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Article

Construction Project Delays as Emergent Phenomena: A Theory of Hidden Recursive Disturbance and Temporal Restructuring

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Abstract: Despite decades of research on various factors, delays in construction projects remain a persistent issue. This study aims to investigate the causes of construction project delays and thereby promote the healthy development of the construction industry. It focuses on analyzing the driving factors behind project delays and uses the G1 weighting method to determine the weight coefficients of each factor. Combining system dynamics with simulation analysis of eight constant-type driving factors, the results indicate that the factors significantly influencing construction project delays are individual differences, goal orientation, uncertainty, and internal organizational support. Construction project delays are not simply the accumulation of risk events, but rather a process of temporal restructuring under the influence of implicit recursion.

Keywords: construction delays; implicit recursive disturbance; temporal restructuring; system dynamics

1. Introduction

High quality, low cost, and short construction duration are the ultimate objectives of any construction project. These objectives define the core elements of project management, namely “three controls, two managements, and one coordination”—specifically, schedule control, quality control, cost control, contract management, safety management, and organizational coordination [1–3]. However, in actual project management practice, project managers often focus primarily on quality control and safety management while neglecting schedule control, allowing schedule delays to become a common occurrence [4-5]. Schedule delays are one of the key factors leading to the loss of control over project progress, quality, and investment objectives, as well as disputes among project stakeholders, and they have a significant impact on the economic and social benefits of the project [6-8].

The factors leading to schedule delays are diverse and primarily manifest in the following areas: Inadequate planning and design: During the project initiation phase, insufficient or careless planning and design work can easily create hidden risks for subsequent construction [9-10]. For example, design flaws may require frequent changes during construction, or underestimating the project’s difficulty and complexity can result in unrealistic schedule plans [11]. Insufficient resource supply: Regarding human resources, issues such as an insufficient number of workers, inadequate technical proficiency, or improper personnel allocation may arise [12]; regarding material resources, untimely material delivery, substandard quality, or equipment malfunctions can all affect construction progress [13]; regarding financial resources, funding shortages can prevent the project from operating normally, such as the inability to pay workers’ wages or purchase materials and equipment on time [14]. Inappropriate Construction Techniques and Methods: The use of outdated or unsuitable construction techniques and methods may reduce construction efficiency, increase construction difficulty, and consequently lead to schedule delays [15-16]. Poor management: Insufficient competence and experience within the project management team may lead to issues such as ineffective coordination, poor communication, and decision-making errors [17–18]. However, while these factors have always existed, construction project delays have become a widespread new phenomenon. The application of the theory of implicit recursive perturbations and time reconstruction aims to provide methodological support for construction project management.

In actual projects, delays arise from the continuous accumulation and amplification of minor, frequent, and often unrecorded disruptions—such as inconsistent inspection standards, ambiguous technical specifications, and routine variations in how inspectors and technicians perform their duties. Although these disruptions may seem insignificant when viewed individually, they recur and are amplified recursively within a tightly coupled network of activities. This paper proposes a mechanism theory primarily based on tightly coupled systems. Applying system dynamics methods, it establishes causal feedback models and stock-flow models to identify and screen factors influencing construction project delays. It conducts qualitative and quantitative analyses of the identified factors and quantifies the impact of each factor on construction project delays.

2. System Dynamics

2.1. Basic Concepts of System Dynamics

2.1.1. Feedback Theory

In systems dynamics, feedback is a key theoretical concept. Within a system, the relationship between the input and output of the same unit or subcomponent constitutes a form of feedback. A feedback system refers to a system that includes a feedback mechanism and its effects, and it often possesses one or more feedback loops. A closed loop consisting of a series of interacting links is called a feedback loop; a simple system consists of a single loop, while a complex system consists of three or more loops. In a feedback system, a loop exhibiting positive feedback characteristics is called a positive feedback loop.

2.1.2. Causal relationship

A Causal Loop Diagram (CLD), also known as a causal loop diagram, is an important tool for representing feedback systems and serves as the initial stage of model-building. In a causal loop diagram, positive (+) and negative (-) signs represent the polarity of each causal chain, indicating that if one variable changes, the corresponding variable will also change. A positive causal chain indicates that, all other conditions being equal, if the cause increases, the effect will be greater than its original level; if the cause decreases, the effect will be less than its original level.

2.1.3. Traffic Volume Chart

Cause-and-effect diagrams are highly effective for illustrating a system’s causal relationships and feedback loops, making it easier to understand the system’s structure during the early stages of modeling. Building on this foundation, flow-state diagrams are drawn to quantitatively determine the relationships between variables. Only by establishing mathematical relationships between these variables can the entire system be analyzed and studied more effectively.

Flows and states are another critical concept in system dynamics; without them, it is impossible to simulate how feedback loops change over time. Additionally, a typical flow-stock diagram includes two other types of variables: auxiliary variables and constants.

(1) State variables: Also known as stock variables or level variables, these represent cumulative quantities that reflect the system’s state and whose changes are solely driven by flow. They provide the information basis for decision-making and action. The mathematical concept of a stock is integration, and its mathematical expression is:

$$Stock(t) = \int_{t_0}^{t} \left[Inflow(t) - Outflow(t) \right] ds + Stock(t_0) \tag{1}$$

(2) Rate variables: Flow, as a rate variable, is a state variable whose value is determined by feedback-based decision-making and represents the change in the state variable over time. It represents the derivative of the stock and can therefore be expressed using a differential equation, with the mathematical expression as follows:

$$\frac{d(Stock)}{dt} = Inflow(t) - Outflow(t) \tag{2}$$

(3) Auxiliary variables: In the decision-making process, these serve as intermediate factors. They primarily manifest in the information exchange during data transmission, specifically in the

relationship between speed variables and efficiency variables, and may change instantaneously depending on variations in related variables.

(4) Constants: In systems analysis, constants are quantities that do not change over time. Information is fed into stocks and flows by constants, either directly or indirectly.

2.2. Equations of a system dynamics model

The generation of SD equations involves converting flowcharts into mathematical simulation equations to describe the functional relationships between variables. The main types of these equations are as follows:

(1) State-variable equations (L equations)

In system dynamics, the accumulation of state variables over time can be represented by state equations. The form of these equations is:

$$L\ Level.K = Level.J + DT\left(Inflow.JK - Outflow.JK\right) \tag{3}$$

(2) Rate-variable equation (R equation)

In system dynamics, rate equations are denoted by the letters R and represent the relationships between input and output variables. The form of the feedback determines the structure of the equation; therefore, there is no fixed format, but it can generally be written as:

$$\text{R Rate.KL = Variables, constants, expressions} \tag{4}$$

(3) Auxiliary equation (A equation)

Before formulating a rate equation, it is essential to carefully consider the necessary information it must contain and perform certain algebraic calculations in advance. These additional algebraic operations are referred to as auxiliary equations, denoted by the letter A . Auxiliary equations do not have a standard form; they can take the form of algebraic relationships involving variables, constants, or functions corresponding to tabular data. Their format is as follows:

$$\text{A AU.K = Constants, variables, functions, express ions} \tag{5}$$

(4) Constant equation (C equation)

A constant equation assigns a value to a constant using a fixed format. Its general mathematical expression is:

$$C\ C_i = N_i \tag{6}$$

(5) Table functions (T equations)

In model construction, the complex relationships between certain variables cannot be expressed using simple mathematical combinations, but they can be represented graphically. Functions expressed in this way are called tabular functions, denoted by the letters T Tabular functions are essentially a form of auxiliary equations. Their general expression is:

$$\begin{aligned} &A\ Table\left(TNA, P.K, N_1, N_2, N_3\right) \\ &T\ TNA - E_1, E_2, \cdots, E_M \end{aligned} \tag{7}$$

(6) Initial-value equation (N equation)

Initial value equations are primarily used to assign initial values to variables such as level variables, rate variables, and auxiliary variables. Initial values can be determined in three ways: (a) based on the conditions reflected by the system; (b) based on the system's equilibrium conditions; or (c) calculated using a model. The general form of such equations is:

$$\text{N Variable names=Values, variables, expre ssions} \tag{8}$$

2.3. Steps in System Dynamics Modeling

Model building in system dynamics is an iterative process characterized by gradual refinement and step-by-step achievement of objectives. System dynamics models can be categorized into qualitative and quantitative models. Since models represent abstractions and simplifications of real-world systems, their practicality must be carefully evaluated during the modeling process—specifically, whether the model enhances our understanding of the system being simulated. The specific steps involved in system dynamics modeling are illustrated in Figure 1.

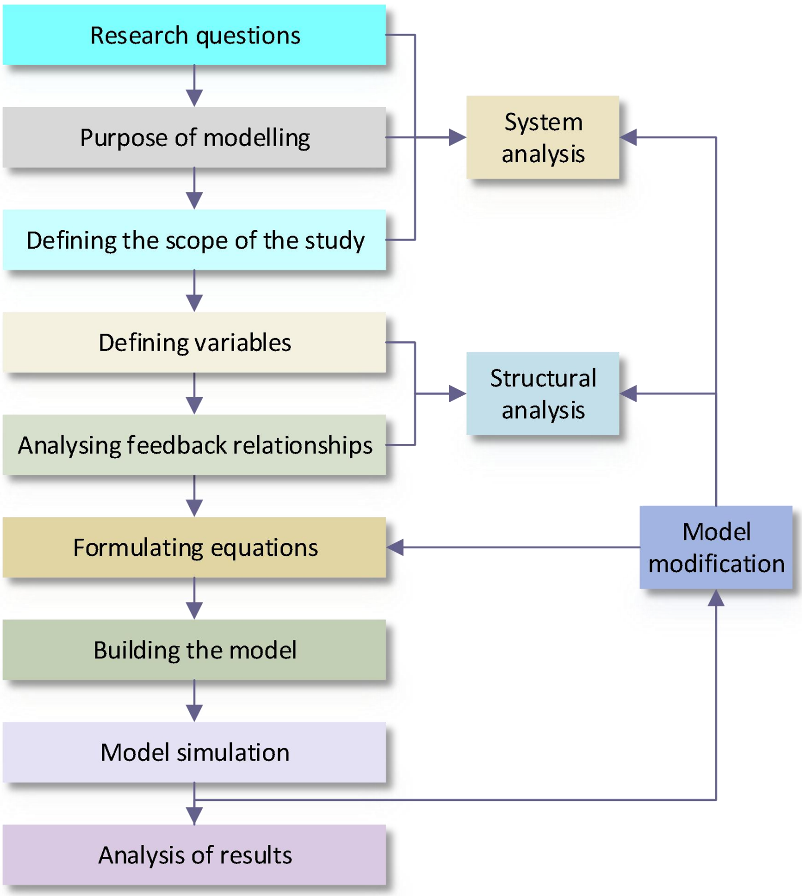


Figure 1. Modeling Steps for System Dynamics

3. A System Dynamics Model of Delay Evolution in Construction Projects

3.1. Direct Operational Impact (DOI)

DOI refers to disruptions that directly affect the task level: work interruptions, rework, idle time, and disruptions to the sequence of processes.

DOI affects all activities—it is a local issue at the node level.

The formal definition is as follows:

$$DOI_t = f\left(IDV_t, TBA_t\right) \tag{9}$$

3.2. Recursive amplification as positive feedback in the SINV framework

IDV and TBA interact recursively through a reinforcement loop:

TBA (divergent interpretation) → variable execution → non-compliant output → IDV (inconsistent acceptance) → rework/ambiguous feedback → reinforcement of TBA.

Within the SINV framework, this loop continues indefinitely and cannot be corrected. Each perturbation reduces absorption capacity, thereby nonlinearly increasing the probability of propagation.

3.3. Time Reconstruction: Structural Consequences, Not Core Mechanisms

Definition: Time Reconstruction (TR) is a network-level process in which implicit interference within internal products reconstructs the temporal logic of project schedules. It is an observable structural consequence of implicit recursive interference, rather than a core theoretical innovation.

Two Dimensions:

D1: Time-Dependent Reconstruction—Critical Path Migration, Sequence Rearrangement, and Spontaneous Synchronization Constraints.

D2: Erosion of temporal flexibility—floating-point compression, recovery window contraction.

Why Time-Dependency Reconstruction (TR) Is Not a Core Contribution: The existing literature has already described critical path migration. What was previously missing was an explanation of the implicit dynamic mechanisms that compel such reconstruction. Our contribution lies in linking reconstruction to the amplification of invisible, recursive perturbations originating from IDV and TBA and driven by SINV.

3.4. The complete causal chain

IDV/TBA → (under the influence of SINV) recursively amplifies DOI → (via gating conditions: tight coupling, low absorptive capacity) temporal reconstruction → DEL. The complete causal chain is shown in Figure 2.

Background factors (IEP, INSO) modulate the amplitude of IDV/TBA.

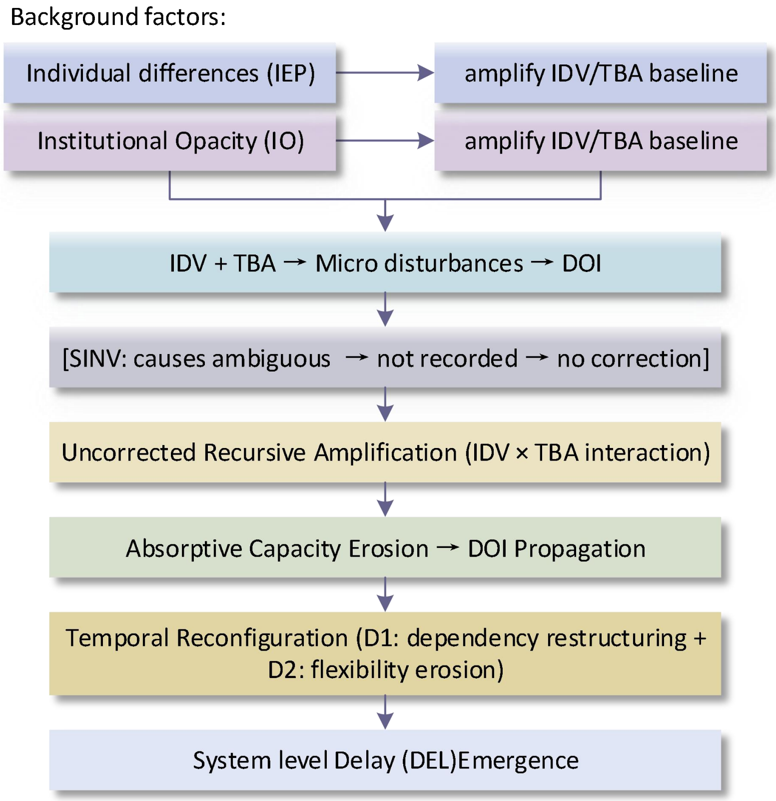


Figure 2. Cause and effect chain diagram

3.5. Boundary Conditions and Counterexamples

This theory applies to tightly coupled, time-sensitive projects with complex interpretations (e.g., infrastructure, core structures of high-rise buildings, and interior finishing phases). The theory does not apply or requires adjustment in the following situations:

(1) Fully automated processes (without IDV/TBA).

(2) Loosely coupled, modular construction with sufficient buffer margins.

(3) Projects without on-site acceptance handoffs, or where technical briefings are conducted entirely in digital or executable formats.

These boundary conditions are critical for falsifying the theory.

3.6. Formal representation

Scope: DEL specifically refers to project delays caused by interactions between IDV and TBA under SINV conditions. Exogenous disturbances (such as natural disasters, major design changes, and political intervention) are excluded from this scope.

(1) Generation of local operational disturbances under SINV conditions:

$$DOI_t = f\left(IDV_t, TBA_t, IDV_t \times TBA_t\right) \tag{10}$$

where: DOI_t = direct operational impact at time t, IDV = verification uncertainty, TBA = interpretive execution uncertainty.

This formula indicates that local operational disturbances arise not only from independent effects but also from recursive interactions between these two mechanisms.

(2) Reduced absorption capacity

$$A_{t+1} = A_t + \alpha\left(DOI_t\right) \tag{11}$$

where: A_t represents the absorption capacity at time t, and α is the perturbation erosion coefficient; recursive perturbations gradually weaken the system's ability to absorb additional perturbations in the future.

(3) Transmission sensitivity

$$P_t = g\left(\frac{1}{A_t}, C_t, F_t\right) \tag{12}$$

where: P_t = probability of disturbance propagation, C_t = degree of close coupling, F_t = remaining time flexibility (floating window and recovery window). As absorption capacity decreases and time flexibility diminishes, the likelihood of disturbance propagation increases nonlinearly.

(4) Conditions for temporal reconstruction

$$TR_t = \begin{cases} 0, & \text{if disturbances are locally absorbed} \\ h\left(DR_t, FE_t\right), & \text{if } P_t \geq \theta \end{cases} \tag{13}$$

Specifically: $TR_t =$ Time Reconstruction, $DR_t =$ Time Dependency Reorganization, $FE_t =$ Time Flexibility Erosion, and $\theta =$ Resilience Threshold.

Therefore, time restructuring occurs when recursive perturbations exceed the system's absorption threshold and trigger structural changes in the time-dependent dynamics.

(5) Spontaneous formation of delays

$$DEL_t = \phi\left(TR_t\right) \tag{14}$$

where: $DEL_t =$ system-level emergent delay; $\phi =$ the transformation from time reconstruction to observable schedule delay.

This formula emphasizes that project delays are not merely the accumulation of isolated disruptions, but rather an emergent phenomenon resulting from the restructuring of time within a tightly coupled project system.

Although SINV does not appear explicitly in the equation, it determines whether the recursive loop (α, g) can run continuously. Formally speaking, when $SINV = 1$ (high ambiguity), positive feedback is enabled by preventing updates to IDV or TBA; when $SINV = 0$ (full traceability), a damping term is introduced to reset IDV/TBA.

4. Simulation

4.1. Case Background

A 3-hour direct delay caused by TBA (reinforcement rework) and IDV (failure to pass inspection) consumed the float time. Due to a work stoppage caused by high temperatures (construction prohibited from 11:00 a.m. to 3:00 p.m.), the concrete pour was postponed from 8:30 a.m. to 3:00 p.m. The pour was completed at 7:00 p.m. Curing required 24 hours → Originally scheduled for removal at 19:00 on Day 2, but due to the prohibition on night work → rescheduled for removal at 08:00 on Day 3. The 3-hour implicit disruption evolved into a 19.5-hour absolute delay. The key point is that a non-critical path became the new critical path—resulting in a time restructuring. The site log classified this event as "General Rework—Coordination Issue" and did not attribute it to IDV/TBA, thereby reflecting SINV.

4.2. Model Development and Validation

4.2.1. Weighting of indicators for construction project delays

This paper conducted semi-structured in-depth interviews with five senior experts who have over 20 years of experience in construction projects (two of whom are involved in construction project management, two in green building design, and one in real estate development construction projects). Each expert ranked the key factors leading to construction project delays and assessed the relative importance γk of each weighting indicator to calculate its weight. When applying the G1 method for subjective weighting, inconsistencies in the ranking results arose due to the experts' differing perspectives on the issues. These inconsistencies were addressed as follows:

Suppose an expert rated as L may have ratings of $L_1, L_2, \cdots, L_s$, $\left(1 \le L_s \le L; s = 1,2,\cdots,h; \sum_{s=1}^{h} L_s = L\right)$, which yield the same ranking order, and assigns rational values to assess their importance, that is: Expert L_s assigns a ranking of $X_{n1}^{(s)} \ge X_{n2}^{(s)} \ge \cdots \ge X_{nm}^{(s)} \left(m = 1,2,\cdots,L_s; s = 1,2,\cdots,h\right)$ to the m evaluation criteria listed above, while Expert k assigns a rational weight $\gamma_{nk}^{(s)}$ to the ratio of the relative importance of criteria $X_{k-1}^{(s)}$ and $X_k^{(s)}$ in Group s . First, calculate the arithmetic mean γ_k^*, then use the weighting formula above to obtain the weighting coefficient ω_{nk} for X_{nk} . For each $k \left(1 \le k \le m\right)$, take the arithmetic mean of the L_s ω_{nk} values as the composite result, denoted as:

$$\omega_k^{(s)} = \frac{1}{L}\sum_{k=1}^{L_s} \omega_{nk}^{(s)} \left(s = 1,2,\cdots,h; k = 1,2,\cdots,m\right) \tag{15}$$

$$y_j = \sum_{p=1}^{m}\left(1 - \frac{Cov(j,p)}{\sigma_j \sigma_p}\right)\left(j = 1,2,\cdots,m\right) \tag{16}$$

The resulting weights for each evaluation metric X_k are as follows:

$$\begin{gathered} \omega_k^* = \alpha_1 \omega_k^{(1)} + \alpha_2 \omega_k^{(2)} + \cdots + \alpha_s \omega_k^{(s)} \\ \left(k = 1,2,\cdots,m; s = 1,2,\cdots,h\right) \end{gathered} \tag{17}$$

By performing the calculations in the four steps described above, the weighting coefficients assigned by the expert panel to each indicator can be determined. Due to space limitations, this paper directly presents the weights for the drivers of construction project delays, as shown in Table 1. The table lists Internal Organizational Support (INSO), Individual Differences (IDV), Task-Based Approach (TBA), Uncertainty (SINV), Organizational Motivation (DOI), Time Recurrence Indicators (TR(D1), TR(D2)), and Schedule Delay (DEL).

Table 1. Weightings of the factors contributing to delays in construction projects

Construct	Weight	Indicator	Measurement Approach
INSO	0.3021	Number of normative documents; update frequency; perceived difficulty	Document analysis; survey (Likert)
IDV	0.2443	Same specification → different acceptance outcomes	Inter-rater kappa from inspection logs
TBA	0.1173	Same briefing → different technical decisions	RFI frequency per work package
SINV	0.0934	Proportion of DOI with ambiguous/non-attributed causes; frequency of generic codes	Log audit; entropy of cause categories
DOI	0.0832	Unscheduled stoppages >1 hour; rework events	Daily log coding
TR (D1)	0.061	Critical path migration index; resequencing count	Longitudinal CPM comparison
TR (D2)	0.0615	Float compression rate; recovery window reduction	Schedule float decay slope
DEL	0.0372	Final schedule overrun	Baseline vs. actual completion

4.2.2. Formulate the system dynamics equations

Based on the system dynamics causal feedback model and the stock-flow model established above, as well as the specific values of the drivers of system delays in construction projects presented in Table

1, system dynamics equations were formulated using the DYNAMO language, involving a total of 8 constants. These constants include Internal Organizational Support (INSO), Individual Differences (IDV), Goal Orientation (TBA), Uncertainty (SINV), Organizational Motivation (DOI), Time Recurrence Indicators (TR(D1), TR(D2)), and Schedule Delay (DEL). The parameters for the auxiliary equations were derived from the ratings assigned to the described drivers by the five senior experts mentioned above. The relevant scoring results are shown in Tables 2 and 3.

Table 2. Results of the scoring related to construction qualification levels

Construction Qualification Level	**Construction technique**	**Safety awareness among construction workers**	**Level of Environmental Protection at the Construction Site**
INSO	0.94	0.86	0.91
IDV	0.88	0.79	0.81
TBA	0.75	0.68	0.69
SINV	0.68	0.65	0.63

Table 3. Results of the scoring system for the degree of wear and tear on facilities

Time(day)	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Average Loss Degree(%)	0	3.1	6	9	11.2	13.8	18.2	23.4
Time(day)	1	2	3	4	5	6	7	8
Average Loss Degree(%)	28.3	34.6	42.3	53.6	67.5	79.2	91.5	100

By inputting project data into a system dynamics model based on the actual conditions of the construction project, it is possible to estimate the project's delay index. Using the method of controlling variables to adjust certain driving factors in the model, one can analyze how the delay index changes across different scenarios.

4.2.3. Model Validation

(1) System Boundary Test

This test verifies whether a variable influences the problem under study by observing whether a closed loop can still be formed after the variable is removed or added to the model. For example, if the "Internal Organizational Support (INSO)" variable is removed, the sequence "Delay Index → (+) Delay Control Pressure → (+) Internal Organizational Support (INSO) → (+) Organizational Motivation → (+) Goal-Orientation (TBA) → (+) Increased Organizational Motivation (DOI) → (+) Delay Index" fails to form a closed loop. Therefore, "Internal Organizational Support (INSO)" is an endogenous variable influencing the delay index and cannot be removed. Similarly, after testing other variables in the model, it was concluded that the system boundaries of the model are reasonable.

(2) Operational Test

Using the "Check Model" function in Vensim software to test all variables in the model, the results indicate that all variables in the model have been assigned values, have consistent units, and system dynamics equations have been established between all variables.

(3) Mental Model Validation

The purpose of mental model validation is to determine whether the model aligns with actual conditions. This paper employs a validation method based on a comparison of development trends to test this model; the results are shown in Figure 3.

"Internal Organizational Support (INSO)" is closely related to the "implicit recursion intensity" of construction projects. The higher the level of internal organizational support, the weaker the implicit recursion phenomena (such as repetitive decision-making, path dependence, and information feedback loops) in the project, and the higher the time-reconstruction efficiency. By adjusting the "INSO" variable in the model, we observe changes in "implicit recursion intensity." It can be observed that as the value of INSO increases, the intensity of implicit recursion decreases, and the response speed of time reconstruction accelerates. This dynamic trend aligns with objective laws. The identified trend in the intensity of implicit recursion under the influence of INSO demonstrates that the model is valid and consistent with actual conditions.

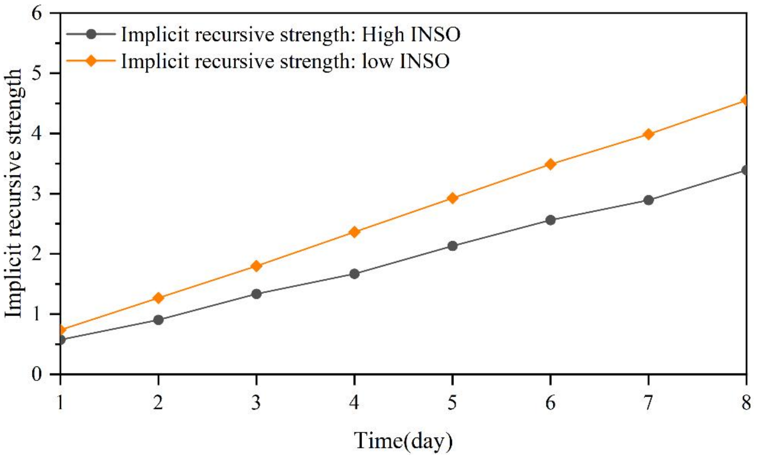


Figure 3. Trend of implicit recursive intensity changes under the influence of INSO

4.3. Simulation Results and Analysis

To further quantify the degree of “implicit recursion-time reconstruction” of construction projects with respect to key factors, it is necessary to modify the value of a single key factor while keeping other key influencing factors constant. This paper conducts simulation analyses based on the values of eight core driving factors (INSO, IDV, TBA, SINV, DOI, TR(D1), TR(D2), and DEL) to analyze the extent to which each factor influences construction project schedule delays and the degree of time restructuring. In the model, the variation in the project completion date represents the difference between the actual and planned completion dates, i.e., the schedule delay (DEL). Various resources within the system influence construction efficiency and the intensity of implicit recursion, thereby affecting the time restructuring behavior of construction projects. The simulation uses “implicit recursion intensity” and “schedule delay” as the primary observed variables. Ten scenarios were set up for simulation, as shown in Table 4, with a focus on analyzing the following two types of outputs:

(1) Schedule Delay (DEL): The final schedule overrun value resulting from the amplification of initial disturbances (TBA, IDV) through time recursion (TR(D1), TR(D2)).

(2) Time restructuring coefficients: Characterized by the degree of critical path migration, the compression rate of float time, and other metrics.

Table 4. Different scenario simulation schemes

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Scenario 1	0.114	0.156	0.276	0.289	0.351	0.184	0.184	0.114
Scenario 2	0.114	0.156	0.276	0.289	0.351	0.184	0.184	0.114
Scenario 3	0.214	0.156	0.276	0.289	0.351	0.184	0.184	0.214
Scenario 4	0.114	0.256	0.276	0.289	0.351	0.184	0.184	0.114
Scenario 5	0.114	0.156	0.376	0.289	0.351	0.184	0.184	0.114
Scenario 6	0.114	0.156	0.276	0.389	0.351	0.184	0.184	0.114
Scenario 7	0.114	0.156	0.276	0.289	0.451	0.184	0.184	0.114
Scenario 8	0.114	0.156	0.276	0.289	0.351	0.284	0.284	0.114
Scenario 9	0.114	0.156	0.276	0.289	0.351	0.184	0.184	0.114
Scenario 10	0.114	0.156	0.276	0.289	0.351	0.184	0.184	0.114

a) Analysis of Simulation Results for Project Completion Dates

After simulating the model under normal conditions and 10 different scenario scenarios, a sensitivity analysis chart for project completion dates was obtained, as shown in Figure 4. The figure indicates that Scenarios 2, 3, 4, and 5 have the greatest impact on project construction progress. The latent recursive drivers corresponding to these four scenarios are as follows:

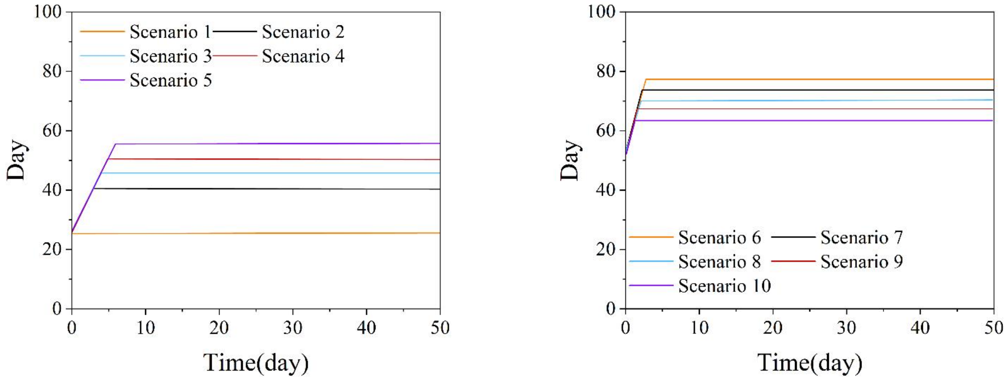
Scenario 1: Individual Differences (IDV)—Inadequate technical briefings by technical personnel, leading to differing acceptance results for the same specification.

Scenario 3: Goal-Orientation (TBA)—Lack of technical workers with extensive hoisting experience, resulting in differing technical decisions for the same instructions.

Scenario 4: Uncertainty (SINV)—Incomplete registration of component arrival information and disorganized stacking, making it impossible to clearly attribute the causes of interference.

Scenario 5: Internal Organizational Support (INSQ)—Low standardization of precast component design and insufficient organizational support.

The project completion times for these four scenarios were 41 days, 46 days, 52 days, and 57 days, respectively—16 days, 21 days, 27 days, and 32 days longer than the initial target of 25 days. While other factors, such as the organizational winter period (DOI) and time recursion indicators (TR(D1), TR(D2)), also influence project completion dates, their impact on project schedule is far less significant than that of the first four factors. Analysis of the simulation results for the ten scenarios reveals that delays in construction project schedules are essentially the cumulative effect of implicit recursion.



(a)Scenario 1–5 Project Completion Date (b)Scenario 1–10 Project Completion Date

Figure 4. Graph of sensitivity change analysis of project completion date

b) Analysis of Simulation Results for Assembly Speed

After simulating the model under normal conditions and 10 different scenario scenarios, the simulation results for assembly speed are shown in Figure 5. Assembly speeds decreased in all scenarios except the normal simulation; however, the decline was more pronounced in Scenarios 2, 3, 4, and 5, corresponding to an increase in the project completion date (delay DEL). The implicit recursive drivers for these four scenarios are as follows:

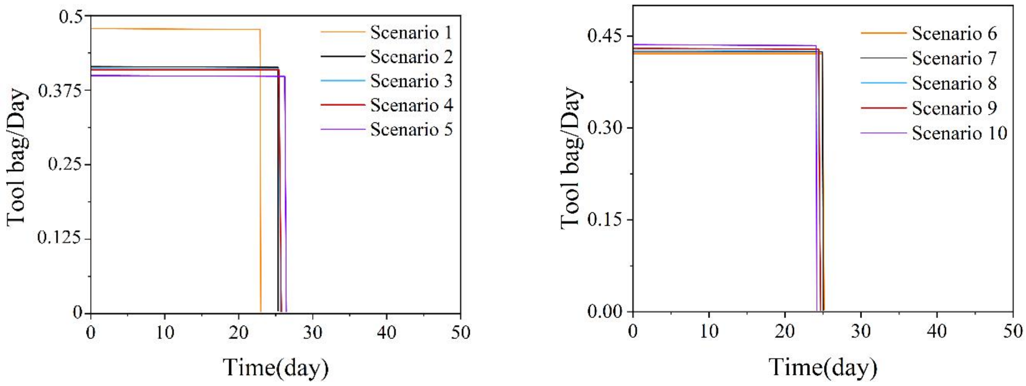
Scenario 1: Individual Differences (IDV)—Inadequate technical briefings by technicians, leading to differing acceptance results for the same specifications.

Scenario 3: Goal-Oriented Approach (TBA)—Lack of technicians with extensive hoisting experience, resulting in differing technical decisions for the same instructions.

Scenario 4: Uncertainty (SINV)—Incomplete records of component arrival information and disorganized storage, with the causes of disruptions unable to be clearly identified.

Scenario 5: Internal Organizational Support (INSQ) — Low standardization of precast component design and insufficient organizational support.

The four drivers mentioned above have the greatest impact on project construction speed. Their mechanism of action is as follows: an initial decline in construction speed (implicit interference) → the time recursion mechanism (TR(D1): critical path shift; TR(D2): float compression) is progressively amplified, thereby causing project schedule delays.



(a)Scenario 1–5 Assembly Speed (b)Scenario 6–10 Assembly Speed

Figure 5. Analysis of the variation of the sensitivity of the assembling speed

5. Conclusion

For a long time, construction project delays have been viewed as a problem resulting from the cumulative effects of multiple factors. This paper argues that factor-based approaches fail to explain dynamic emergence because they overlook a core issue: the invisibility of disturbances—namely, the inability to trace disturbances caused by IDV/TBA back to their source. We propose a mechanistic, simplified theory under which the ambiguity of causality enables recursive amplification. Through simulation analysis of eight constant-type drivers, we identified four factors that have a significant impact on the delay index of construction project systems: Individual Differences (IDV), Target-Based Approach (TBA), Uncertainty (SINV), and Internal Organizational Support (INSQ). Consequently, relevant project managers can control the delay index of construction projects by adjusting these four drivers. In contrast, the findings suggest that the driving forces behind implicit recursion stem more from structural factors such as insufficient organizational capacity, information asymmetry, and a lack of standardization.

In summary, the nature of construction project delays is not a simple linear accumulation but rather a phenomenon of time reconstruction driven by implicit recursion.

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