Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/
Journal of Tianjin University Science and Technology
ISSN (Online):0493-2137
E-Publication: Online Open Access
Vol: 58 Issue: 09:2025
DOI: 10.5281/zenodo.17066714

OPTIMIZING SAFETY–SCHEDULE TRADE-OFFS IN INDIAN CONSTRUCTION PROJECTS USING SYSTEM DYNAMICS AND EMPIRICAL ANALYSIS; A CASE STUDY IN VISAKHAPATNAM, INDIA

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Abstract

The construction industry is a complex, risk-prone, and dynamic sector. In India, rapid urbanization, strict deadlines, intensive labor activities, and changing safety rules strengthen these issues. A critical problem lies in balancing strict schedules and safety, as pressure to hurry frequently results in compromised actions, accidents, and delays. Traditional risk models consider safety and scheduling distinctly, failing to get the feedback-driven nature of delays, which comes from interrelated factors like fatigue, poor training, financial constraints, and weak hazard communication. On the other hand, the majority of studies take safety and scheduling separately, relying on assumptions and static models that disregard feedback loops and the project's dynamic condition. Traditional scheduling excludes, moreover, few researches, especially in India connect early-stage safety measures to schedule reliability. Thus, this creates a clear gap for dynamic, data-driven models that represent and analyse safety–schedule interactions. This research addresses that gap by exploring this relationship in the Indian Construction Sector using a mixed-methods approach merging comparative case analysis, a 100-participant survey, SPSS-based statistical testing and analysis, and system dynamics (SD) simulation modelling in Python. Two projects, government-funded (Case A) and private-sector (Case B), were analyzed through accident, schedule, and safety investment records. Descriptive showed safety-related delays averaged 35.25% of overall delays, while the effect of schedule pressure on safety scored 3.81/5. Multiple regression portrayed safety climate positively predicted performance ($\beta = 0.43$, $p = .001$), whereas schedule pressure negatively ($\beta = -0.35$, $p = .022$). Correlation ($r = 0.47$, $p < .002$) demonstrated a moderate-to-strong positive relation between safety and schedule. Reliability tests indicated strong internal consistency for key factors such as Safety Climate ($\alpha = 0.88$), Fatigue ($\alpha = 0.82$), and Training Effectiveness ($\alpha = 0.86$). System SD simulations portrayed that when safety measures were presented exactly after incidents, compliance enhanced, but increased fatigue and buffer use. Whereas, when safety measures were integrated from the beginning, accidents, fatigue, and delays were considerably reduced. A balanced strategy showed that early safety investment improves performance, positioning safety as a schedule enabler rather than a constraint. The findings offer a quantitative decision-support framework that allows managers, contractors, and policymakers to integrate safety into scheduling practices for optimal project outcomes.

1. INTRODUCTION

Construction is extensively known as a high-risk industry with repeated safety challenges and schedule delays. In India, the construction industry accounts for almost 24% of all work-related fatalities: an estimated 11,614 out of about 48,000 yearly occupational deaths. These high figures replicate that safety issues are widespread and persistent can be worsened by selecting the unregulated workers and poor authorities' oversights on the

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construction sites (Patel & Jha, 2016). Simultaneously, enduring schedule overruns trouble construction projects in India, resulting from poor planning, the absence of resource management, and contractual conflicts (Doloi et al., 2012). Schedule delays not only amplify costs but can also cause high pressure due to the work acceleration, potentially at the risk of jeopardizing labor and work safety. Researchers have identified that efforts to speed up project completion (such as overtime, fast-tracking) often “breed accidents” due to fatigue and errors. For instance, Irumba et al. (2010) said that projects under intense schedule pressure are more prone to experience more unsafe work and higher accident rates in an unsafe environment, which in turn causes additional delays and a systematic imbalance between safety and schedule. This relationship indicates that keeping one of them in isolation may compromise the other.

However, traditional project management approaches rarely integrate safety as a fundamental factor. Most of the construction scheduling focuses on cost, time, quality, and scope, assuming safety compliance as a given or treating accidents as an external factor. Practically, safety and schedule performance are highly dependent on each other; for example, an unsafe environment can lead to incidents that cease the work, whereas a tight schedule can cause unsafe shortcuts. The literature progressively calls for an expanded perspective. Recently, studies have started to include safety in multi-objective project planning models, for example, integrating safety and quality considerations into time–cost trade-off decisions. However, gaps remained in quantitative exploration of how safety interventions affect schedule outcomes and reciprocally how pressurized schedule impacts safety over the project lifecycle, especially in developing countries’ context having scarce data and resources.

Systems dynamics (SD) proposes a strong methodology to address such a complex challenge. Initiating from control theory and organizational science (Forrester, 1961; Sterman, 2000), “SD modelling enables simulation of how interdependent variables evolve under various policies”. In construction project management, SD has been widely applied to study the dynamic performance of the projects and to predict complicated outcomes (Chapman, 1998; Love et al., 2002). For instance, Leon et al. (2018) developed an SD model making eight performance dimensions (cost, schedule, safety, quality, etc.) to holistically forecast the outcomes of the project. Their model revealed that accounting interdependencies among performance metrics, including safety-enhanced forecast accuracy and allowed scenario-based analysis for managerial decision-making. Similarly, Abdul Nabi et al. (2020) used an SD simulation to observe construction safety performance, resulting that unsafe acts and safety breaches can be predicted by modelling factors like safety climate and management practices. These studies highlight the importance of system dynamics in catching the feedback loops essential in project safety and progress.

Building on this previous work, the current study concentrates explicitly on the safety–schedule trade-off. It utilizes SD modelling in combination with a comparative case study and empirical survey data. By Indian construction projects from different sectors, one private and 5 government that portray various techniques for safety and schedule

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management, we aim to extract visions applicable across similar contexts. The research responds to the question: *Can early implementation of safety management strategies improve overall project schedule performance, thereby "optimizing" the trade-off between safety and schedule?* The hypothesis is that investment in safety (through training, oversight, and resources) will decrease accidents and work disturbances, which in turn stops project delays, aligning with the idea that safety and productivity can be complementary in the long run (Hinze, 2007). The study's insights are: (1) a system dynamics model and simulation-based decision support framework for assessing trade-off safety and schedule interventions, and (2) empirical evidence derived from survey responses and regression analyses support and validate the model's assumptions and policy recommendations. The research findings aim to assist project managers, contractors, and policymakers in making strategies to improve worker safety and project efficiency, avoiding the need to compromise one for the other.

2. LITERATURE REVIEW

Numerous studies have been conducted on both construction safety and project scheduling; however, just limited number of studies address the dynamic relationship between them.

- **Safety in the Construction Industry:**

Internationally, construction has one of the poorest safety records, especially in developing countries. Common accident causes include falls, struck-by incidents, electrocutions, and caught-in/between hazards (Hinze, 2007). Developing countries face extra challenges due to informal labor practices (not hiring the right person for the right work), limited regulatory enforcement, and the absence of a reporting system for accidents (Patel & Jha, 2016). In India, as recorded, tens of thousands of construction workers suffer fatal accidents per year. Annually, about 12,000–14,000 deaths happen in India's construction industry; this is a number that is likely underestimated due to a poor reporting system (British Safety Council, 2022; Counterview, 2019). Researchers suggest that only Delhi has reported more than 1,200 injuries in 2 years, with nearly a third being fatal (Saha & Ghosh, 2022).

Researchers have recognized organizational safety climate, labor training, and commitment to management as critical factors affecting the outcome of construction safety (Choudhry & Fang, 2008; Mohamed, 1999). For instance, establishing a strong safety culture and investing in efficient training programs causes lower incident rates. Conversely, impractical and tight deadlines to reduce the cost can lead to a high increase in project risk (Mohamed et al., 2015). Evidence from various case studies and on-site accident investigations often shows schedule pressure as the reason for the accidents.

- **Schedule Performance in the Construction Industry:**

Many studies have observed why there is an overrun in construction projects most of the time. Factors like poor site management, insufficient and poor planning, sudden changes in design, and resource scarcities are commonly cited (Doloi et al., 2012; Assaf & Al-Hejji,

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2006). Doloi et al. (2012) found that the absence of commitment and poor coordination were among the top delay reasons in the Indian construction industry. Government projects, specifically, often face bureaucratic barriers and changes in scope, which cause delays (Iyer & Jha, 2006). Whereas these analyses typically treat safety separately, some delay reasons are indirectly safety-related, for example, ceasing or making slow progress of work after some accidents due to the implementation of safety measures. The CPM & PERT (Traditional schedule management techniques) do not encompass accident risk; thus, unpredicted safety incidents become "unknown-unknowns" that disrupt timelines.

- **Safety–Schedule Trade-off:**

The relationship between safety and schedule is often seen as a trade-off, where gain in one will cause expense in the other: accelerating work (to save time) might require taking safety shortcuts, whereas safety protocols might need excess time (for training, PPE usage, inspections). Whereas this intuitive trade-off has been qualitatively discussed, it has seldom been checked through quantitative methods (Hallowell, 2010). Some researchers have tried to include safety in project optimization models. For example, Cheng et al. (2012) introduced safety as a factor in a time–cost optimization, representing that the ideal solution shifts when potential accident costs/delays are accounted for. Zhang et al. (2014) proposed a multi-objective genetic algorithm for balancing time, cost, quality, and safety, stating that moderate investments in safety can decrease overall project risk. Nevertheless, these models frequently need assumptions about how safety investments translate to time/cost outcomes. There is a dire necessity for a dynamic model that can simulate causal mechanisms, like how an increase in safety training now affects the future delay probability. This is where system dynamics can help to truly answer this question.

- **System Dynamics (SD) in Construction:**

SD has been applied to different construction management problems to get feedback processes and non-linear interactions. Chapman (1998) used SD to understand how changes in key project personnel impact the productivity of design and duration of projects. Love et al. (2002) utilized SD to model rework cycles in projects, presenting how design errors lead to rework and cause delays, which then may cause errors due to rushing in the work. Thus, these studies highlight feedback loops similar to those in safety–schedule problems (e.g., pressure causing errors/accidents which cause more pressure). More precisely, Irumba et al. (2010) developed an SD model concentrating on unexplored rework and safety in a Ugandan project, uncovering that delays in capturing quality problems led to accidents and schedule blowouts. Likewise, Abdul Nabi et al. (2020) combined system dynamics with a cellular automaton model to simulate the effect of safety climate and managerial decisions on labor behaviour and accident rates. Their model conceptualized construction safety as a developing property of interactions between management policies and behaviours of workers, supporting the idea that better safety management (like increased safety supervision) can change the route of safety performance over time.

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To summarize, previous studies recognized that safety and schedule are interconnected through complex feedback loops; however, practical tools for analysing this trade-off remain limited. This research fills that gap by incorporating a system dynamics simulation with real-world data from different construction projects (case projects) and structured survey data. Through this way, it builds upon existing literature in both domains and offers a novel analysis of safety–schedule interactions within the context of Indian construction projects.

3. METHODOLOGY

For the public-sector analysis (Case A), data were compiled from five government-funded construction projects in Visakhapatnam, each of similar scale and scope. Safety performance records, schedule data, and related indicators were normalized and averaged to produce a representative public-sector profile. This aggregated case was compared with the private-sector case (Case B), which represents a single project of comparable size and duration. While aggregation smooths project-specific variations, it provides a robust sectoral overview and facilitates comparative analysis. This research employed a mixed-methods approach encompassing a comparative case study, system dynamics modeling, and statistical analysis of survey data. The main design is a case-based simulation study: we started by evaluating specific projects (both private and public sectors) to collect empirical data and visions, then built a system dynamic SD model taken from these cases, and lastly validated and improved the model through a questionnaire survey of project personnel.

1. Case Selection and Data Collection:

The two case projects were chosen because of their contrasting features with respect to ownership and performance. Case A represents a government-funded infrastructure project (a highway extension), while Case B is a commercial building developed by a private company. Both projects are of similar scale with a planned timeline of approximately 24–30 months, enabling an expressive comparison. For each case, comprehensive records were gathered, containing safety documentations (accident/incident logs, lost-time injuries), scheduling data (baseline plan versus actual progress, significant delays), and safety investment details such as budget allocations for safety training and personnel protection equipment PPE. In Case A (government), the project faced considerable schedule overruns (approximately a 20% extension in time), but relatively limited accidents or injuries were reported. Conversely, Case B (private) was completed within the schedule without schedule overrun, yet recorded a higher number of safety incidents, with two lost-time accidents. These preliminary observations propose an opposing approach: Case A aimed to emphasize and prioritize safety by stricter compliance, potentially compromising efficiency, while Case B appeared to prioritize timely completion, potentially at the expense of accepting higher risk. To further investigate these differences, we conducted semi-structured interviews with the safety managers and project managers of each project and administered a questionnaire to other project team members involved actively in the projects.

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2. Questionnaire Design and Interview:

A structured questionnaire was designed to gather perceptions of project personnel on the relationship between safety and schedule dynamics. It contained Likert-scale items and realistic questions, divided in 4 sections:

A) Safety Climate and Practices – included statements like "Management prioritize safety over speed when assigning tasks" and "Workers are trained to reject unsafe work,".

B) Schedule Pressure and Work Conditions – includes items such as "We frequently rush to meet deadlines" and "Overtime is common on this project,".

C) Outcomes – catching self-reported indicators like involvement in an accident or having perception of project delay.

E) Demographics – covering the respondent's role, experience, and project identifier. The survey was conducted to project managers, contractors, site engineers, site supervisors, and skilled labours from both Case A and Case B, resulting a total of 100 responses. This sample covered a mix of managerial and field – level respondents, integrating multiple lookouts. The questionnaire data were coded and analysed in SPSS Software. A reliability test was conducted on multi-item scales for various groups such as safety, schedule, project performance, trainings, and demographic to ensure that the data is reliable. Later on, composite indexes are calculated: for example, an average "Safety Compliance Score" from items rating housekeeping, PPE usage, and adherence to safety protocols; and a "Schedule Performance Perception" score from items on timeliness and productivity. These indices, along with project type (private vs. public), were used in subsequent statistical analysis.

Semi-structured interviews were held with safety managers, project manager, and site engineers to enrich findings from the case data and support model development. These interviews offered direct views of how safety and schedule pressures are practically handled in construction projects. The qualitative data contributed to the validation of critical feedback loops and refinement of causal assumptions in the SD model. Due to that, the model accurately shows both the official process and real-world realities on site.

3. System Dynamics (SD) Model

The system dynamics model was organized into three significant feedback loops that identify the connections between safety, schedule, and resource dynamics in construction projects. Reinforcing Loop R1 shows how an increase in safety investment improves compliance, thus decreasing accidents and delays finally protects the budget. Reinforcing Loop R2 shows the accident-driven regulatory response, whereas increased accident rates intensify regulatory pressure, leading to further safety investment. Adversely, Balancing Loop B1 points out the trade-off between schedule pressure and safety. As greater pressure increases over time, it causes fatigue, which intensifies accident risk and causes more delays. These feedback loops constitute the foundational logic of the model,

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empowering simulation of dynamic project behaviours under changeable situations. The causal loop diagram was reviewed by limited domain experts (project managers with over 15 years of experience from various countries) to validate the proposed causal hypotheses and confirm that no critical factor was overlooked. Their feedback resulted in minor refinements to the loop, including the addition of a link representing labor's morale/alertness, and the recognition that accidents can also adversely impact worker morale and productivity (further influencing schedule performance).

4. Simulation

To simulate the dynamics of the project, a stock-and-flow model was established according to the causal loop diagram (CLD) and applied in Python using ordinary differential equations. The simulation model integrated important state variables such as Safety Compliance Level, Worker Fatigue, Schedule Buffer, and Accident Count, along with flow rates and feedback relationships taken from the case study and literature. The model was run over a period of 25 months to represent a typical project duration, with parameters adjusted using empirical data and survey responses. The behavior of the model was evaluated for logical consistency using extreme-condition and dimensional tests, and its validity was partially confirmed by comparing simulation results with real project outcomes.

4. RESULTS

1. Analysis

- **Descriptive Analysis**

Table 1 shows the descriptive statistical analysis shows the evaluation of the central tendencies, variability, and distributional features of safety-related delays and schedule pressure impacts.

The assumptions for normality were confirmed using skewness (absolute values <1) and kurtosis (absolute values <2) values, which come within the suggested thresholds for parametric tests as Field (2018) and Kline (2015). These values approve the correctness of parametric analytical methods for the following inferential statistical procedure.

Table 1: Descriptive Statistics Using SPSS

		Delay Due to Safety Problems (%)	Schedule Pressure Affects Safety (1-5)
N	Valid	100	100
	Missing	2	2
Mean		35.25	3.81
Median		28.00	3.05
Std. Deviation		10.582	0.75
Skewness		.220	.160
Std. Error of Skewness		.142	.142
Kurtosis		-.030	-.970
Std. Error of Kurtosis		.279	.279

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- **Regression Analysis**

The data from the survey were used to statistically check relationships that mirror the model's structure. A multiple regression analysis was run to assess whether the perceptions of safety climate and schedule pressure (independent variables) significantly predicted the self-reported project performance (dependent variable, combining perceived safety performance and on-time performance ratings). In order to account for potential system changes between the two cases, a dummy variable for project type was included in the regression model (0 = government Case A, 1 = private Case B). The specified regression equation was:

$$\textit{Project Performance} = \beta_0 + \beta_1\,(\textit{Safety Climate}) + \beta_2\,(\textit{Schedule Pressure}) + \beta_3\,(\textit{Project Type}) + \varepsilon.$$

All variables were standardized (z-scores) to facilitate the interpretation of the coefficients, Table 2.

Table 2: Multiple Regression Analysis

MEASURE	MEAN (CASE A)	MEAN (CASE B)	T-VALUE	DF	P
SAFETY COMPLIANCE	4.3	3.8	2.12	98	.037
OVERTIME HOURS/WEEK	4.1	8.5	-3.53	98	.003

- **T-Test**

An independent-samples T-Test was carried out for comparison of mean responses between the two projects on significant indicators, for instance, safety compliance score and overtime hours reported in Table 3. These statistical tests serve to counterpart the simulation by checking whether the hypothesized trade-offs and differences are visible in the real sample.

Table 3: T- Test

PREDICTOR	B (UNSTD.)	SE B	BETA (STD.)	T	P
SAFETY CLIMATE (Z)	0.43	0.13	0.36	3.51	.001
SCHEDULE PRESSURE (Z)	-0.35	0.16	-0.26	-2.37	.022
PROJECT TYPE (0=GOV, 1=PRIVATE)	-0.30	0.15	-0.22	-2.17	.036

- **Reliability Test**

To certify internal consistency of the questionnaire, Cronbach's Alpha (α) was calculated for all the factors, like safety items, fatigue items, and Training Items, and was calculated through responses from 100 respondents using the Reliability Test. *Table 4.* An α value greater than 0.70 is commonly considered acceptable, whereas values more than 0.80 show strong reliability. Nunnally and Bernstein, 1994.

Table 4: Reliability Statistics

Construct	Cronbach's Alpha (α)	Number of Items
Safety Items	0.88	5
Fatigue Items	0.82	4
Training Items	0.86	4

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- **Pearson Correlation Analysis**

To assess the linear relation between Safety Management and Schedule Performance, a Pearson correlation analysis was carried out. In this test, the Pearson's value is 0.47 and the p-value is <.002. The Pearson correlation is shown in *Table 5.*

Table 5: Pearson Correlation

Variable 1	Variable 2	Pearson's r	p-value
Safety Management	Schedule Performance	**0.47**	**< .002**

- **System Dynamics (SD) Model Analysis:**

Using understandings from the cases and literature, a causal loop diagram (CLD) was initially developed to illustrate the hypothesized relation between safety and schedule variables. Figure 1 shows the important feedback loops recognized.

One significant loop is the schedule pressure–fatigue–accident loop: it shows that when schedule pressure increases (like efforts to avoid delay), leading to an increase in overtime work, it contributes to worker fatigue. A higher fatigue raises the accident risks, and when an accident happens, it slows or halts the operation, causing further delays which intensify the schedule pressure. This creates a reinforcing feedback loop (balances only when pressures are decreased or minimized).

Another loop is the safety investment loop: increased investment in safety, such as training, supervision, and PPE equipment, enhances safety compliance and lowers or minimizes the possibility of accidents. Fewer accidents and disturbances enable the project to be within schedule and reduce *the need* for last-minute schedule pressure. This creates a balancing loop that can stabilize the system. These loops interact with additional factors: for example, accident cases frequently trigger management to increase safety measures (a response-based balancing loop), and schedule delays may trigger allocation of extra resources or insertion of a buffer to recover lost time (an intervention that either relieve schedule pressure or, if done via overtime, feed the fatigue loop).

Reinforcing Loop (R1): Safety Investment → Compliance ↑ → Accidents ↓ → Delays ↓ → Budget ↑

Reinforcing Loop (R2): Accidents ↑ → Regulatory Pressure ↑ → Safety Investment ↑

Balancing Loop (B1): Schedule Pressure ↑ → Overtime ↑ → Fatigue ↑ → Accidents ↑ → Delays ↑

Figure 1: Causal Loop Development CLD

- **SD Model Simulation**

A stock-and-flow simulation model was developed according to the CLD (Sterman, 2000. The model, made using Python with ordinary differential equations (and cross-checked in Vensim software for consistency), contains the following key state variables (stocks), Fallah-Fini, et al, 2020: Safety Compliance Level (a continuous index ranging from 0 to 1 indicating the proportion of safety protocols effectively implemented), Worker Fatigue (an index showing cumulative fatigue/stress among labors group), Schedule Buffer (the

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remaining time before project deadline, measured in days), and Accident Count (or risk level). Key flow rates and causal relationships were shown. For example, *safety compliance* increases through safety investments like training and oversight, but declines in situations of high fatigue or complacency. *Fatigue* comes with sustained overtime and is reduced with rest (modelled as a recovery delay). Risk of accident rises when fatigue is high and compliance is less; moreover, realized accidents lower compliance temporarily due to work stoppage or psychological shock, and consume a part or all of the schedule buffer.

Several model parameters were measured using case study data or relevant literature. For example, the initial schedule buffer for each case was set according to their planned vs. actual schedules (Case B began with ~30 days buffer, which was almost exhausted by the end, Case A had ~60 days but experienced 30 days overruns, ultimately ending with negative buffer). The influence of fatigue on accident risk was calibrated using reported accident rates; an increase in fatigue index by 1 (on a 0–10 scale) was estimated to double the monthly probability of accident, drawing from the previous studies and the frequency of case accidents. Where direct data were lacking, questionnaire responses were used to form parameter values. For instance, respondents from Case B reported regular overtime averaging 10 hours/week, which was used to estimate the *fatigue accumulation rate* in that scenario. The model was then simulated for a 25-month period reflecting the typical project duration. The model behaviour was verified for logical consistency through extreme condition tests and dimensional consistency. A partial validation was also conducted by comparison of the simulation result with the actual outcome of the project, Sterman, 2000; Barlas, 1996. For instance, the base simulation using Case B's parameters forecasted 3 accidents over a year's period in total, which nearly aligns with the two major accidents recorded (accounting for some variance).

5. RESULTS

- **Descriptive Statistics**

a. Project Delays due to Safety-Related

The descriptive analysis shown in *Table 1*: Descriptive Statistics Using **SPSS** reflects that safety problems help significantly to project delays, accounting for an average effect of 35.25% (SD = 10.58). The 28.00% median delay shows that half of the projects experience safety-related delays greater than this value. A mild positive skewness (0.220) and almost normal kurtosis (-0.030) are shown from the distribution, indicating the greatest project cluster in the 25-35% delay range with a few extreme cases. These findings underline the important schedule effect of safety incidents in project schedules, reinforcing the need for better safety monitoring and mitigation strategies.

b. Schedule Pressure on Safety Performance

Table 1 indicates that respondents conveyed considerable impact of schedule pressure on safety (Mean = 3.81/5, SD = 0.75), with a median score of 3.05. The symmetrical distribution with skewness = 0.160 and slightly platykurtic pattern (kurtosis = -0.970)

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suggests a reliable pattern about the effect of schedule pressures, with ratings clustered closely around the mean. These outcomes determine that schedule demands regularly jeopardize safety practices, emphasizing the significance of applying pressure-aware management tactics and shielding buffers in project scheduling. According to Table 1, both variables demonstrated satisfactory normality (skewness <1 and kurtosis <2), validating the application of parametric statistical methods for more analysis of these key project management problems (George & Mallery, 2010; West, Finch, & Curran, 1995).

- **Result of Regression Statistics**

As per the results of the multiple regression analysis in **Error! Reference source not found.**, statistically there is an important difference between cases A and B across the critical practical measures. Safety Compliance was considerably greater in Case A (M = 4.3) than in Case B (M = 3.9, t-value = 2.12, DF = 98, P = 0.037), suggesting that the management in this group (Case B) to follow safety very rigorously. On the other hand, in the case of overtime hours/week, Case B shows significantly more overtime hours per week (M= 8.6) than Case A (M= 4.1, t-value = -3.53, DF = 98, P = 0.003), indicating a potential trade–off between work hours extension and the safety protocols. The converse relation between overtime hours and safety compliance is consistent with the theory of Job Demands-Resources (Bakker & Demerouti, 2017), which schedule pressure may reduce labour's ability to maintain adherence to safety protocols. Greater safety compliance in Case A proposes that work hour restrictions enhance safety adherence, despite other factors such as training and supervision likely assist (*Nguyen et al., 2022).* These findings underline the balanced scheduling policies required to decrease overtime without compromising safety standards (Kutner et al., 2005.

- **T – Test Result**

shows the regression model evaluated the influence of safety climate, schedule pressure, and project type on project performance, with all predictor variables standardized using z-scores. These t-tests are a fundamental component of linear regression analysis and are interpreted in accordance with the guidelines provided by Kutner et al. 2005 and supported by Field, 2013. The outputs for separate predictors show that safety climate substantially supports improved project performance (B = 0.43, t = 3.51, p = .001), indicating that a more positive safety climate is linked with better outcomes. On the other hand, schedule pressure negatively affects performance (B = –0.34, t = –2.37, p = .022), representing that increased time-related pressure tends to weaken project performance. The project type variable, coded as 0 = government and 1 = private, displays a significant impact as well (B = –0.30, t = –2.17, p = .036), suggesting that, keeping other factors constant, private projects demonstrated lower overall performance in comparison to public projects. These results support that every predictor creates a statistically meaningful contribution to explaining project results within the regression framework.

- **Reliability Test Result**

Cronbach's Alpha was calculated for the evaluation of internal consistency of the important Likert-scale included in the questionnaire, Table 4: Reliability **Statistics**. If

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Cronbach's alpha is 0.70 or higher**,** it is considered satisfactory for early-stage research, whereas if it's greater than 0.80, it shows stronger reliability, Nunnally and Bernstein, 1994. Results indicated high reliability for all thematic groups: Safety Climate (α = 0.88), Fatigue and Overwork (α = 0.82), and Training Effectiveness (α = 0.86). The results approve that the items within each construct reliably measured their planned dimensions, validating the formation of composite indices for additional analysis.

- **Pearson's Correlation Result**

Based on Table 5, the Pearson correlation analysis exposed a moderate positive relationship between safety management and schedule performance ($r = 0.47$, $p < .002$). This statistically significant correlation indicates that projects having stronger safety management practices tend to have better performance in meeting schedule deadlines. More clearly, better safety management highly supports timely project delivery. As per Cohen's (1988) guidelines ($r \approx 0.10$ – Small, $r \approx 0.30$ - Medium, $r \approx 0.50$ – Large), this correlation represents a medium-to-large effect size, supporting the notion that safety initiatives extend beyond regulatory compliance and can boost operational efficiency. This finding is especially related to the present study, as it provides empirical support for a core feedback loop in the proposed SD model: "enhanced safety compliance reduces delays and increases schedule performance". Significantly, this result challenges the common belief that improved safety will slow down the project timeline. Instead, the findings present that safety and schedule performance can support each other when projects are efficiently managed. It means safety should not be considered as an issue for meeting deadlines, but as a precious factor that contributes to projects being successfully delivered.

- **Result of SD Model Simulation**

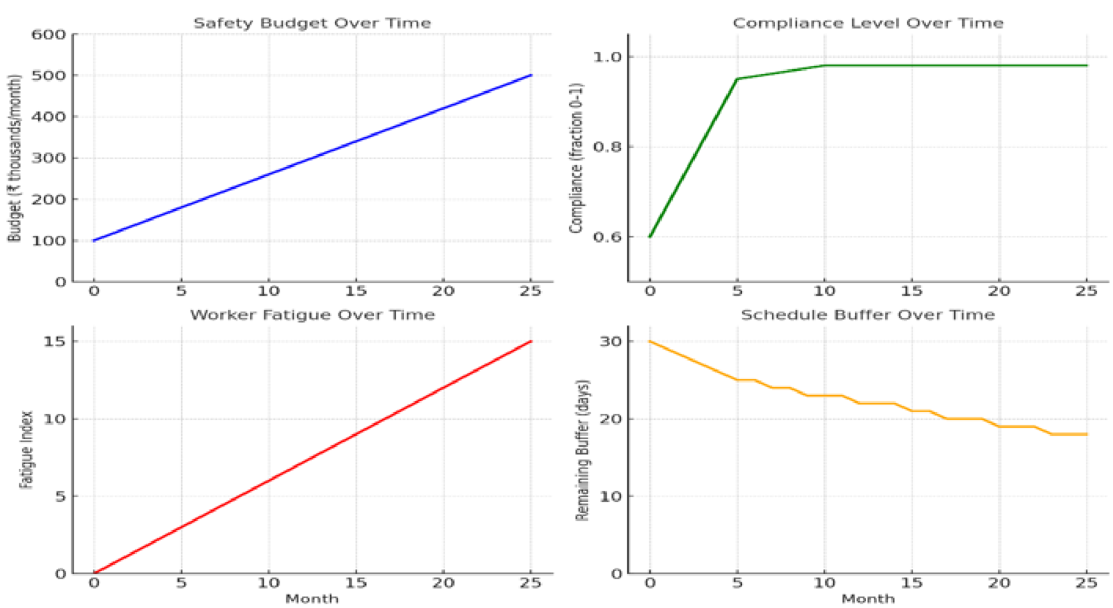

Figure 2: Baseline Simulation Reflecting Case B (Private Project)

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As per Figure 2, simulation results for a baseline scenario reflecting the private project (Case B) indicate a setting where investments in safety start at a modest level and gradually increase over time.

The model assumes a monthly safety budget that increases from ₹100,000 to ₹180,000 in the first 5 months (and will be continuously increasing linearly afterward), representing an accident-driven approach where safety spending escalates based on early warning signs in response.

Due to this, safety compliance rises from an initial level of 0.6 (60%) to approximately 0.95 by month five, as shown in the top-right (Compliance Level Over Time,

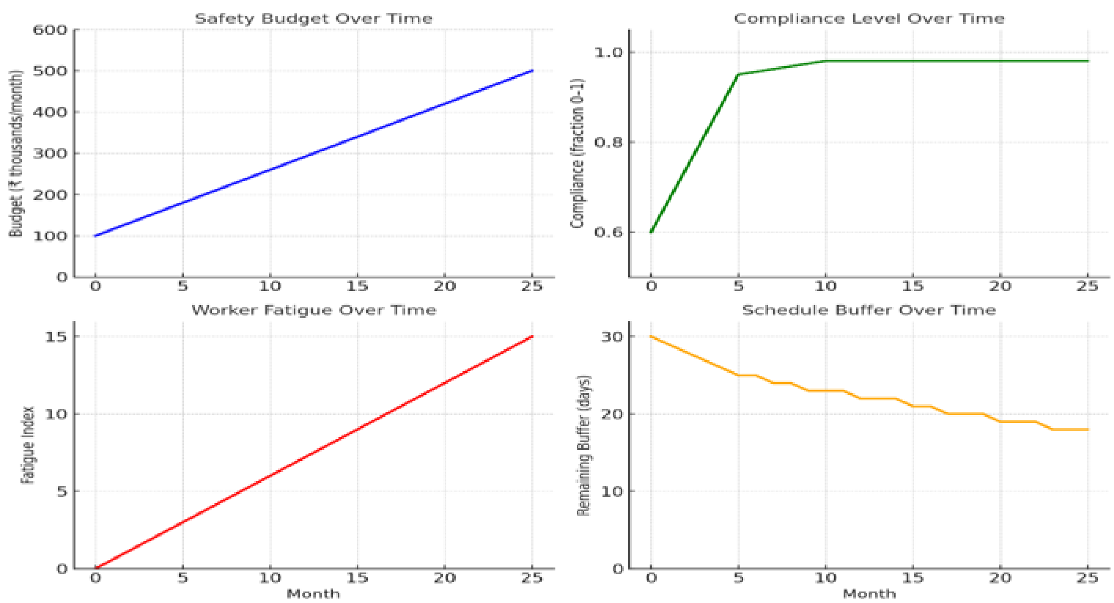

Figure 2 *2*).

This fast advancement highlights those early investments can obtain almost full compliance; however, the delay in the beginning of those investments says the project begins with poor safety.

The Safety Budget Over Time (top-left,

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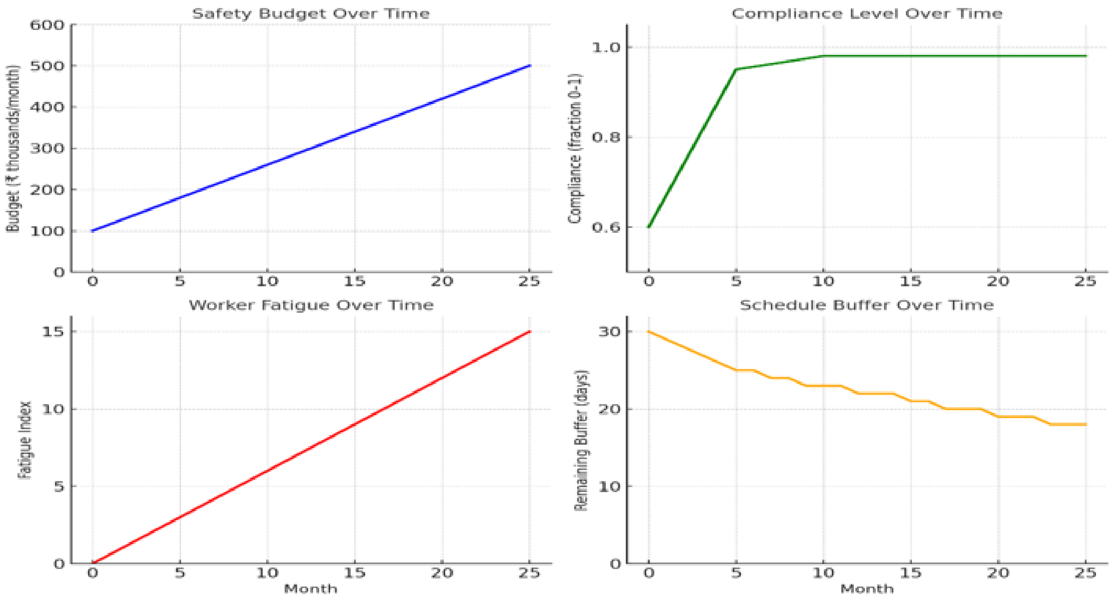

Figure 2 2) displays the linear increase in safety expenditure. Though compliance is higher in month 6, the Worker Fatigue Over Time plot (bottom-left,

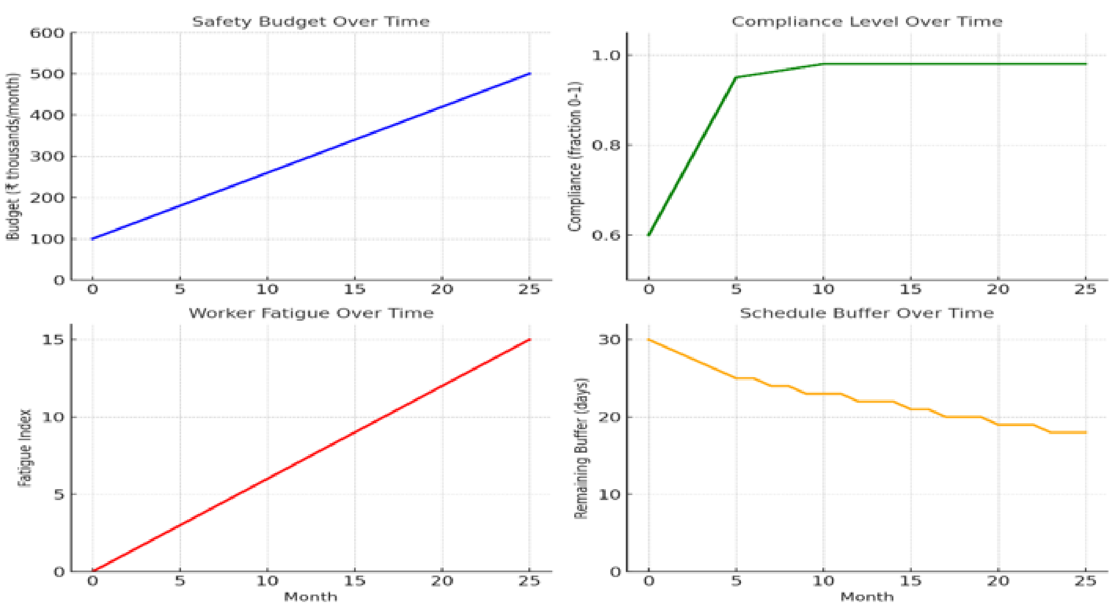

Figure 2) shows a continuous growth in fatigue, reaching a high level of about 15 on the fatigue index by month 25.

This growth is because of continuous schedule pressure and overtime, as the model assumed that despite improved compliance, work intensity remains high to meet deadlines.

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The growing fatigue has a harmful consequence, contributing to some accidents and productivity fatalities. The Schedule Buffer Over Time (bottom-right,

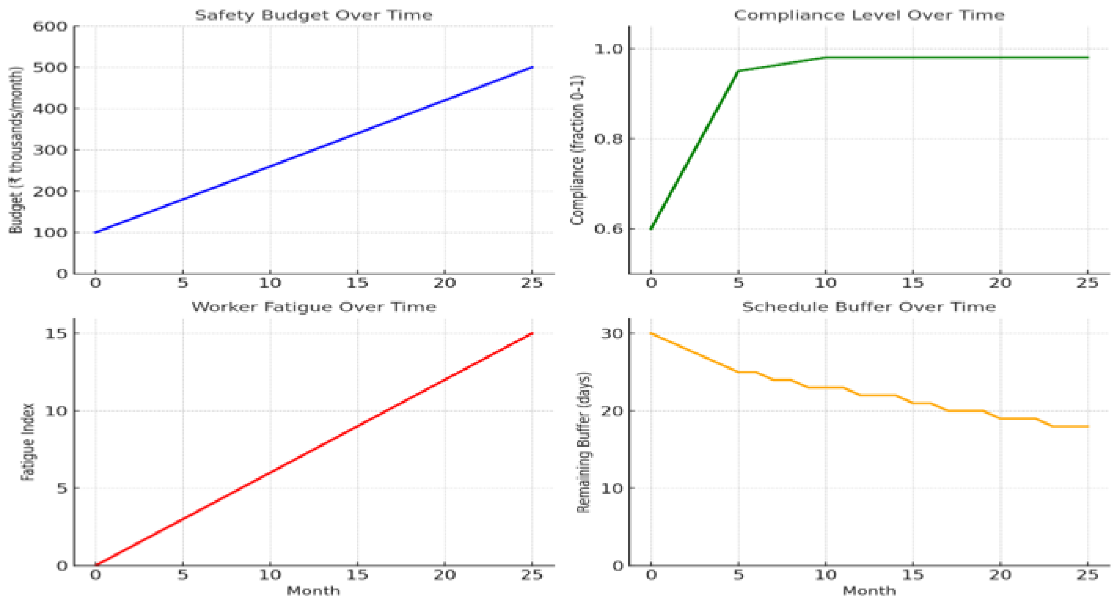

Figure 2) begins with 30 days and reduces to approximately 18 days by month 25.

In this scenario, the project is completed before the deadline (buffer not fully depleted); nonetheless, the reduction from 30 to 18 days implies that about 12 days of delay were incurred relative to the initial schedule.

Remarkably, the model registered some minor accidents early in the project when compliance was still low; these incidents reduced the schedule buffer and likely acted as a catalyst for rising the safety budget.

In summary, Figure 2's baseline scenario proposes that accident-driven safety advances can ultimately attain great safety compliance, but ongoing schedule pressure contributes to significant fatigue and depletes a part of the schedule buffer.

The private project (Case B) showed the same pattern; it was completed on time, but only by utilizing a significant buffer and intensifying labor (many respondents described that the project was "too challenging" in the final stages, with high fatigue).

This scenario highlights that enhancing safety compliance mid-project is beneficial; however, if it follows incidents and is under tough time pressure, workers may still suffer more fatigue, which could be a hidden risk for quality or forthcoming safety.

ISSN (Online):0493-2137
E-Publication: Online Open Access
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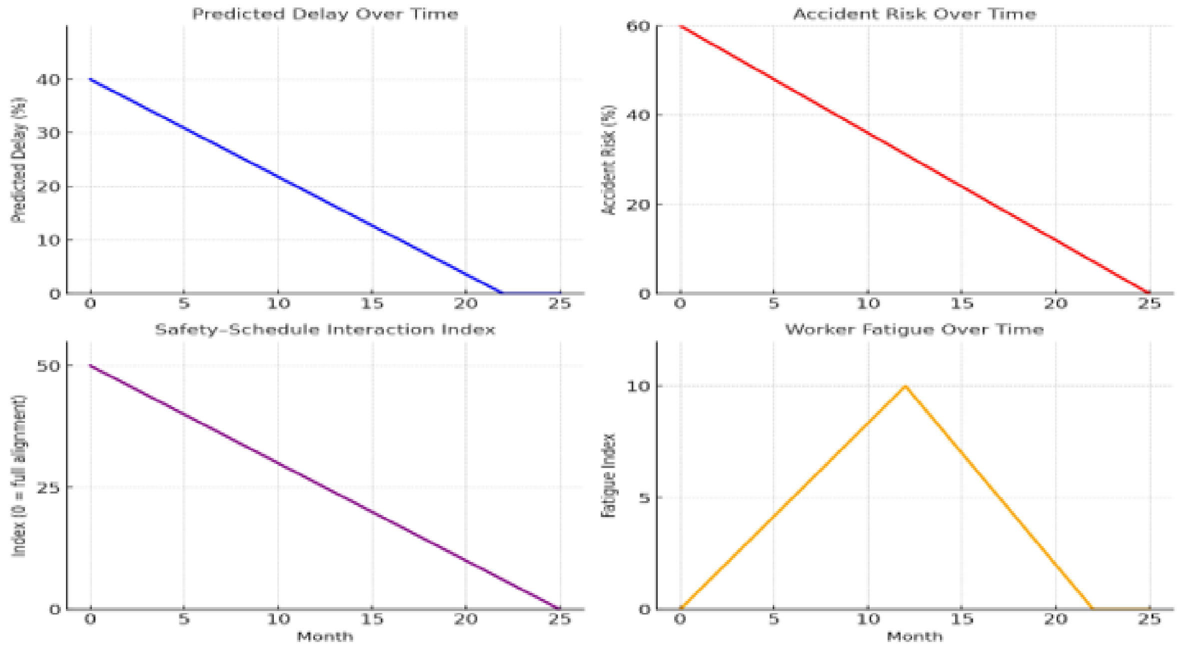

Figure 3: Improved Safety Simulation Highlighting an Early-Stage Strategy (what if scenario for Case A or Improved Case B)

As per Figure 3, simulation outputs for an improved safety scenario explain the potential advantage of integrating safety strategies early in the project (akin to a what-if scenario for Case A or an enhanced policy for Case B). In this case, safety measures are strengthened from the beginning, greater initial safety budget and training results prior compliance level of 0.8 (80%), which then rapidly reaches 1.0 (or 100% efficient compliance) and is preserved. The Predicted Delay Over Time (top-left plot, *Figure 3*) begins at about 40% (indicating that if no action were taken, a 40% schedule overrun was expected based on initial situations and risks). However, this gradually reduces to 0% by month 22. This specifies that the project, which was primarily projected to have a late finish, is able to recover and realign with the deadline due to the applied safety interventions. The Accident Risk Over Time (top-right) also declines from an almost 60% probability of an incident in the early stage to about 0% at the end of the project. This essential decline has occurred due to the greater compliance and lesser fatigue, which demonstrates that early incorporation of safety mitigates accidents. The Safety–Schedule Interaction Index (bottom-left, Figure 3) is a compound metric designed to compute the alignment degree between safety and schedule; it begins at 50 (on a relative scale) and declines to 0, indicating that by the end of the project, safety and schedule objectives are fully aligned with no remained trade-off tension. Finally, Worker Fatigue Over Time (bottom-right) displays a primary rise to almost 10 (on the index) around the project mid-point, followed by a constant decline to 0 among months 22–25. This indicates that in the earlier stages, still some overtime and stress persisted as the project accelerated; nevertheless, as safety measures took hold and all possible milestones were accomplished without incident, the work pressure eased, enabling recovery. The output

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of this scenario is that the project avoids both accidents and any delay; indeed, the model indicates that it could even complete a bit ahead of the originally estimated schedule (as predicted delay drops to 0 prior to the final month). Practically, Figure 3. reveals that an initial investment in safety (for instance, training, enough staffing to prevent overwork, and strong compliance from first) can yield benefits by removing accident-related disturbances and minimizing the inefficiencies of fatigue. The government project (Case A) moderately mirrors this scenario, had few minor accidents, possibly because of stronger initial safety compliance, yet still not perfectly eliminate delays due to having schedule overrun. The difference, based on the model's interpretation, may be that Case A's safety measures were ok, but not fixed with efficiency measures, whereas the best scenario would balance better safety with smart scheduling. In any case, the boosted safety simulation emphasizes that the trade-off can be altered into a win–win outcome, where accidents are minimized or avoided and schedule performance is enhanced alongside.

The outputs of the simulation were further analysed to have a case comparison. In the baseline scenario, Figure 2, the model recorded a total of 3 accidents and an ultimate schedule buffer of +18 days (finishing 18 days prior to the deadline). In the enhanced safety scenario, Figure 3, incidents were almost 0 (virtually none) with 0 days final buffer (on time).

- **Balanced Strategy for Case A versus Case B**

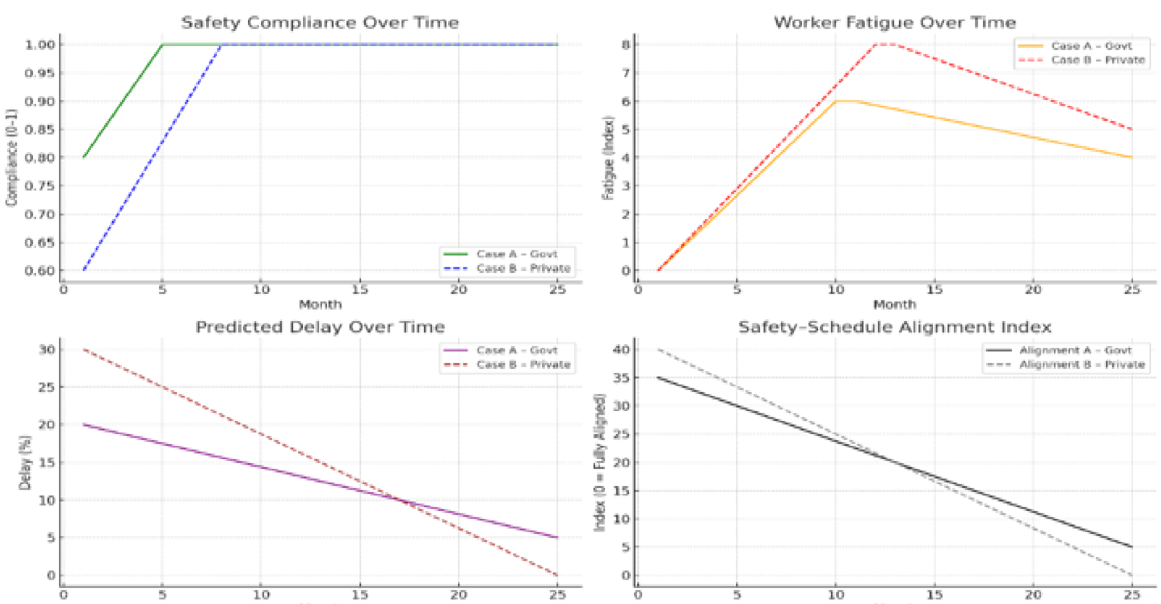

Figure 4: Balanced Strategy Simulation for Case A vs. Case B

The impact of an embedding safety strategies at the outset on both project types is compared using this simulation. Case A (government projects) begins with greater compliance (0.8), reaching 1.0 by month 5, however, Case B (private projects) enhances

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from 0.6 to 1.0 by month 8. Worker fatigue in Case A remains moderate (peaking at 6), whereas Case B displays greater initial fatigue (about 8) that reduces with improved workload management.

The delay forecasted decays from 20% to 5% in Case A and from 30% to 0% in Case B, representing stronger schedule recovery in the private project when safety is incorporated priorly. The safety–schedule alignment index improves in both cases, yet only Case B achieves full alignment (index = 0), illustrating that effective implementation can complement safety goals.

In summary, this scenario proposes that early investment in safety delivers performance benefits in both public and private sectors, with Case B getting more in terms of delay recovery and alignment. The outcomes confirm that safety and schedule objectives can be interdependent to each other when managed.

6. DISCUSSIONS

The combined findings from the system dynamic simulation and empirical analysis give various key insights. Foremost, they challenge the belief that there is an inevitable trade-off between safety and schedule in construction projects. Even though in the initial consideration, it might appear that allocating time and resources to safety will slow a project down, but our findings show the opposite for the medium to long term; prioritizing safety can lead to improved schedule performance in any construction project. it is due to the time saved by prohibiting accidents that outweigh the time invested in applying safety precautions. In Case B (private case), management initially focused on speed a lot, and in fact, the project was completed within schedule, but not without cost. Workers highlighted more fatigue and the project faced multiple safety accidents, which could simply have resulted to serious delays. The public case (Case A) shows a more cautious approach, achieving better safety outcomes (no major accidents), but it was behind schedule. The optimized scenario and analysis convey that a balanced approach merging the early adoption of safety procedures with effective scheduling could have enabled Case A to finish within schedule without compromising its strong safety record, and could have decreased the human cost in Case B while still being on time.

These findings align with the theory of system dynamics and previous research. The reinforcing loop of “schedule pressure → fatigue → accidents → delays” observed in this study reflects the feedback processes identified by Irumba et al. (2010) and others, wherein project managers responding to delays by pressurizing the labors may unintentionally trigger a self-defeating cycle that leads to further delays due to accidents or mistakes. This study empirically validates this loop in an Indian context. It also contributes to the literature by quantifying the balancing influence of safety budgeting: enhancing safety compliance disrupts this cycle, such as decreasing accidents, enabling smoother project implementation, and finally relieving the schedule pressure. This dynamic was reflected in the regression analysis, where a positive correlation between safety climate and schedule performance was observed. This reinforces the idea that effective management practices foster a worthy cycle of higher morale, fewer accidents,

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and improved productivity. This opinion is also recommended by Mohamed, 1999, and echoed in **Abdul Nabi et al. (2020),** who distinguished that safe worker behavior can be aligned with productive behavior.

From a practical perspective, the outputs propose that construction project stakeholders should reconsider their ideas regarding safety expenditures. Rather than counting safety measures as a burden on the schedule or an obligatory compliance cost, they should be regarded as a strategic investment in productivity and risk management. For instance, dedicating budget for extra safety training or hiring a safety officer may have initial costs and take some project time because of training, but it can stop big incidents that might close a site for weeks or even months. Case B scenario basically came critically close to an accident-induced shutdown; the fact that it was within schedule was due to luck that the incidents were not more serious. This is inconsistent with the concept of leading indicators of safety (like near-misses, safety audit scores) serving as forecasters of project success. Future extension of this model could integrate this (tracking near-miss frequency) as an early warning signal.

Moreover, the discussion spreads to differences in organizational context. Public vs. private project atmospheres can affect safety and schedule urgencies. Public projects (Case A) may have more bureaucratic processes (like compulsory safety clearances, weak and slower decision-making), which can definitely delay tasks but also impose a baseline of safety. Private projects might be more adaptive and time-focused, but need a strong internal safety culture to make sure that worker welfare is not compromised by speed. Interestingly, this regression analysis revealed that, a project being public or private was not significant unless we include safety climate and perceived schedule pressure. This recommends that any organization, whether public or private, can potentially reach the optimal balance if they implement the right practices. Private companies can enforce strict safety standards, and the public sector can rationalize procedures to prevent unnecessary delays, enabling both to move toward comparable outcomes.

1. Policy and Managerial Implications

For Project Managers

- Integrate safety-related activities into CPM schedules from the first day.
- Keep track of fatigue level, overtime hours, and compliance to spot early warning signs.
- Implement simulation tools to evaluate "what-if" scenarios prior to bringing changes.

For Contractors

- Dedicate enough budget for safety and training resources at the commencement time.
- Connect safety monitoring and evaluation directly to productivity objectives.
- Prevent any schedule compression that jeopardizes safety.

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For Policymakers

- Require incorporation of safety measures into project planning and scheduling.
- Promote using effective predictive simulation models (like the model proposed in this paper) for large projects.
- Portray safety requirements as facilitators of schedule reliability.

For Clients (Owners)

- Allocate incentives to both timely delivery and safe performance (Incentive–Based Management).
- Mandate comprehensive safety plans as a contractual requirement of the project.
- Acknowledge safety as a strategy to shelter schedules from major interruptions.

7. RECOMMENDATIONS AND LIMITATIONS

This research gives valuable insights into the safety–schedule trade-off in the Indian construction projects; it has some limitations. The survey was cross-sectional, so self-reported, potentially carrying perception bias in spite of partial validation against some project records. This study was limited to Visakhapatnam projects, restricting generalizability; therefore, future researchers should expand this to projects in other states. The Python-based dashboards and mobile applications were excluded in this model; Moreover, other factors like financial restrictions, work quality, risks, and labor morale. Addressing these gaps, future researchers should include mobile applications, Python dashboards, and a wider range of real project variables to draw a more complete picture.

Practically, the findings recommend taking safety as a schedule efficiency booster rather than a trade-off or catalyst, allocating investment in safety training and supervision from the start, controlling fatigue as a performance metric besides cost and time, and utilizing simulation tools for decision support accuracy. Lastly, discovering the strengths of public and private projects, which can give a balanced approach, addressing the apparent conflict between safety and schedule into a win–win outcome for both operational and worker well-being.

8. CONCLUSION

This study portrayed the dynamic linkage between safety investments and schedule performance in the Indian construction sector, using a combination of empirical analysis and system dynamics modelling. Practical case studies from government-funded (Case A) and private-sector (Case B) were analysed using field data, structured surveys, and SPSS-based statistical analysis, followed by Python-based simulation modelling to evaluate system behavior over time. For Case A (Public–Funded Projects), data were gathered from 5 various government-funded construction projects in Visakhapatnam, India. Safety performance records, schedule data, and related indicators were then

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averaged across these projects to produce a representative dataset. This combined case profile was then compared with the private-sector project (Case B) to evaluate safety–schedule trade-offs.

The results challenge the conventional belief that safety and schedule are fundamentally in conflict. Regression analysis portrayed a positive correlation between safety climate and perceived schedule performance, illustrating that safety and productivity are not opposing goals but mutually strengthening outcomes. The baseline simulation (figure 2), modelled on Case B, indicated that while response-driven safety enhancements can ultimately obtain compliance, they also cause hidden costs in the form of higher worker fatigue and schedule buffer consumption. Earlier incidents in the project will reduce consumed contingency time, so the project can only succeed by pushing the worker into higher stresses in some cases, even beyond their limit.

Oppositely, the improved safety scenario (figure 3) demonstrated that an early incorporation of safety approach focuses on early compliance, training, and fatigue management minimized accidents and concurrently improves schedule reliability. This scenario reflected the safety-focused nature of Case A, while overcoming its drawbacks using better resource alignment. The final balanced strategy simulation is shown in figure 4, implemented this optimized approach to both cases, portraying that Case A could have met the project deadline without compromising its safety record, and Case B could have prevented labor fatigue while still being within schedule.

These results are consistent with system dynamics literature, which shows reinforcing feedback loops (schedule pressure → fatigue → accidents → delay) can be interrupted via timely safety interventions. Notably, the simulation findings backing empirical evidence from the field, reinforcing that investing in safety is a strategic decision, not merely a compliance expense.

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