a practical framework that does not neglect the safety aspect while resolving all of the potential issues that occur in the project, such as the change of design, specification, time completion, or external problems that cannot be controlled, such as weather, market, and political condition.

Scrum is a part of an agile framework mainly used to resolve complex problems within a short time frame (Schwaber and Sutherland, 2017). One of the main advantages is adaptability for various industries. There are several previous studies that identified how Scrum has been adapted in different contexts of Agile software development projects. This adaptability is crucial for organizations seeking to tailor Scrum to their particular needs and constraints, such as practitioner skills, resources, and legacy infrastructure (Garcia et al., 2022). Scrum practices can also enhance team dynamics and efficiency in interdisciplinary collaboration by integrating agile methods that require flexibility and a "learn by doing" approach, which aligns with the iterative and adaptive nature of Scrum. This adaptability is crucial for addressing the complex and changing requirements of various projects, whether in software development, construction, or research (Hidalgo, 2019).

Currently, there are already some cases of scrum adapted to non-software industries. One of it was the development of a Scrum-Based New Product Development (SBNPD) framework for the design and development of physical products. This framework integrates tools and practices suitable for the non-software industry, demonstrating that Scrum's iterative approach can be practical beyond its traditional software development roots (Cano et al., 2021). In addition, Chaouch et al. 2019) use scrum frameworks to integrate risk management into a development project, considering scrum as its method. The project aims to increase the risk management mechanism and the construction project's success. Scrum is used here to evaluate the potential of a safety culture that can be implemented within the organization.

While Scrum was originally and commonly implemented in IT product development, its application in the construction industry is still relatively low. A previous study highlights the potential benefits of Scrum in construction firms' design and planning departments, including improved collaboration and adaptability. This study identifies necessary adaptations to fit the unique needs of the construction sector, suggesting that Scrum can be effectively tailored to enhance project management and design processes in construction (Streule et al., 2016). The research proves that Scrum is more effective in transferring knowledge periodically and continuously. Previous research also states some drawbacks of scrum analysis on a similar development project, such as increased planning complexity and short sprint periods that must be done continuously. This will lead to a longer time of experiment planning, data collection, and analysis.

Scrum sprint retrospectives are helpful to be implicitly included in the Occupational Safety & Health (OSH) model to encourage safety and project completion performance. Scrum allows the team to reflect on the sprint and identify ways to mitigate risks in future sprints. Traditional frameworks can be inflexible compared to the Scrum framework. They may need to adapt better to the changing nature of project requirements and lack transparency, leading to difficulty in identifying and mitigating potential risks. This research will delve deeper into Scrum's role in increasing safety performance.

This research is expected to find a significant relationship between the implementation of the scrum framework toward the parameter of safety performance and project completion equally. This study uses a System Dynamics approach to observe the intricacies between the scrum and the parameters. The System Dynamics approach assumes the existence of a feedback loop, which will be compared to the cause-and-effect analysis. From that comparison, the dependent and independent variables can be defined explicitly (Morecroft, 2015). This study explores the dynamic relationship between variables defined by the Causal Loop Diagram (CLD) to describe the complex system through a simulation (Mahato and Ogunlana, 2011). In system dynamics modeling, the constructed CLD is assumed to be able to explain the reference modes of behavior that depict the actual system condition (Yearworth, 2014).

This research aims to analyze the relationship between project management, adaptation of the scrum framework, and project safety (OSH) practices. The relationship between the subsystems is interconnected and visualized using the CLD, whereas the inactivity of one subsystem will affect the other. Therefore, this research will carry out all subsystems within the toll-road construction project and define their relationship. This research expects to formulate policy scenarios from the defined relationship to obtain optimal safety performance while maintaining the project success criteria.

This paper seeks to explore the implementation of Scrum in construction projects to address safety issues within the construction sector. Our research stands out in its originality by not only leveraging Scrum to enhance project management performance but also explicitly targeting the improvement of safety practices. By doing so, this research provides an approach that ensures both the efficient management of construction projects and a significant reduction in workplace accidents.

2. Materials and methods

This research was conducted on a state-owned contractor company undergoing a toll road construction. This research is initiated by conducting a literature study on the System Dynamics approach to safety risk evaluation. After the resources needed for the research are sufficient, the objective of the research conceptual model is constructed. The construction of the model includes defining model limits and studying variables. Variable identification is based on three scopes: project management, adapting the scrum framework, and project safety (OSH) practices. Each scope has its variables that are interconnected with others. Then, the conceptual model is constructed using a Causal Loop Diagram (CLD).

Constructing a complex CLD safety project management system requires additional data collection, such as FGD and project document studies (Guldenmund, 2010). The Focus Group Discussion (FGD) held by the Group Model builds on system dynamics involving the project stakeholders, including the OSH manager, workers, and upper management. The referenced FGD is used to validate the model to correspond to the actual practices conducted on construction project management (Chen and Jin, 2013). After the conceptual model is validated, further data collection is performed through a Likert scale questionnaire to obtain the respondents' perceptions of the constructed model.

The constructed CLD is then converted into a simulation model using a Stock and Flow Diagram (SFD) describing a more detailed causal effect relationship and forming the mathematical model between the interconnected model. The next step is estimating and deciding the parameter value of the simulated model. After the simulation model is finished, the model is run using the existing condition. The model run results must be verified by examining the formulation and variable units to determine whether they align with the system logic (Maftuhah, 2013). The model run results must also be validated using five methods: structure testing, adequacy of model boundaries testing, model parameter testing, extreme condition testing, and model behavior testing. The invalidity of the model can be traced with error >5%, which indicates the need to re-evaluate the input used, the relationship between variables, and the formulated mode. After the model is validated, evaluation of the existing system continues by overlooking the variable value related to achieving the research objectives.

The policy scenario is formulated to seek the optimal safety response parameter by changing the variable and parameter and the model structure. The improvement scenario formulation references the expert judgment of the observed system. The improved scenario models are run repeatedly and compared to the existing condition. This improvement and model run is done for multiple iterations to seek the most optimal scenario for increasing the project's safety performance by overlooking the incident and incident rate during the project completion.

3. System dynamics modeling

System modeling creates abstract representations of systems to describe their components, interactions, and behaviors, including activities, boundaries, and relationships (Daellenbach and McNickle, 2005). System dynamics modeling is a computer-based approach that can analyze complex system behavior (Forrester and Senge, 1980). System Dynamics offers a strategic tool for long-term planning and policy design. By providing a clear understanding of the systemic structure and potential future behavior, it enables informed decision-making that considers both immediate and long-term consequences. This approach is particularly valuable in managing large-scale infrastructure projects where interdependencies and delays play a critical role (Coyle, 1996)

The critical steps of system dynamics modeling include defining objectives, identifying components, specifying relationships, determining boundaries, developing diagrams, simulating scenarios, and validating the model with actual data. The model simulation running process takes 32 months, corresponding to the time needed for the toll road construction project. This research project adapted the scrum framework to predict the project's safety performance. The modeling step is initiated by constructing the CLD (Causal Loop Diagram) as depicted in **Figure 1**.

Once the CLD is validated, it is converted into a Stock Flow Diagram (SFD) to model the system exactly. SFD models the system precisely, using stocks, flows, and auxiliaries. It is used to simulate and analyze the system's behavior. By converting the CLD to an SFD, modelers can create a more detailed and accurate system model, which can be used to simulate and analyze the system's behavior.

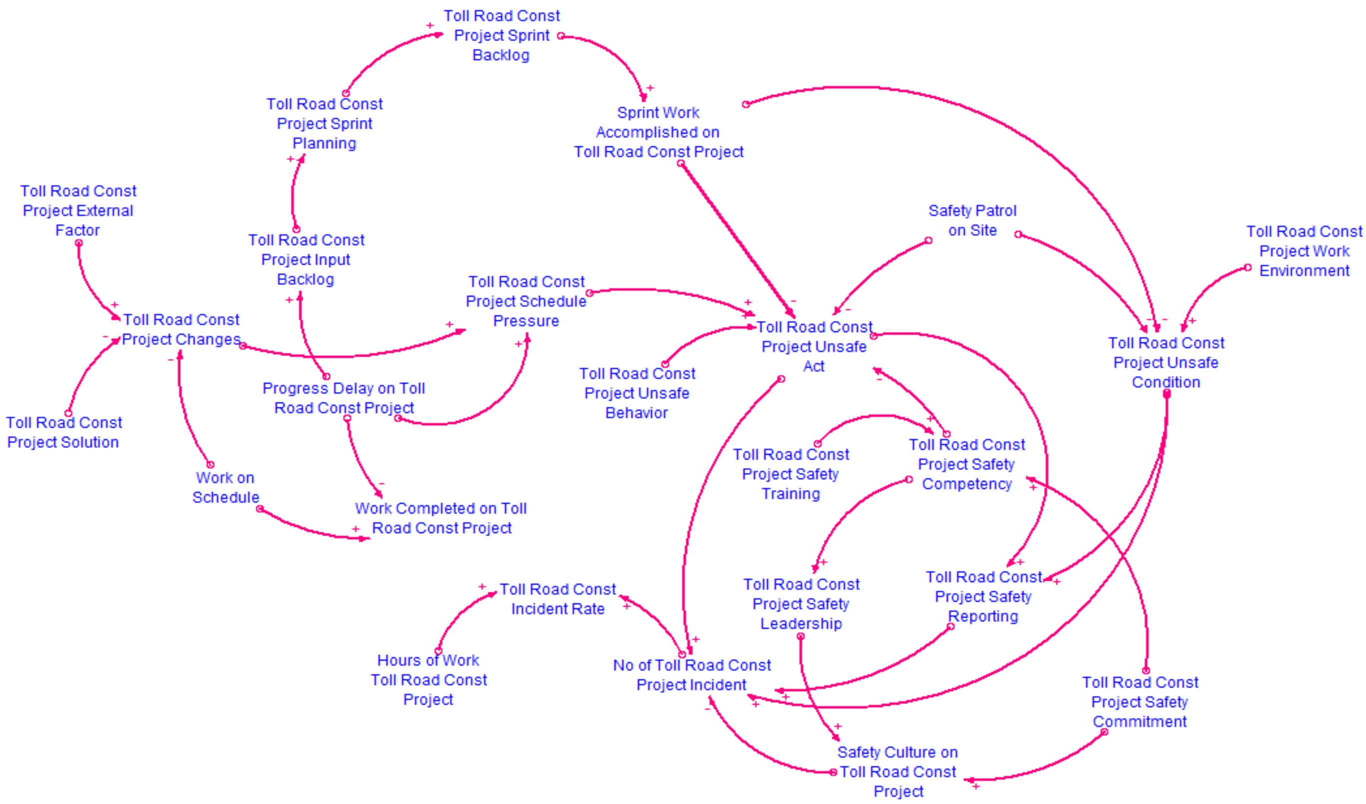


Figure 1. Causal Loop Diagram (CLD) of construction project model.

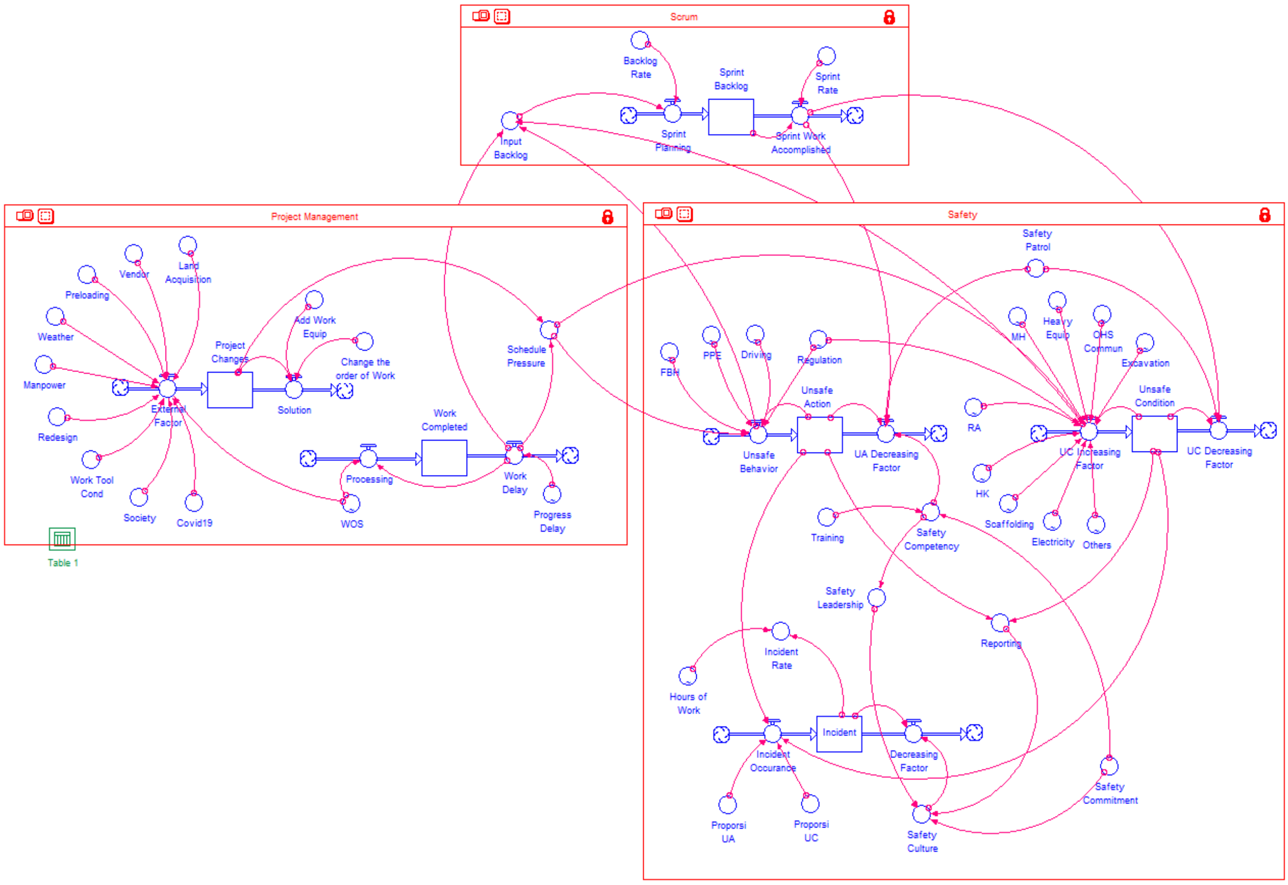
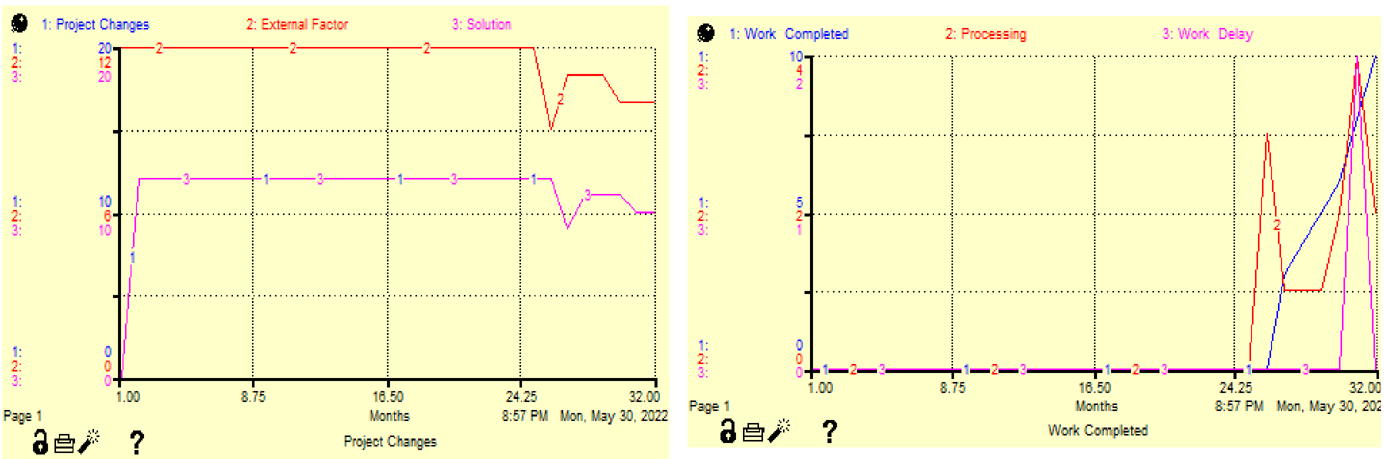


Figure 2. Stock and Flow Diagram (SFD) of construction project model.

Figure 2 depicts a system dynamics model with stocks, flows, converters, and connectors. Stocks, shown as squares, represent accumulated conditions like resources or tasks, changing based on inflows and outflows, which creates delays and gathers system information. Flows, depicted as arrows, represent activities such as resource consumption or task progression. Converters, often circles, contain equations producing output values per period, transforming information for other variables. Connectors, lines linking these elements, transmit information to regulate flows, ensuring proper data and instruction flow within the model (Soderquist, 1997). In the figure, stocks represent "Tasks," "Backlog," or "Work in Progress," with flows indicating processes like task movement or sprint completion. Converters calculate productivity rates or risk factors, while connectors ensure correct information flow about project status, risks, and performance metrics, enabling dynamic adjustments and real-time responses. This illustrates the interaction of project management, Scrum processes, and OSH practices to achieve the project goals.

3.1. Sub-system 1: Project management

The Project Management subsystem involves planning, executing, and monitoring projects. Key elements include defining scope, objectives, and deliverables, creating timelines, allocating resources, tracking progress, generating reports, and managing risks. This structured approach ensures efficient and successful project outcomes (Rose, 2013). Within the project management subsystem, project changes are considered unwanted variables that hinder the efficiency and success of project outcomes as they can pressure the available schedule. External factors and work progress throughout the project can influence increasing tasks (Rangelov, 2023). Meanwhile, the decreasing number of functions can be influenced by proactive actions to solve the coming problems, such as changing the work order or adding extra equipment to the field. Managing these changes ensures project success (Zhang, 2013).



(a) **(b)**

Figure 3. Simulation running output related to project management sub-system. **(a)** Running output of project changes; **(b)** running output of work completed.

Figure 3a shows that the total changes of the projected task (1, blue) correspond to the number of actions used to solve that problem (3, pink). To conclude, the project change can be solved directly by implementing the right alternative solution to complete the project according to the contract time. In addition, project management also considers several variables that influence the number of work completed (1, blue). According to **Figure 3b**, Work completed is influenced by work process (2, red) and work delay (3, pink). Meanwhile, work delays influence the reduction in work completed. However, work delays will be worked on later so that all work can be completed according to schedule at the end of the project.

According to **Figure 3b**, the total work completed increases in month 26. That unchanged value is caused by the amount of work in progress that, on month 26th, the work is focused on achieving the task in parallel and series. On the month 27th, three ongoing jobs are simultaneously completed and increasing until the project is finished. The phenomenon where ongoing jobs are completed simultaneously and grow rapidly towards the end of the project is commonly known as the completion curve or S-curve in construction project management, where the completion is slow at the beginning, ramps up during the middle, and slows down towards the end (Cristóbal, 2017; Griffin and Curcuruto, 2016). That is why it can be completed simultaneously when the project is approaching the end. To conclude, based on the simulation, the project completion is still by the project contract.

3.2. Sub-system 2: Scrum framework

The Scrum sub-system, part of agile project management, focuses on iterative progress through sprints. Scrum promotes transparency, inspection, and adaptation, ensuring continuous improvement and effective project delivery (Schwaber and Sutherland, 2017). Scrum is a complex process that affects the output, including sprint planning, maintaining a sprint backlog, daily stand-ups, sprint reviews, sprint retrospectives, and managing a product backlog (Majeed, 2012).

Sprint backlog is influenced by the number of backlogs that accumulate as input, which in this case are safety behavior, condition of the working environment, and delayed work. As the backlog increases, so does the sprint backlog, which is the other way around. Besides, the backlog will enter into sprint planning to plan which backlog needs to be completed during the sprint phase. During the simulation, only 70% of the backlog was entered into the sprint planning and completed during the sprint phase. The Sprint backlog is filled with the list of backlogs that must be accomplished during the sprint. According to the simulation, we can obtain that only 80% of the sprint backlog during the simulation was achieved by sprint work. The sprint backlog amount is reduced by the number of backlogs that progressed.

Figure 4 shows that the input backlog (4, green) and sprint planning (2, red) were carried out in the same period, while the sprint backlog (1, blue) and sprint work completed (3, pink) were carried out in the following period. The graph visualizes how the generated backlog needs to be planned into the sprint backlog during the sprint phase. Therefore, no sprint backlog was completed at the beginning of the month. The pattern shown on the sprint backlog fluctuates following the entering backlog. The entering backlog here is influenced by unsafe behavior, work environment conditions, and work that is delayed during project work. However, it is already known that the number of sprint backlogs and backlogs accomplished is reduced over time. The reduced backlog happens because the sprint backlog at the beginning period is immense and reduced as time goes on until the end of the project.

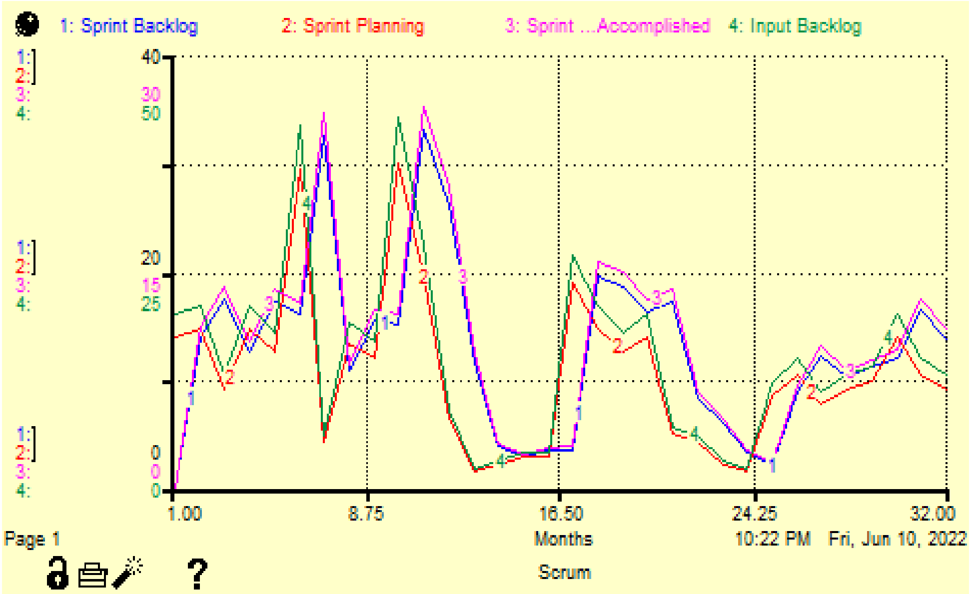


Figure 4. Simulation running output related to Scrum.

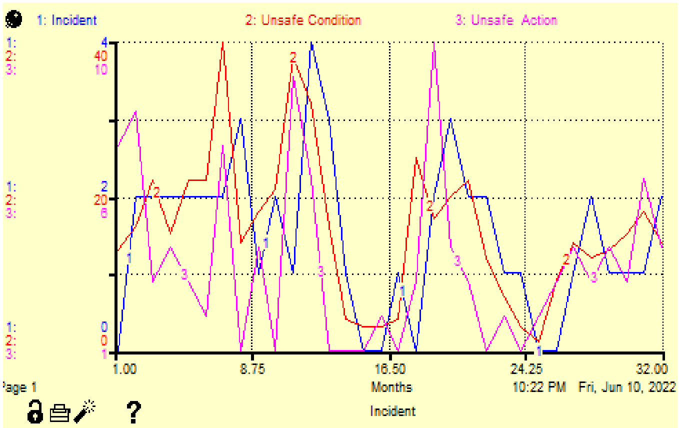
3.3. Sub-System 3: Occupational safety and health

The Occupational Safety and Health (OSH) sub-system aims to enhance organizational safety performance. It includes developing comprehensive safety policies and procedures to provide a safe working environment. Training and education programs are essential to ensure employees understand and adhere to safety practices. Incident reporting systems facilitate the documentation and analysis of accidents and near-misses, helping to identify root causes and prevent future occurrences (Erdogan et al., 2018). Regular safety audits and inspections are conducted to proactively uncover and address potential hazards. Risk assessments are carried out to evaluate potential risks and implement controls to mitigate them (Xia et al., 2018).

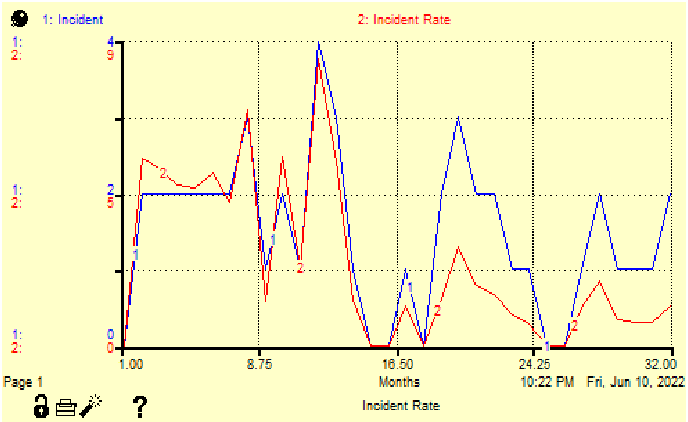
The OSH sub-system has several safety performance metrics, such as accident rates and injury counts, monitored to continuously measure and improve safety performance (Mullen et al., 2017). The overarching goal of the OSH sub-system is to prevent worker exposure to hazards, reduce incidents resulting in death, injury, and property damage, and promote a culture of health and safety among employees, customers, and the public (Griffin and Curcuruto, 2016). Hence, the system uses unsafe actions and conditions as parameters that influence the occurrence of incidents in the project.

According to the existing conditions, 20% of unsafe acts and 5% of hazardous conditions potentially cause incidents during the project period. To conclude, the increase in unsafe acts and conditions is directly proportional to the number of incidents in the project. Organizations commonly approach the increase in unsafe acts and conditions by evaluating the quality of their stakeholders' safety culture.

According to **Figure 5a**, the number of incidents highly fluctuates, with the incident (1, blue) mostly occurring on the 12th of the month. The pattern happens because, during that period, unsafe acts (2, red) and unsafe conditions (3, pink) are at their peaks. Besides, transitioning between different years required several re-adjustments toward the project conditions, leading to increased worker fatigue and, eventually, the potential of unsafe acts and conditions. In addition, unsafe acts and conditions are also affected by the workers' backgrounds, such as education and working experience. People with lower education levels or a lower safety culture in their previous working environments potentially experienced increased unsafe acts and conditions. Another study notes that 62.3% of workers who committed unsafe acts, despite having high knowledge, still engaged in unsafe behaviors due to the lack of supervision and training to reduce unsafe actions (Nadia et al., 2023). That is why regulations related to safety awareness that fit the workers' background are needed to ensure the workers pay attention to the safety procedure and do not repeat the same mistakes.



(a)



(b)

Figure 5. Simulation running output related to OSH sub-system. **(a)** Running output of unsafe action and conditions; **(b)** running output of incident rate.

The incident rate shows the number of incidents that occur each month. For example, if the incident rate is five, 5 of 100 people are potentially injured during the period. **Figure 5b** describes the intricacies between the incident rate, the number of incidents, and the workers' working hours. The graphs also suggest that increased incidents or the incident rate will lower workers' working hours. The incident rate in this study is used as the reference for understanding the safety problems faced within the project timeframe. Besides, incident rate data can also be used as the base for understanding the hazard exposure risks within the project, which also leads to how much workload is carried out by the management when an incident occurs.

4. Results and discussion

4.1. Results

4.1.1. Overview of strategic scenario analysis

This study uses the Occupational Safety and Health (OSH) scenario model as the response variable to indicate the effectiveness and efficiency of each generated scenario. It also considers several control variables, such as backlog rate, sprint rate, progress delay, safety commitment, training, and safety patrol. The value for each of those parameters is decided by expert judgment. The decided variable control value for each scenario is used to understand the effect of each controlled variable on the response variable indicated by the incident and incident rate.

Table 1 shows two values: the existing value is obtained from the observed system, and the scenario value is obtained from the expertise judgment for the improvement policy. On the scrum framework sub-system, the scenario value is pre-determined at 50% and 100% levels for the backlog and sprint rate. This value is determined to understand the effect of implementing 50% and 100% scrum toward the response variable. The optimal incident and incident rate decrement is observed after comparing the scrum implementation rate with the response variable. Similar steps were also replicated in the project management and the OSH sub-system's variable control to the improvement scenario level in the table.

Table 1. Control variable value.

No	Sub-system	Controlled Variable	Existing Value	Scenario Value
1)	Scrum framework	Backlog Rate	0%	50%, 100%
2)		Sprint Rate	0%	50%, 100%
3)	Project Management	Progress Delay	4 tasks	0 task
4)	Occupational Safety and Health	Safety Commitment	92%	100%
5)		Training	80%	100%
6)		Safety Patrol	79%	100%
7)	Additional	Reward and Punishment	92%	100%

Table 2 shows the impact of implementing each of the scenarios. According to the Bureau of Labor Statistics (BLS), the recordable incident rate for construction in 2022 was 2.4 per 100 full-time workers, down from 2.8 in 2019. This reduction of 0.4 per 100 full-time workers represents a decrease of approximately 14.3% over the two years (Bureau of Labor Statistics, 2022). In comparison, the reductions in almost all scenarios analyzed in this study are significant enough. The decrease in variable also indicates that the improvement implemented in the scenario has profoundly impacted the project's safety performance.

Table 2. Improvement scenario level.

Imprv. Scenario Level	Controlled Variable				Responses Variable		Significancy Result
	Scrum	PM	OSH	Reward-Punishment	#Incident	Incident Rate	
Existing					**1.47**	**2.42**	
S1	√	-	-	-	−61.7%	−52.6%	Significant
S2	-	√	-	-	0.0%	0.0%	Insignificant
S3	-	-	√	-	−25.5%	−23.6%	Significant
S4	√	√	√	-	−74.5%	−67.1%	Significant
S5	-	-	-	√	−29.8%	−29.5%	Significant
S6	√	√	√	√	−76.6%	−70.2%	Significant

In Scenario 1, the Scrum sub-system is applied by increasing the backlog and sprint rates from 0% to 50% and 100%, respectively. The increase in backlog and sprint rate emphasizes the iterative progress toward safety risk management on the project, which resolves vast areas of safety and project issues. Scrum implementation has significantly reduced incidents and the incident rate by 61.7% and 52.6%, respectively. The decreased value validates that the approach provided by Scrum likely enhances project oversight and proactive issue resolution, leading to these improvements.

In scenario 2, the project management subsystem is enhanced by reducing the progress delays from 4 to 0 tasks. The simulation result shows a 0% effect, indicating that improving the project management by reducing the schedule pressure does not significantly affect the project's safety performance. This insignificance suggests that implementing this scenario should not be preferred to increase safety performance.

In Scenario 3, the OSH sub-system is strengthened by increasing several parameters related to safety culture, such as safety commitment, training, and patrol frequency, to 100%. The improvement in safety culture shows a significant decrease in both the number of incidents and the incident rate by 25.5% and 23.6%, respectively. In addition to Scenario 5, a new policy introducing rewards and punishments related to safety for the workers has been added. Implementing the policy is expected to significantly reduce the number of incidents and the incident rate by 29.8%. Both scenarios show that increasing safety performance by nurturing workers or implementing policy can substantially improve the project's safety performance.

Table 2 shows the best scenario for optimizing the safety performance in scenario 6, which combines all the interventions from scenarios 1, 2, 3, and 5. This comprehensive strategy results in the most significant reduction of incident numbers by 76.6% and the incident rate by 70.2%. Another scenario that obtains similar results is scenario 4, without additional reward punishment policies. A similar result describes that the additional reward-punishment policy, while decreasing the incident and incident rate, does not significantly impact performance when another policy is implemented. The insignificance is happening because the effect of scenario four is being overshadowed by other individual policies' significances, especially the scrum and OSH policies that have a higher individual impact on the response level.

In conclusion, implementing a multifaceted improvement strategy that includes the Scrum framework, project management, safety enhancements, and reward-punishment policies leads to the most significant reductions in incidents and the incident rate. The results also explain that the Scrum framework can consistently improve project safety performance. Although each measure can contribute to increasing safety performance to varying degrees, the combined application yields the best results.

4.1.2. Sensitivity analysis

Sensitivity analysis for a System Dynamics simulation is crucial to ensure the system behaves logically under extreme conditions. This involves testing the system by changing input values to their maximum levels and checking the reasonableness of output results. Sensitivity analysis helps identify critical parameters significantly impacting the system's behavior, allowing for more accurate predictions and informed decision-making. For instance, in occupational safety, sensitivity analysis can determine the most sensitive parameters related to employment policies and staff knowledge, skills, and attitudes, as highlighted by Maani (2009). By applying sensitivity analysis under extreme conditions, modelers can gain a deeper understanding of the system's behavior and make more robust policy decisions, as emphasized by Sterman (2002).

The model is run under a particular condition according to previous policy scenarios. However, the project's implementation is highly uncertain. Thus, it is important to verify that the modeled policy is still relevant in different uncertain states. This study uses unsafe action and condition rates to check the model's robustness.

Table 3. Sensitivity analysis value.

No	Controlled Variable	Variable Value		
		Existing	**State 1**	**State 2**
	Changed Value	+0%	−50%	+100%
1	Unsafe Action Proportion	0.2	0.1	0.3
2	Unsafe Condition Proportion	0.05	0.025	0.1

Table 3 shows there are two extreme states of unsafe acts and conditions: decreasing and increasing both parameters toward the existing value by 50% and 100%, respectively. The Reduced proportion value of unsafe action and conditions is expected to affect and decrease the number of incidents and the incident rate. In other words, increasing unsafe acts and conditions can validate whether the generated policy still effectively enhances safety performance by increasing the number and rate of incidents. Besides unsafe acts and conditions, other factors potentially affecting the project are assumed to be fixed.

Figures 6a and **6b** show the comparison graph to visualize the interaction of each scenario toward the extreme states. According to the graph, scenario six can consistently obtain optimal results in effectively reducing the incident amount and rate in all extreme states. The results indicate that the combination of Scrum, project management, safety enhancements, and reward-punishment policies is still relevant in every extreme state. The result is consistent with the normal condition, that scenario four also has a similar decrement to scenario 6 in both extreme states.

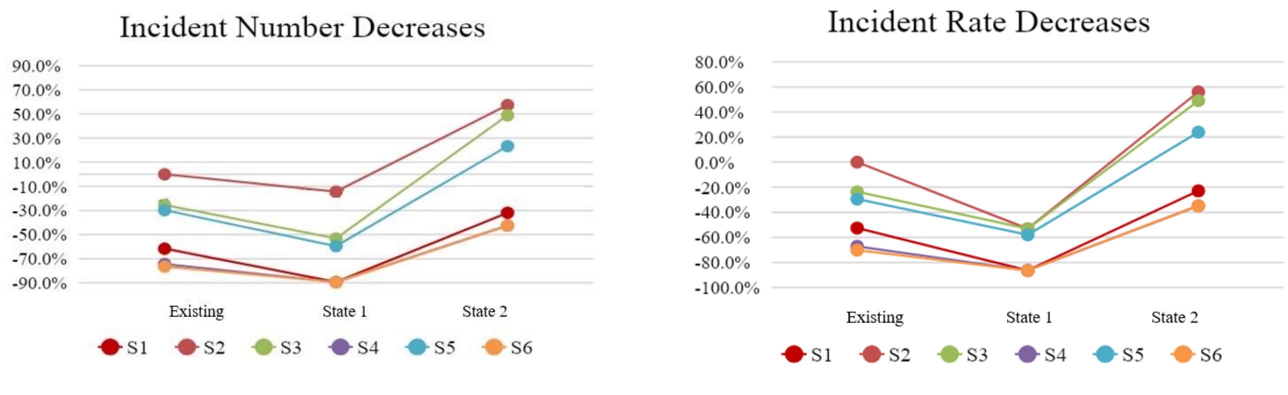


Figure 6. Interaction between the changed safety performance to the extreme states. **(a)** incident number decrease between states; **(b)** incident rates decrease between states.

In addition, by observing the individual scenario policies, scenario 1, which implements the scrum policy, performs well in all states. If the prioritization is placed on efficiency, scenario one could be the best option. The project achieved a significant decrease in all extreme states by implementing the scrum policy alone. Scenario 1 has a low to no difference in state 1 with decreased levels of unsafe acts and conditions as the incident rate is already low enough that the impact of the individual effect of OSH and reward-punishment policy is relatively insignificant.

In conclusion, scenario 6, with its multifaceted improvement strategy, which includes Scrum, project management, safety enhancements, and reward-punishment policies, can obtain more consistent results in all kinds of extreme states. However, scenario 1, which implements Scrum alone, can be considered by the project if the history of unsafe acts and conditions is already low. The sensitivity results highlight that the Scrum framework is highly effective in significantly enhancing both project safety and deliverables project performance. This effectiveness is consistently observed, even under extreme conditions, demonstrating Scrum's robustness and reliability in optimizing project outcomes.

4.2. Discussion

4.2.1. Discussion and interpretation of strategic scenario

The strategic scenario analysis in this case study is mainly focused on evaluating different scenarios to improve safety performance. Six scenarios were modeled and simulated which include several sub-systems: scrum framework, project management, and OSH (Occupational Safety and Health). These scenarios are constructed to support stakeholders in understanding the impact of strategies on minimizing and increasing safety performance overall.

First, the optimization of the scrum framework is done by maximizing the rate of backlog and sprint. This scenario points out the importance of efficient task management and continuous improvement within the scrum framework to increase safety performance. The positive correlation result also corresponds to previous studies that explain whether an effective safety practice within a project management project framework can improve the safety performance outcomes significantly (Pham and Pham, 2011).

Scrum framework is advantageous as it can address modern complexities in project management by offering practical, sustainable, and valuable solutions by emphasizing iterative planning, execution, and evaluation, which is crucial for navigating the uncertainties of work environments. This iterative approach not only enhances project success rates compared to traditional methodologies but also helps teams manage stressors effectively, thereby promoting a conducive environment for safety practices (Lawong and Akanfe, 2024). Furthermore, a study also underscores that theoretical guidelines must be adapted to the unique characteristics of each organization to optimize Scrum implementation. The findings support the notion that a well-implemented Scrum framework can lead to significant improvements in project outcomes, including safety performance (Morandini et al., 2021).

Second, eliminating the progress delay shows a minimum result for safety performance outcomes. This result explains that while adherence to the schedule is essential in management project practices, it is not the main determinant of safety performance. This finding aligns the Andersen and Richardson’s (1997) observation annotating that systemic factors often relatively have a more significant influence rather than project management metrics in influencing safety performance outcomes.

Several notable digital innovations in previous studies have proven to influence increasing safety management in construction, such as Integrated Digital Delivery (IDD) to enhance health and safety (H&S) management, Artificial Intelligence (AI) to transform health and safety management systems in construction projects, and Safety Management System (SMS) framework to address critical safety factors affecting construction projects. These findings support the idea that while timely project completion is valuable, the integration of systemic safety measures, digital technologies, and effective management practices is much more crucial for ensuring optimal safety performance in construction projects (Amo Larbi et al., 2024; Khalid et al., 2021; Waqar et al., 2023)

Third, maximizing training, patrol, and commitment to safety significantly improved safety performance outcomes. This scenario highlights the importance of safety culture and proactive safety measures, consistent with several works of literature that emphasize the importance of a strong safety culture in management projects to minimize the factors that influence incidents (Cooper, 2002; Neal et al., 2000).

Fourth, implementing a punishment mechanism for safety violations showed mixed results. While this scenario contributed to the decrease in unsafe actions, its impact was insignificant compared to the other scenarios. This result indicates that punishment mechanisms alone may not be as effective as positive reinforcement strategies in promoting safety performance outcomes (Bird and Germain, 1986).

The scenario combining all strategies produced the best results, significantly reducing the number of incidents and the incident rate. This scenario supports the holistic approach to safety management, where integrating multiple strategies creates synergistic effects, enhancing overall safety performance (Shreckengost, 1985). This comprehensive approach also underscores the need for multifaceted strategies that address various aspects of safety management simultaneously (Sterman, 2002).

4.2.2. Discussion and interpretation of sensitivity analysis

The sensitivity analysis of this study validated the robustness of the model. The sensitivity analysis shows that variance in the controlled variable, which in this study is unsafe actions and conditions, showed consistent results between the scenarios. This robustness indicates that the proposed comprehensive strategy is resilient to fluctuations in individual components, making it a reliable approach for safety management in construction projects.

While previous studies have primarily focused on individual aspects of safety management or project efficiency, this analysis’s integrated approach reveals the compounded benefits of combining multiple strategies. Scenario 6’s robustness under extreme conditions suggests that such integrated strategies are not only effective in normal conditions but also resilient to variations, a finding that adds depth to the existing literature on construction project management.

Real-world examples, such as the implementation of integrated safety management systems in large infrastructure projects like the Channel Tunnel and Boston Big Dig, have shown similar benefits. These projects demonstrated that comprehensive safety and management strategies could significantly reduce incidents and improve overall project performance, even under challenging conditions (National Academy of Engineering, 2003).

The findings align with industry standards and best practices advocated by organizations such as the Project Management Institute (PMI) and the Construction Industry Institute (CII). These standards emphasize the need for robust safety management systems that integrate various strategies to ensure project success (Rose, 2013). Scenario 6's consistent performance across extreme conditions validates the practical applicability of these recommendations, highlighting their relevance for construction projects worldwide.

5. Conclusion

Based on system modeling and model simulation results, the Scrum framework and project work safety subsystem are crucial in enhancing safety performance over time. This research analyzed the relationship between adopting the Scrum framework, project management practices, and project safety practices within a toll road construction project. The study found that the Scrum framework significantly enhances safety performance and project completion.

Six scenarios were tested to determine the effectiveness and efficiency of each improvement strategy. Scenario 6, which combined Scrum, project management enhancements, safety culture improvements, and a reward-punishment system, produced the best safety performance, reducing incidents by 76.6% and incident rate by 70.2%. This comprehensive approach was the most effective strategy for enhancing safety performance. In certain conditions, alternative scenarios 1, 4, and 6 were equally effective in reducing incidents and the incident rate. In addition, the result also shows that the scrum framework can improve the project safety performance consistently in several extreme states.

This research advances the field by applying the Scrum framework to construction project management, demonstrating its effectiveness in managing complex and projects. The system dynamics modeling used in this study offers a novel approach to understanding and improving safety performance through a holistic analysis of project systems and their interdependencies. The findings provide valuable insights for industry practitioners and contribute to the broader knowledge base on scrum framework and safety management in dynamic project environments.

Future research could validate the effectiveness of Scrum in other types of construction projects, such as high-rise buildings and factory installations. By conducting applied research in these varied contexts, it would be possible to determine whether the positive impacts on safety performance and project management observed in this study are replicable across different project types. Such validation could broaden the scope of Scrum's applicability, providing further evidence of its potential to address OSH (Occupational Safety and Health) issues comprehensively within the construction industry.

Author contributions: Conceptualization, AS; methodology, AS; software, AS and OA; validation, KKU and IWM; formal analysis, AS, OA and HDY; investigation, OA; resources, AS; data curation, AS and OA; writing—original draft preparation, AS and OA; writing—review and editing, AS and HDY; visualization, AS and OA; supervision, AS; project administration, AS and OA; funding acquisition, AS. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Penelitian Kerjasama Antar Perguruan Tinggi (PAKERTI), Institut Teknologi Sepuluh Nopember, Contract Number 1054/PKS/ITS/2022.

Conflict of interest: The authors declare no conflict of interest.

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