CivilEng

Article

Critical Factors Affecting Green Innovation in Major Transportation Infrastructure Projects

Shuhan Wang [1], Long Li [1], Xianfei Yin [2,*], Ziwei Yi [3], Shu Shi [4] and Meiqi Wan [1]

[1] School of Management Engineering, Qingdao University of Technology, Qingdao 266520, China; yunling9@163.com (S.W.); lilongchn@qut.edu.cn (L.L.); wmq21772023@163.com (M.W.)
[2] Department of Architecture and Civil Engineering, College of Engineering, City University of Hong Kong, Hong Kong, China
[3] China Construction Harbour and Channel Engineering Bureau Group Co., Ltd., Qingdao 266000, China
[4] Qingdao Metro Real Estate Development Co. Ltd., Qingdao 266005, China
* Correspondence: xianfyin@cityu.edu.hk

Abstract

The complexities of megaprojects, particularly major transportation infrastructure projects (MTIs), require technological innovation that advances economic, social, and ecological objectives. Traditional engineering innovation emphasizes economic gains while neglecting sustainability. Therefore, implementing green innovation (GI) in MTIs is essential. This research examines key factors and correlations influencing MTI-GI to strengthen theoretical understanding and guide effective implementation. First, literature and interviews are used to identify MTI-GI influencing factors through the technology–organization–environment (TOE) framework. Second, an intuitive fuzzy number approach reduces subjectivity in expert scoring and, combined with the DEMATEL method, constructs a fuzzy DEMATEL model to quantify factor importance and identify critical drivers. Critical factors are then analyzed to formulate GI promotion strategies. Results reveal that MTI-GI influencing factors span technology, organization, and environment dimensions. Prioritizing green technological innovation and feedback mechanisms, optimizing organizational structures, and aligning with regional environmental characteristics are crucial for successful MTI-GI implementation. These findings support GI expansion in MTIs and offer targeted strategies for managing complex systems.

Keywords: major transportation infrastructure projects (MTIs); green innovation (GI); influencing factors; intuitive fuzzy set; DEMATEL

check for updates

Academic Editors: Angelo Luongo and Aleksandar Stevanovic

Received: 4 August 2025
Revised: 16 September 2025
Accepted: 18 September 2025
Published: 22 September 2025

Citation: Wang, S.; Li, L.; Yin, X.; Yi, Z.; Shi, S.; Wan, M. Critical Factors Affecting Green Innovation in Major Transportation Infrastructure Projects. *CivilEng* **2025**, *6*, 52. https://doi.org/10.3390/civileng6030052

Copyright: © 2025 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

As systems characterized by huge investment, long life cycles, and numerous stakeholders facing complex uncertainties and high risks [1], megaprojects are critical to social production, economic growth, and daily life across transportation, energy, water conservancy, and communication sectors [2]. Compared with other major infrastructure projects, major transportation infrastructure projects (MTIs) represent typical engineering–environment systems deeply integrated with natural ecosystems across vast spatial scales [3]. While improving regional economies, MTIs may pose environmental risks such as ecologically sensitive area disturbances and biodiversity loss [4]. At present, MTIs face dual challenges: transforming traditional engineering paradigms and meeting ecological civilization demands [5]. Consequently, technological innovation has shifted from prioritizing technical advancement and economic benefits to balancing industrial

progress with ecological protection. However, path dependence in stakeholder practices rooted in traditional infrastructure models causes delayed adoption of eco-friendly technologies, creating tensions between innovation dynamics, ecological ethics, and environmental responsibility [6]. Therefore, while building on traditional innovation foundations, urgent integration of environmental ethics dimensions into innovation paradigms becomes imperative.

Green innovation (GI), a new paradigm targeting environmental governance, integrates environmental responsibility, ecological ethics, and sustainable development goals beyond traditional innovation, emphasizing multifaceted benefits while addressing ecological risks from innovation uncertainties [7], and has become the preferred choice for MTI to cope with high resource consumption and environmental disturbances and to gain a competitive edge [8]. Green innovation of major transportation infrastructure projects (MTI-GI) is the positive interaction between technological development and ecological ethics during engineering construction, balancing economic, social, safety, and environmental values to advance sustainable development of MTIs [7], which also aligns with the United Nations Sustainable Development Goals (SDGs). In practice, similar GI principles have been demonstrated in other megaprojects. For example, the Hong Kong–Zhuhai–Macao Bridge adopted innovative measures for the protection of the Chinese White Dolphin [9], while Beijing Daxing International Airport implemented green building design and "sponge airport" construction [5]. Such cases offer valuable insights for advancing MTI-GI.

MTI-GI, as a sustainable development practice embedded throughout construction and operation, is shaped by characteristics of MTIs such as large scale, strong regional connectivity, and significant spillover effects. At the same time, it requires the joint efforts of multiple actors, including government, enterprises, and the public. Its implementation process typically entails multi-level decision-making, multidimensional goals, and cross-regional collaboration, where the need to balance economic benefits, social equity, and ecological protection becomes particularly salient [7]. In such a highly complex system, the implementation of MTI-GI is inevitably shaped by multiple factors that either promote or hinder innovation [10]. Therefore, constructing an influencing factor system and quantifying interaction intensity identifies core MTI-GI drivers, enabling targeted innovation incentives to overcome path dependence and accelerate GI advancement. In this context, combining intuitive fuzzy numbers with the DEMATEL model enhances the robustness of expert judgments under uncertainty, mitigates subjective bias, and systematically identifies the relative importance and interaction paths of MTI-GI driving factors. This integration offers a systematic analytical tool for understanding the key factors of MTI-GI.

Although the interaction of multiple factors is crucial to the advancement of MTI-GI, prior research has primarily focused on isolated aspects such as environmental pollution control and technological upgrading [11,12], while lacking an integrated analysis of how diverse technological, organizational, and environmental factors interact to shape innovation dynamics. This absence of a systemic perspective makes it difficult to clearly identify the core driving mechanisms, leaving decision makers without concrete guidance on where to intervene. This research investigates the key factors of MTI-GI and applies fuzzy DEMATEL to reveal the factors' influence intensity, clarifying the mechanism framework. This research enriches the theoretical foundation of the GI framework and provides actionable decision support for policymakers and project stakeholders, offering directional and motivational guidance for advancing MTI-GI with both academic and practical value.

The rest of the paper is organized as follows. Section 2 reviews major transportation infrastructure engineering innovation and green innovation. Section 3 introduces the research framework and methods. Section 4 analyzes the results of the model. Section 5

provides insights into the findings and suggests strategies. Finally, Section 6 summarizes the research and proposes future research directions.

2. Literature Review

2.1. Megaproject Innovation

Megaproject innovation refers to the systematic pursuit of effective solutions to technical challenges throughout the lifecycle [13]. As engineering complexities increase, innovation becomes critical for overcoming development bottlenecks [14]. Compared with general engineering and enterprise innovation, megaproject innovation arises under conditions of exceptional scale, multi-party governance, and long-term implications. A geomechanical monitoring strategy was developed for the Gotthard Base Tunnel to manage excavation-induced deformations [15], demonstrating innovation tailored to megaproject-specific demands. Megaproject innovation manifests in engineering products, equipment, construction technologies, and integrated systems, with most organizational forms exhibiting high heterogeneity and dynamism [16], and its application scope has expanded to high-end equipment manufacturing, green energy, and environmental protection industries [17].

Megaproject innovation has been widely discussed for technical complexity, subject integration, and stage dynamics [18]. However, rigid constraints in time, cost, quality, safety, and environmental protection often deter contractors and owners from innovating when technologies suffice [19]. Organizational structure complexity and engineering technology integration further challenge innovation promotion [10]. The dual effects of megaproject innovation produce profound impacts: while addressing technical challenges and stimulating regional growth, they may also generate societal issues through environmental neglect [20]. Therefore, sustainable development responsiveness becomes essential [21].

Globally, major transportation infrastructure initiatives' scope, characterized by substantial investment, significant societal impact, and considerable technical challenges, continues to broaden [2]. As a typical engineering–environment complex system, MTIs must now address economic, environmental, and social considerations under national sustainable development strategies and public demands for high living standards [5]. Traditional innovation paradigms overemphasize technological and economic gains, neglecting the interplay between advancement, ethics, and environmental stewardship [22]. Consequently, emerging frameworks in transport megaprojects increasingly anchor engineering breakthroughs in ethical responsibility and ecological performance, aligning innovation goals with societal values.

2.2. Green Innovation

As an extension of traditional innovation theory under sustainable development, green innovation (GI) integrates environmental protection throughout production systems to synergistically enhance economic performance and environmental benefits [23]. Different from traditional innovation, GI has dual externalities: promoting the green transformation of enterprises through technology spillover while generating positive environmental externalities through pollution reduction and resource conservation [24]. GI's essence involves enhancing products and processes using eco-friendly technologies across energy conservation, emission reduction, sustainable design, and material recycling to mitigate environmental impacts from economic activities [25].

GI exhibits substitutability, permeability, and synergy, with its performance driven by industrial structure optimization and knowledge diffusion mechanisms [26] that facilitate green technology access through knowledge spillover and resource transfer, accelerating GI gains [27]. Amid escalating global environmental challenges, GI has emerged as a critical force shifting GDP growth toward sustainable, resilient development [28]. Current transfor-

mations emphasize infrastructure–environment–technology synergies [29], highlighting the need to advance GI and build resilient infrastructure systems [30]. Infrastructure upgrading that combines high-speed rail and digital infrastructure under policy support achieves synergistic effects in pollution control and carbon reduction [31].

MTIs are resource-intensive with significant ecological footprints. Integrating GI with MTIs reduces environmental burdens and enhances project social acceptance, establishing environment–social–economic synergy paradigms [28]. While GI applications in MTIs show progress, systematic research on influencing factors remains insufficient. High technical complexity and environmental constraints limit single-entity capabilities for GI implementation in MTIs. Clarifying key influencing factors has thus become a critical research focus, helping promote GI dissemination through core mechanism analysis and laying foundations for systematic GI implementation.

2.3. Influencing Factors of MTI-GI

While prior technology readiness provides momentum for subsequent advancements [32], excessive reliance on innovation resources may hinder progress [33]. In transportation infrastructure, sustained technological innovation is essential for aligning systems with evolving societal needs [34,35], and the ecological feasibility of solutions directly determines the achievement of sustainable development goals [36]. Notably, digital twin (DT) applications [26,29,37] have further highlighted digitization as a core driver of innovation in transportation infrastructure.

The project management system plays a central role in sustaining social responsibility in megaprojects [38,39]. Project organizations depend on personnel as key performers, with employee training shown to improve construction waste management efficiency, underscoring the importance of human resource development for project sustainability [40]. Effective incentive–supervision mechanisms enhance innovation performance [41–43]. Organizational awareness of social responsibility mediates institutional pressures and external influences on megaproject practices [38,44]. Efficient investment strategies ensure efficient resource allocation, providing stable financial support for innovation [45,46], while public scrutiny of innovation's social impact and corporate accountability guides investment priorities [47].

Megaprojects are embedded within dynamic and complex natural–social environments [48]. Regional disparities significantly shape infrastructure policy and the attainment of sustainable development goals [49,50]. Government reinforcement of innovation-related regulations and social responsibility policies [38,41,46], combined with consumer demand for green products and services [32], creates a dual driver from both policy and market sides. The linear spatial characteristics of MTIs produce heterogeneous interactions with route ecosystems, necessitating differentiated technological responses for distinct ecological settings [51]. Similarly, varied terrain and complex geology [52] demand innovations that address simultaneous challenges of structural safety, ecological restoration, and environmental performance.

3. Methodology

DEMATEL method can analyze factor interactions to clarify relationships, system positions, and identify key indicator subsystems [53]. Fuzzy numbers effectively address system uncertainty and incomplete evaluation information, particularly handling fuzzy data, which traditional methods struggle with [54]. The fuzzy DEMATEL method interprets expert judgments expressed in linguistic terms, which are then transformed into fuzzy numbers to reduce ambiguity and build consensus. The data have proved that the fuzzy DEMATEL method has practical application value. For example, Liu et al. [55] examined

the critical factors influencing organizational resilience of MTIs, while Alqershy and Shi [56] investigated the barriers to social responsibility implementation in Belt and Road mega infrastructure projects. Its application enables researchers and practitioners to grasp variable interdependencies, pinpoint key factors, and support evidence-based decisions to enhance performance and outcomes. Therefore, the fuzzy DEMATEL method was adopted in the research to achieve the goal of exploring the key influencing factors of MTI-GI. Compared with methods such as ANP and ISM, the fuzzy DEMATEL method is more effective in capturing interactions among multiple factors and identifying key drivers, offering greater explanatory power and applicability for analyzing complex systems. Through literature review, semi-structured interview, and questionnaires, we obtained influencing factors and correlation strengths; we applied fuzzy DEMATEL to identify key drivers, and proposed promotion strategies. The implementation process is detailed in Figure 1.

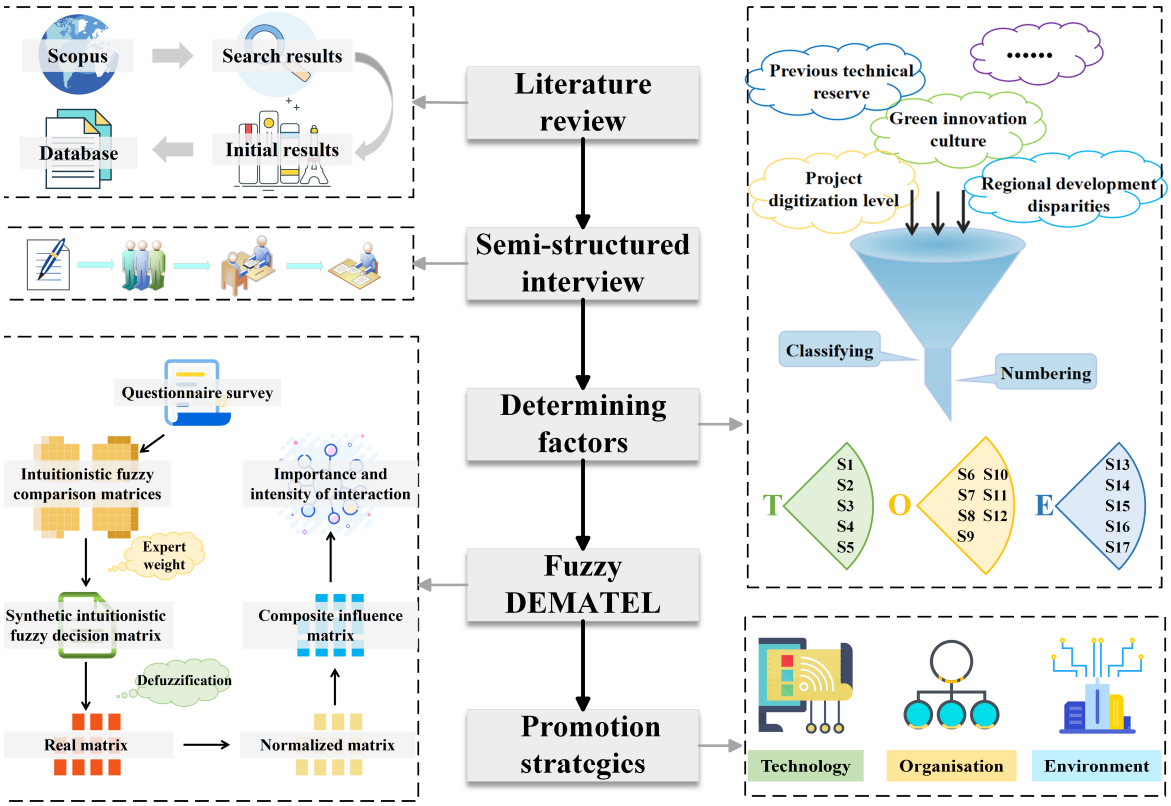


Figure 1. Research framework for analyzing MTI-GI drivers.

3.1. Data Collection

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were adhered to during this systematic review [57]. Peer-reviewed journals in English aligned with the MTI-GI theme were selected to identify frequently mentioned influencing factors. Scopus (https://www.scopus.com/) (accessed on 19 August 2024) was used as the core search platform, as the comprehensiveness and authority of the included literature meet the research needs. We searched for literature using keywords related to megaprojects, major transportation infrastructure projects, and green innovation. The key inclusion criteria considered in initial results were: (1) Article and review. (2) 1 January 2018 to 31 December 2026. Then, repetitive or irrelevant literature to MTIs and GI was eliminated to obtain the preliminary database. Furthermore, a full-text study was conducted, and ultimately 22 studies were selected as the final database for the influencing factors of MTI-GI (Figure 2). A detailed literature review is presented in Section 2.3, which reveals that MTI-GI is subject to multiple influences from technological innovation, organizational

management, and the external environment. The TOE framework can integrate relevant factors from these three dimensions to effectively identify the key driving factors and constraints in complex systems [58]. Compared with socio-technical systems theory, institutional theory, or innovation ecosystem approaches, the TOE framework is more concise and operable. Therefore, adopting the TOE framework can help clarify the influencing factors of MTI-GI and provide an analytical basis for promoting MTI-GI, which is more applicable in this research. Based on Section 2.3 and the TOE framework, 17 influencing factors were identified (Table 1). Experts were invited to evaluate factor comprehensiveness and effectiveness through semi-structured interviews [59]. Subsequently, a questionnaire assessed inter-factor influence intensity across five levels: no (0), small (1), medium (2), large (3), and strong (4). The two-part questionnaire detailed the 17 factors (Part 1) and collected expert scores (Part 2). Experts scored factors and annotated uncertain items and unresolved cases were discussed via online meetings before final determination.

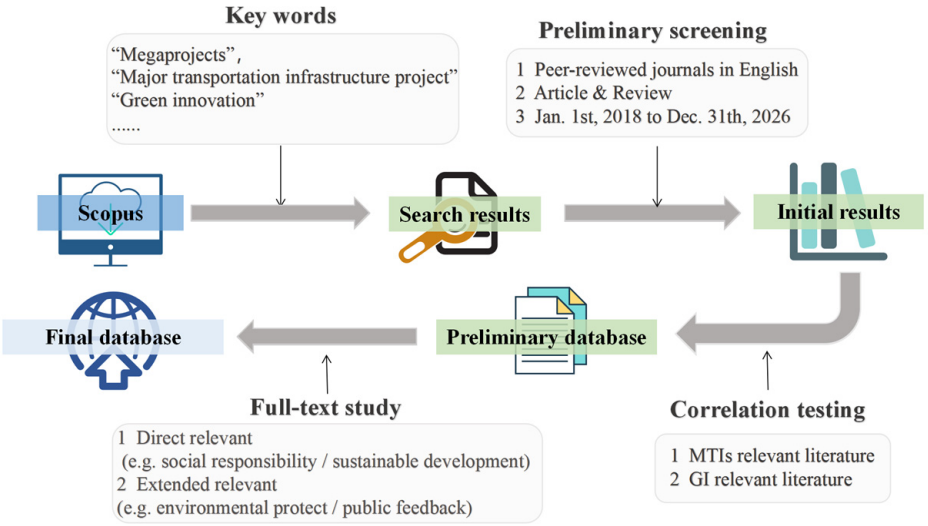


Figure 2. Flowchart of the systematic review process for identifying MTI-GI influencing factors.

3.2. Modeling Process

Based on the above data collection and processing results, the calculation steps of the intuitionistic fuzzy DEMATEL model are as follows.

Step 1: Collect and analyze the influencing factors of MTI-GI and determine the index set of the influencing factors, that is, the 17 influencing factors in Table 1, which are recorded as $\{a_1, a_2, \ldots, a_n\}(n = 17)$.

Step 2: The direct relationship between the influencing factors is determined through expert scoring. Then, each expert's intuitional fuzzy judgment matrix will be constructed.

Table 1. Classification of influencing factors.

Dimension	No.	Influence factor	Descriptions	Source
Technology	S_1	Previous technology readiness	While offering technical foundations and mitigating environmental risks, prior tech readiness may hinder GI due to path dependence.	[32]
	S_2	Technology upgrade/expansion capability	Technology system with strong upgrade/expansion ability can stimulate synergy effect and improve GI quality by integrating new technology. Otherwise, it's easy to produce technology exclusion and hinder the GI process.	[34,35]
	S_3	Reliance on innovation resources	Although the accumulation of innovation resources can form ecological synergies, over-reliance can easily lead to participants' satisfaction with the status quo and weaken the endogenous impetus of GI.	[33]
	S_4	Innovative technology constructability	It refers to the feasibility of implementing green technologies in projects, impacting GI risk management and ecological efficiency and serving as a key indicator for balancing innovation and implementation.	[36]
	S_5	Project digitization level	While project digitization can enhance GI performance, it must also mitigate risks such as data security concerns, cost pressures, and technology dependence, ensuring a balance between technology and human factors.	[26,29,37]
Organization	S_6	Traditional project management system	Standardized management ensures project stability, but rigid processes may limit dynamic responses to ecological optimization needs. Thus, balancing the normative framework with GI requirements is essential.	[38,39]
	S_7	Professional training scale	Expanding professional training scale enhances technical and management skills while fostering innovation awareness and responsibility among professionals to promote the adoption and dissemination of GI.	[40]
	S_8	Incentive mechanisms	Effective incentive measures can motivate stakeholders and channel resources toward projects with more innovative potential and value to provide continuous impetus for GI.	[41,42]
	S_9	Supervision mechanisms	Supervision mechanisms enhance ecological responsibility by regulating GI practices, ensuring that innovation activities are in line with ecological efficiency objectives, and enhance transparency to consolidate social credibility.	[42,43]
	S_{10}	Green innovation culture	Integrate ecological responsibility and environmental ethics into innovation and cultivate team awareness of social responsibility and green innovation to create an innovation-driven atmosphere.	[38,44]
	S_{11}	Return on investment in new technologies	High returns can enhance confidence, attract innovative talents, and optimize resource allocation, forming a virtuous cycle of "investment–income–reinvestment", which drives GI to achieve sustainable development.	[45,46]
	S_{12}	Public feedback on new technologies	Positive feedback on new technologies can enhance the impetus for innovation and promote technology optimization and negative feedback can help identify problems and promote improvement.	[47]
Environment	S_{13}	Maturity of laws and regulations	Mature laws and regulations ensure that innovation develops in a positive way within legal compliance, which helps to clear rights and responsibilities of participants and promote the in-depth development of GI.	[38,41,46]
	S_{14}	Regional development disparities	The differences in economic foundation, resource allocation and ecological demand caused by the cross-regional characteristics of MTIs necessitates spatial adaptation strategies to advance GI.	[49,50]
	S_{15}	Market demand	The regional expansion of MTIs leads to changes in market demand, and the stronger market demand forces enterprises to constantly innovate to stimulate innovation vitality.	[32]
	S_{16}	Ecological environment along the project	The fragile ecological environment leads to higher construction costs but also drives green technology innovation to achieve a harmonious coexistence of MTIs and the ecological environment.	[51]
	S_{17}	Geographical features along the project	Geographical features along the project drive GI in rational site selection, technology development, and vulnerable area protection through natural resource distribution and unique topographic conditions.	[52]

If there are s experts, then the set of all decision experts is $G = \{g_k | k = 1, 2, \cdots, s\}$. All experts are invited to score the influence relationship between any two influencing factors $(a_i, a_j)(i, j = 1, 2, \cdots, n, \text{and } i \neq j)$ in the form of intuitive fuzzy sets, which are specifically expressed as $h_{ij}^{(k)} = (u_{ij}^{(k)}, v_{ij}^{(k)}, \pi_{ij}^{(k)})$. Therein, $u_{ij}^{(k)}$ represents the degree to which expert g_k prefers a_i when comparing indicator a_i and a_j. $v_{ij}^{(k)}$ represents the degree to which expert g_k prefers a_j when comparing indicator a_i and a_j. $\pi_{ij}^{(k)}$ indicates the expert's hesitation in comparing indicators a_i and a_j. And $u_{ij}^{(k)}$, $v_{ij}^{(k)}$, $\pi_{ij}^{(k)}$ meet the definition of intuitionistic fuzzy set; then the intuitionistic fuzzy judgment matrix judged by a single expert g_k is as follows:

$$H^{(k)} = (h_{ij}^{(k)})_{n\times \mathrm{n}} = \begin{bmatrix} (\mathrm{u}_{11}^{(k)}, v_{11}^{(k)}, \pi_{11}^{(k)}) & (\mathrm{u}_{12}^{(k)}, v_{12}^{(k)}, \pi_{12}^{(k)}) & \cdots & (\mathrm{u}_{1n}^{(k)}, v_{1n}^{(k)}, \pi_{1n}^{(k)}) \\ (\mathrm{u}_{21}^{(k)}, v_{21}^{(k)}, \pi_{11}^{(k)}) & (\mathrm{u}_{22}^{(k)}, v_{22}^{(k)}, \pi_{22}^{(k)}) & \cdots & (\mathrm{u}_{2n}^{(k)}, v_{2n}^{(k)}, \pi_{2n}^{(k)}) \\ \vdots & \vdots & & \vdots \\ (\mathrm{u}_{n1}^{(k)}, v_{n1}^{(k)}, \pi_{n1}^{(k)}) & (\mathrm{u}_{n2}^{(k)}, v_{n2}^{(k)}, \pi_{n2}^{(k)}) & \cdots & (\mathrm{u}_{nn}^{(k)}, v_{nn}^{(k)}, \pi_{nn}^{(k)}) \end{bmatrix} \quad (1)$$

Step 3: The synthetic intuitionistic fuzzy decision matrix is constructed by synthesizing the intuitionistic fuzzy judgment matrix of s experts.

Firstly, the intuitionistic fuzzy entropy determines the experts' weights. Burillo and Bustince (1996) [60] proposed using intuitionistic fuzzy entropy to describe the uncertainty of information contained in intuitionistic fuzzy sets. According to the intuitionistic fuzzy judgment matrix of each expert, the intuitionistic fuzzy entropy C_k is calculated by Equation (2). According to Equation (3), the weight w_k of expert g_k weight is obtained.

$$C_k = \frac{1}{n^2} \sum_{j=1}^{n} \sum_{i=1}^{n} \frac{\min\left\{u_{ij}^{(k)}, \mathrm{v}_{ij}^{(k)}\right\} + \pi_{ij}^{(k)}}{\max\left\{u_{ij}^{(k)}, \mathrm{v}_{ij}^{(k)}\right\} + \pi_{ij}^{(k)}} \quad (2)$$

$$w_k = (1 - C_k)/(s - \sum_{k=1}^{s} C_k) \quad (3)$$

In the formula, $0 \leq w_k \leq 1, k = 1, 2, \cdots, s$ and $\sum_{k=1}^{s} w_k = 1$. The greater the intuitionistic fuzzy entropy, the higher the degree of uncertainty of the evaluation, and the less weight should be given to the expert.

Then, by synthesizing the intuitional fuzzy decision matrix of s experts, the synthetic intuitionistic fuzzy decision matrix H is constructed as follows:

$$H = \sum_{k=1}^{s} w_k H^{(k)} = (h_{ij})_{n\times n} \quad (4)$$

In the formula, $h_{ij} = (u_{ij}, v_{ij}, \pi_{ij}), u_{ij} = \sum_{k=1}^{s} w_k u_{ij}^{(k)}, v_{ij} = \sum_{k=1}^{s} w_k v_{ij}^{(k)}, \pi_{ij} = \sum_{k=1}^{s} w_k \pi_{ij}^{(k)}$.

Step 4: Defuzzy the synthetic intuitionistic fuzzy matrix.

Intuitionistic fuzzy, which is a centralized membership degree, non-membership degree, and hesitation degree, can reflect experts' uncertainty in the actual decision-making process and indicate each expert's risk preference. In this work, the risk preference coefficient $\gamma \in [0, 1]$ is introduced to convert the degree of hesitation into a definite degree of preference where γ represents the proportion of hesitators choosing support, $\gamma > 0.5$ indicating that experts are risk inclined, and vice versa. The actual matrix $B = (b_{ij})_{n\times n}$ is

obtained after defuzzification, where b_{ij} represents the definite preference degree of the decision-making group. The calculation formula is as follows:

$$b_{ij} = u_{ij} - v_{ij} + (2\gamma - 1)\pi_{ij}, \gamma \in [0,1] \quad (5)$$

Step 5: Calculate the comprehensive influence matrix.

The matrix $B = (b_{ij})_{n\times n}$ is normalized according to Equation (6), and the normalized matrix $T = \left[t_{ij}\right]_{n\times n}$ is obtained. Therein,

$$t_{ij} = \frac{b_{ij}}{\max(\max_{1\le i\le n}\sum_{j=1}^{n} b_{ij}, \max_{1\le j\le n}\sum_{i=1}^{n} b_{ij})} \quad (6)$$

The comprehensive influence matrix R can be obtained by using Equation (7):

$$R = \sum_{l=1}^{\infty} T^l = T(E-T)^{-1} = (r_{ij})_{n\times n} \quad (7)$$

In the formula, E is the identity matrix.

Step 6: Determine the importance of each influencing factor.

According to the comprehensive influence matrix R, the influencing degree P_i, the influenced degree Q_i, the centrality M_i, and the causality X_i of each factor can be calculated, and the calculation formula is shown in Equation (8). The centrality M_i indicates the importance of each factor in the system. A higher value reflects stronger influence on MTI-GI. The causality X_i denotes the interaction among factors: when $X_\mathrm{i} > 0$, the factor significantly influences others and is regarded as a driving factor; when $X_\mathrm{i} < 0$, it is mainly influenced by others and considered a result factor.

$$P_i = \sum_{j=1}^{n} r_{ij},\ Q_i = \sum_{j=1}^{n} r_{ij},\ M_i = P_i + Q_i,\ X_i = P_i - Q_i,\ i = 1,2,\cdots,n \quad (8)$$

4. Result and Analysis

The validity of the sample size should be determined based on research purpose and characteristics of the respondents [61]. Since the fuzzy DEMATEL method emphasizes the professionalism of expert judgment rather than the statistical representativeness of a large sample, the indicator set $\{\mathrm{a}_1, \mathrm{a}_2, \cdots, \mathrm{a}_{17}\}$ was scored by three experts (Section 3.1). Although the sample size is limited, the inclusion of experts from academia, industry, and government, together with their consensus-building discussions, helps mitigate this constraint. To ensure representativeness, experts were selected based on the following criteria: (1) At least ten years of research or practical experience in MTI-GI. (2) Coming from universities, government agencies and enterprises, and being able to reflect diverse perspectives. (3) Recognized professional reputation and influence in the field. By applying strict selection criteria, the three experts could provide comprehensive and authoritative judgments, ensuring the rigor and reliability of the findings. Expert language was blurred using {no (0.05,0.95,0), small (0.25,0.65,0.10), medium (0.50,0.40,0.10), large (0.75,0.15,0.10), strong (0.95,0.05,0)} [62] to obtain each expert's intuitionistic fuzzy judgment matrix. Using Equations (2)–(4), expert weights (0.31, 0.32, and 0.37) and the synthetic intuitionistic fuzzy decision matrix were obtained. Given that all experts are risk preference types, a 0.7 coefficient was applied, aligning with the logic of using situational parameters to characterize decision-makers' attitudes in different contexts [63]. Equation (5) defuzzified results into actual matrix B (Table 2). Equations (6) and (7) calculated comprehensive

influence matrix R (Table 3). The values in Table 2 represent the defuzzified results of experts' judgments, indicating the direct interaction strength among factors. Table 3 presents the comprehensive interaction strength, derived through standardization and iterative calculations, which incorporates both direct and indirect effects to reveal the overall interrelationships within the system. Equation (8) determined influencing degrees, influenced degrees, centrality, and causality for MTI-GI factors (Table 4). The causality diagram is shown in Figure 3.

Table 2. Actual matrix B.

	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	S_{11}	S_{12}	S_{13}	S_{14}	S_{15}	S_{16}	S_{17}
S_1	−0.9	0.17	0.58	0.3	0.57	0.64	−0.16	−0.24	−0.4	0.26	0	−0.16	0.14	−0.4	0.34	−0.41	−0.32
S_2	0.42	−0.9	0.3	−0.4	0.72	−0.4	−0.09	0.15	−0.24	0.3	−0.25	0.15	−0.16	−0.25	0	−0.57	−0.57
S_3	0.3	0.38	−0.9	−0.09	0.64	0.2	−0.09	−0.4	−0.16	−0.25	0	−0.25	−0.24	−0.24	0.54	−0.32	−0.32
S_4	0.24	−0.41	−0.4	−0.9	0.57	0	0.15	−0.25	−0.4	0.54	0.14	0.57	−0.16	−0.16	0.48	−0.57	−0.41
S_5	0	0.32	0.34	0.64	−0.9	−0.1	0.73	0.46	0.3	0.62	0.36	0.1	−0.09	0.38	0.3	−0.41	−0.57
S_6	−0.25	−0.26	−0.09	−0.4	−0.1	−0.9	0.26	0.06	0.36	0.3	−0.25	−0.25	−0.16	−0.24	−0.09	−0.32	−0.32
S_7	−0.25	0.06	−0.24	0.58	0.82	0	−0.9	−0.26	−0.1	0.48	0.64	0.48	−0.24	−0.25	−0.16	−0.41	−0.57
S_8	−0.1	0.48	0.57	0.06	0.82	−0.24	0.64	−0.9	0.32	0.73	0.58	0.82	0.32	−0.09	0.72	−0.41	−0.57
S_9	−0.1	−0.16	−0.24	0.06	0.48	−0.25	0.54	0.48	−0.9	0.1	0.46	0.64	0.15	−0.25	−0.24	−0.32	−0.57
S_{10}	−0.1	0.46	0.14	0	0.48	−0.4	0.48	0.48	0.32	−0.9	−0.1	0.72	0.42	−0.4	0.64	−0.73	−0.32
S_{11}	−0.1	−0.16	0.64	−0.16	0.14	−0.16	0.48	0.64	0.72	0.54	−0.9	0.57	−0.25	−0.4	0.73	−0.73	−0.32
S_{12}	−0.41	−0.04	0.48	−0.24	0.72	−0.1	0.36	0.64	0.54	0.9	0.64	−0.9	0.26	−0.09	0.57	−0.57	−0.32
S_{13}	−0.25	0.2	0.46	−0.24	0.58	−0.56	0.64	0.57	0.58	0.48	0.1	0.3	−0.9	0.06	0.54	−0.73	−0.32
S_{14}	0.34	−0.04	−0.04	0.54	0.73	0.32	0.17	0.42	0.34	0.46	0.14	0.2	−0.26	−0.9	0.32	0	−0.41
S_{15}	−0.16	−0.02	0.46	−0.4	0.48	−0.09	0.32	0.41	0.64	0.54	0.64	0.48	0.42	−0.2	−0.9	−0.41	−0.41
S_{16}	−0.16	0	0	0.64	−0.04	−0.4	−0.25	−0.4	−0.41	0.06	−0.4	−0.56	−0.25	0.48	0.06	−0.9	−0.32
S_{17}	−0.09	−0.4	0.06	0.54	0.3	−0.24	−0.4	−0.4	−0.24	0	−0.25	−0.16	−0.24	0.32	0.3	0.17	−0.9

Table 3. Comprehensive influence matrix R.

	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	S_{11}	S_{12}	S_{13}	S_{14}	S_{15}	S_{16}	S_{17}
S_1	−0.11	0.03	0.07	0.02	0.07	0.07	−0.01	−0.02	−0.04	0.03	0	−0.01	0.02	−0.05	0.04	−0.06	−0.04
S_2	0.05	−0.1	0.05	−0.05	0.09	−0.04	0	0.03	−0.02	0.04	−0.02	0.02	−0.01	−0.03	0.01	−0.07	−0.07
S_3	0.04	0.04	−0.11	−0.02	0.06	0.03	−0.01	−0.04	−0.02	−0.03	0	−0.03	−0.03	−0.03	0.05	−0.04	−0.04
S_4	−0.04	−0.04	−0.03	−0.12	0.07	0	0.04	0	−0.02	0.08	0.04	0.09	0	−0.03	0.06	−0.08	−0.05
S_5	−0.01	0.05	0.05	0.06	−0.06	−0.02	0.12	0.08	0.06	0.11	0.08	0.07	0	0.01	0.06	−0.1	−0.11
S_6	−0.03	−0.03	−0.02	−0.05	−0.02	−0.11	0.03	0.01	0.04	0.02	−0.03	−0.03	−0.01	−0.03	−0.02	−0.03	−0.03
S_7	−0.04	0.01	−0.02	0.06	0.1	−0.01	−0.08	0	0.01	0.08	0.09	0.08	−0.02	−0.04	0	−0.08	−0.08
S_8	−0.02	0.08	0.1	−0.01	0.16	−0.05	0.14	−0.06	0.09	0.14	0.12	0.16	0.05	−0.04	0.12	−0.12	−0.12
S_9	−0.02	0	−0.01	0	0.08	−0.04	0.1	0.08	−0.09	0.05	0.09	0.11	0.03	−0.04	0	−0.07	−0.09
S_{10}	−0.02	0.07	0.05	−0.02	0.1	−0.06	0.1	0.09	0.07	−0.07	0.04	0.13	0.07	−0.07	0.1	−0.13	−0.07
S_{11}	−0.02	0	0.09	−0.03	0.06	−0.03	0.1	0.11	0.12	0.09	−0.06	0.11	−0.01	−0.07	0.11	−0.13	−0.07
S_{12}	−0.05	0.02	0.09	−0.04	0.13	−0.03	0.1	0.12	0.11	0.15	0.12	−0.05	0.05	−0.04	0.1	−0.13	−0.08
S_{13}	−0.03	0.05	0.08	−0.03	0.12	−0.07	0.12	0.11	0.1	0.09	0.06	0.09	−0.1	−0.02	0.09	−0.13	−0.08
S_{14}	0.03	0.01	0.01	0.06	0.12	0.03	0.06	0.07	0.06	0.09	0.05	0.06	−0.02	−0.13	0.06	−0.04	−0.08
S_{15}	−0.03	0.02	0.08	−0.06	0.1	−0.03	0.09	0.09	0.11	0.1	0.11	0.1	0.06	−0.05	−0.08	−0.1	−0.08
S_{16}	−0.01	−0.01	−0.02	0.08	−0.02	−0.03	−0.05	−0.06	−0.07	−0.01	−0.06	−0.08	−0.03	0.06	−0.01	−0.09	−0.02
S_{17}	−0.01	−0.05	0	0.07	0.02	−0.02	−0.05	−0.05	−0.04	−0.01	−0.04	−0.03	−0.03	0.05	0.03	0.03	−0.1

Table 4. Calculated indicator values for the DEMATEL model.

No.	Influencing Degree	Influenced Degree	Centrality	Causality
S_1	0.01	−0.32	−0.31	0.33
S_2	−0.12	0.15	0.03	−0.27
S_3	−0.18	0.46	0.28	−0.64
S_4	−0.03	−0.08	−0.11	0.05
S_5	0.45	1.18	1.63	−0.73
S_6	−0.34	−0.41	−0.75	0.07
S_7	0.06	0.8	0.86	−0.74
S_8	0.74	0.56	1.3	0.18
S_9	0.18	0.47	0.65	−0.29
S_{10}	0.38	0.95	1.33	−0.57
S_{11}	0.37	0.59	0.96	−0.22
S_{12}	0.57	0.79	1.36	−0.22
S_{13}	0.45	0.02	0.47	0.43
S_{14}	0.44	−0.55	−0.11	0.99
S_{15}	0.43	0.72	1.15	−0.29
S_{16}	−0.43	−1.37	−1.8	0.94
S_{17}	−0.23	−1.21	−1.44	0.98

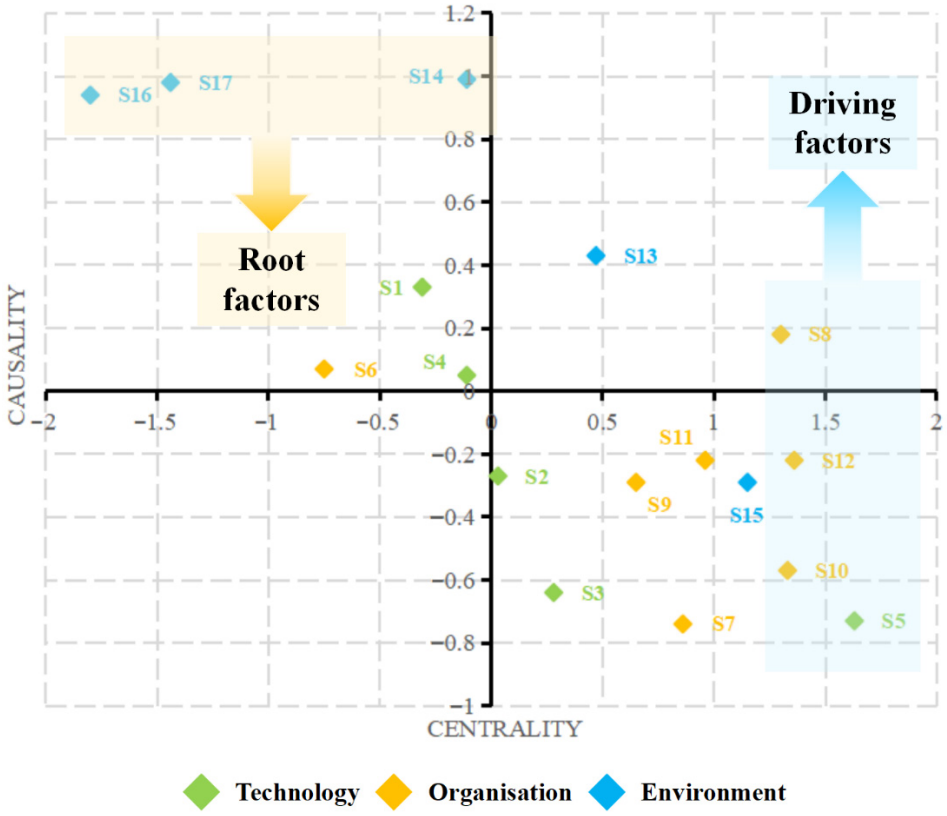


Figure 3. Cause–effect diagram of MTI-GI factors.

4.1. Importance Analysis

The top three influencing factors ranking from high to low impact are S_8, S_{12}, and S_5, which shows that they have a significant influence on different factors in the system. Their changes or states can directly or indirectly affect many other factors, occupying an important position in the system. The top three influenced factors cover S_5, S_{10}, and S_7. This means that the state or change in these factors is easily affected by other elements in the system, which shows their importance and sensitivity. A highly influenced factor is usually a key node in a system, significantly impacting the overall system performance and stability. A higher degree of centrality correlates with greater importance of the influencing factors. The top three factors for centrality include S_5, S_{12}, and S_{10}. This synthetically reflects the extent to which these factors affect and are influenced by other factors in the system. Specifically, factors with a high centrality play a central role in the system. They are influential and susceptible to influence. This bi-directional, high-strength interaction makes the high-centrality element a critical factor in system function and performance.

4.2. Causality Analysis

The factors with positive causality belong to the cause factors, and the scoring order is as follows: S_{14}, S_{17}, S_{16}, S_{13}, S_1, S_8, S_6, and S_4. The factors with negative causality belong to the result factors, which are sorted by their absolute values as follows: S_7, S_5, S_3, S_{10}, S_{15}, S_9, S_2, S_{12}, and S_{11}. Causality represents the tendency of a factor to act as a reason or result in a system. Factors with a high degree of causality are usually the driving factors and the key to promoting the change or development of the system. The opposite factors are more likely to be affected by other factors and are part of the system response or result. Other factors restrict their state or behavior. The degree of causality reflects the causal status of factors in the system and provides crucial reference information for decision-makers. Decision-makers can prioritize factors that have a solid impact to develop strategies and optimize

systems more effectively. At the same time, for factors with low causation, decision-makers can understand the extent to which and path by which they are affected by other factors to ensure the overall coordination and stability of the system.

5. Discussion and Implication

5.1. Discussion

According to Section 4, S5 shows overall dominance in the technical dimension, whose influencing degree, influenced degree and centrality rank in the forefront, reflecting the basic role of digitalization in promoting GI. Project digitization accelerates innovation through resource optimization and decision-making efficiency improvements while being driven by technological innovation, policy support, and market demand factors, creating a self-reinforcing virtuous cycle [29]. Therefore, when advancing MTI-GI, participants should prioritize improving project digitization levels, promoting digital technology integration into project management, and optimizing workflows via automation and intelligence to enhance efficiency. In pursuing digitization development, establishing robust network security systems remains critical to ensure project data security and integrity. Although S5 is highly influenced, its high centrality arises because digitization both absorbs strong external inputs of policy and market and propagates improvements across multiple factors, making it simultaneously sensitive and system-critical. For illustration, digital twin approaches in European railway assets have optimized monitoring and decision-making during bridge load tests, aligning with S5's role in our results [64].

S8 and S10 show strong driving and high dynamic characteristics, respectively, in organizational dimension. Effective incentive mechanisms stimulate participants' enthusiasm and creativity through rewards and punishments, sustaining GI development via continuous innovation. Since S8 was the most influential driver, governments should prioritize incentive mechanism reforms over other organizational adjustments to maximize innovation vitality. Green innovation culture, susceptible to organizational characteristics, leadership style, and team atmosphere, functions as a bridge linking diverse factors to coordinate innovation activities while serving as their spiritual pillar and directional guide. Organizational pressure created by explicit incentives and the cohesion of shared norms and values sustains pro-innovation behavior [38,41]. Concurrently, S12 exerts moderate influence while serving as a network hub, necessitating a closed-loop feedback system integrating "demand-oriented—technological development—social evaluation" [47]. Although S7 is highly influenced, it remains central because capability-building and professional training depend on incentives and culture upstream yet diffuse competencies back into the network, amplifying GI adaptability and resilience. Evidence that incentive alignment enhances megaproject outcomes has been reported in cross-national settings [65].

Environmentally, S14, S16, and S17 constitute the core driving sources. To address the regional development disparity, it is imperative to optimize human resource allocation through enhanced institutional frameworks for coordinated regional development, advance equitable access to public services across regions, and mitigate the "resource curse" phenomenon [26]. Ecological differences drive green construction innovation, compelling projects to consider natural environmental impacts alongside economic gains while adopting sustainable technologies for dual ecological–economic optimization. Geographical constraints demand adaptive innovations; for instance, engineering teams develop new soil stabilization methods for unstable ground or water-efficient techniques for arid regions [51,52]. For instance, road construction on continuous permafrost along the Inuvik–Tuktoyaktuk Highway in Canada required insulated embankments and all-weather construction practices; satellite-based analysis shows road-induced changes in snow accumulation and melt, illustrating how environmental constraints drive adaptive green

infrastructure in practice [66]. These findings reflect the realistic challenges the transportation industry is facing, highlighting the coordinating role of MTI-GI in balancing regional growth, overcoming geographical barriers, and protecting ecosystems while affirming its strong causal influence.

Based on the analysis, this study shows that promoting MTI-GI requires considering technological, organizational, and environmental dimensions together with their interconnections. Understanding the cross-dimensional collaborative strategy framework and leveraging the combined strengths of these elements can ensure effective GI implementation while advancing theoretical and practical development. Moreover, the identified core driving factors are closely aligned with the SDGs, contributing directly to SDG 9, SDG 11, and SDG 13, thereby highlighting the role of major transportation infrastructure projects in advancing sustainable development [67].

5.2. Implication

This research complements multiple theories. First, by situating GI within MTIs, it extends GI theory to complex contexts and broadens its scope. Second, applying the TOE framework to identify MTI-GI factors and build an influencing system expands TOE's application and strengthens GI's foundation. Fuzzy DEMATEL reveals root factors across technology, organization, and environment. Optimizing these factors enables innovation entities to effectively advance MTI-GI, providing new theoretical insights and empirical evidence for understanding GI drivers. In addition, the cross-dimensional structure we adopt resonates with international practice in large-scale transport projects, where environmental externalities, organizational coordination, and technology deployment must be treated as an interacting set rather than isolated levers [68]. Compared with DEMATEL applications that target single topical arenas in transport such as technology adoption [69], our approach embeds TOE within the specific context of MTI-GI and explicitly links causal drivers to actionable strategies, thereby clarifying what DEMATEL adds in complex megaproject settings.

In practice, this research provides guidance for the implementation of MTIs. First, the centrality of project digitization level indicates that continuous technological and process innovation is critical to advance intelligent and green transport infrastructure. Simultaneously, understanding public feedback on emerging technologies, identifying social needs, and achieving precise market positioning are essential to establish innovation's foundational driving force. Second, the industry must prioritize optimizing the organizational system, leveraging effective incentive mechanisms to advance GI, and cultivating a robust green innovation culture that sustains innovation momentum and directional accuracy. Lastly, MTIs' extensive scope and regional connectivity create significant geographical, societal, economic, and environmental differences across regions, which necessitate differentiated strategies and spatially adapted innovations. Evidence from European core network corridors shows how large freight axes integrate environmental targets with operational redesign, offering actionable analogies for MTI-GI implementation in diverse contexts [68]. Furthermore, the framework developed in this study provides structured support for evidence-based decision-making in MTIs by integrating a systematic literature-driven factor identification process with expert consensus evaluation. This dual approach enhances both the rationality and transparency of the decision process, aligning with the growing emphasis on data-driven and participatory decision-making frameworks in infrastructure governance [70].

Three feasible policy measures are proposed based on research findings. Policymakers should advance technological digitization and intelligence through funding and tax incentives. Simultaneously, establishing seamless feedback mechanisms can regulate social-

level innovation processes. Organizationally, governments should implement effective incentive policies to activate innovation entities and expand teams. While recognizing GI's susceptibility to external environmental factors, policies must prioritize sustainable development principles, ensuring environmental protection and social responsibility are integrated into project planning and construction. Given the long lifecycle, safety relevance, and networked nature of MTIs, the results are particularly relevant for transport regulators concerned with reliability, project owners and contractors managing incentives, operators maintaining daily performance, financial and insurance institutions pricing risks, and communities whose engagement shapes acceptance. U.S. experience also shows how insurance incentives and public assistance influence resilience decisions in transport infrastructure, directly speaking to these stakeholder groups [71].

6. Conclusions

MTIs serve as modern society's cornerstone through robust regional connectivity, substantial investments, and extended project cycles. As sustainable development strategies gain traction and public demand for quality-of-life improvements grows, MTI innovation must balance economic, environmental, and social considerations, rendering GI essential. Investigating its influencing factors constitutes foundational research. This study systematically analyzes MTI-GI drivers using fuzzy DEMATEL to quantify inter-factor relationships and identify root causes, subsequently proposing operational strategies and management guidelines. Key findings include: (1) A comprehensive assessment system for MTI-GI has been established across technology, organization, and environmental dimensions, providing a multifaceted analytical framework for understanding GI complexities within these institutions. (2) Fuzzy DEMATEL analysis identifies core MTI-GI drivers: project digitization level, incentive mechanisms, green innovation culture, public feedback on emerging technologies, regional development disparities, geographical features, and ecological environments along projects. Findings emphasize creating integrated innovation support systems spanning technological, organizational, and environmental domains to effectively foster GI. (3) The theoretical foundation of MTI-GI has been strengthened by constructing and analyzing the influencing factor system, extending adaptive systems theory to the context of large-scale transport projects. This research bridges systemic innovation studies with infrastructure governance, offering conceptual pathways for future scholarship. Practically, the findings provide a structured evidence base to inform long-term planning and governance frameworks, reinforcing MTI-GI's critical role in advancing sustainable development and key SDGs.

This research produced valuable and innovative findings but also has limitations that warrant further inquiry. First, the use of fuzzy DEMATEL, while effective for analyzing complex inter-factor relationships, depends heavily on expert judgment and offers only a static view of influence patterns. These constraints may introduce bias and overlook dynamic changes in innovation processes. Second, the study focused exclusively on MTIs, and this focus is suitable for capturing their systemic characteristics, but other types of infrastructure such as energy, water, or urban development face distinct challenges and may follow different GI trajectories. These limitations point to several avenues for future research. Broadening the scope to include diverse infrastructure sectors could generate comparative insights into convergences and divergences in GI practices. In addition, longitudinal or mixed-method approaches could reveal how key drivers interact and evolve over project lifecycles. Such efforts would enhance both the theoretical foundations and the practical relevance of research on GI in complex infrastructure systems.

Author Contributions: Conceptualization, L.L. and S.W.; methodology, S.W.; software, S.W.; validation, L.L., X.Y. and S.W.; formal analysis, L.L.; investigation, S.W. and M.W.; resources, L.L.; data curation, S.W.; writing—original draft preparation, S.W.; writing—review and editing, L.L.; visualization, S.W.; supervision, X.Y.; project administration, Z.Y. and S.S.; funding acquisition, L.L. and X.Y. All authors have read and agreed to the published version of the manuscript.

Funding: The work in this paper was supported by the Guangdong Basic and Applied Basic Research Foundation (2025A1515010190), the Humanities and Social Science Foundation of Ministry of Education of China (24YJC630105).

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors on request.

Conflicts of Interest: Author Ziwei Yi was employed by the company China Construction Harbour and Channel Engineering Bureau Group Co., Ltd. Author Shu Shi was employed by the company Qingdao Metro Real Estate Development Co. Ltd. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

References

1. Flyvbjerg, B. What You Should Know about Megaprojects and Why: An Overview. *Proj. Manag. J.* **2014**, *45*, 6–19. [CrossRef]
2. Guikema, S.D. Infrastructure Design Issues in Disaster-Prone Regions. *Science* **2009**, *323*, 1302–1303. [CrossRef]
3. Li, Y.; Han, Y.; Luo, M.; Zhang, Y. Impact of Megaproject Governance on Project Performance: Dynamic Governance of the Nanning Transportation Hub in China. *J. Manag. Eng.* **2019**, *35*, 05019002. [CrossRef]
4. Jin, Z.; Zeng, S.; Chen, H.; Shi, J.J. Creating Value from Diverse Knowledge in Megaproject Innovation Ecosystems. *Int. J. Proj. Manag.* **2022**, *40*, 646–657. [CrossRef]
5. Zhang, X.; Denicol, J.; Chan, P.W.; Le, Y. Designing the Transition to Operations in Large Inter-Organizational Projects: Strategy, Structure, Process, and People. *J. Oper. Manag.* **2024**, *70*, 107–136. [CrossRef]
6. Fouquet, R. Path Dependence in Energy Systems and Economic Development. *Nat. Energy* **2016**, *1*, 16098. [CrossRef]
7. Bai, D.; Li, M.; Wang, Y.; Mallek, S.; Shahzad, U. Impact Mechanisms and Spatial and Temporal Evolution of Digital Economy and Green Innovation: A Perspective Based on Regional Collaboration within Urban Agglomerations. *Technol. Forecast. Soc. Change* **2024**, *207*, 123613. [CrossRef]
8. Li, L.; Luan, H.; Yin, X.; Dou, Y.; Yuan, M.; Li, Z. Understanding Sustainability in Off-Site Construction Management: State of the Art and Future Directions. *J. Constr. Eng. Manag.* **2022**, *148*, 03122008. [CrossRef]
9. Gorączkowska, J. Enterprise Innovation in Technology Incubators and University Business Incubators in the Context of Polish Industry. *Oeconomia Copernic.* **2020**, *11*, 799–817. [CrossRef]
10. Lin, H.; Zeng, S.; Ma, H.; Zeng, R.; Tam, V.W.Y. An Indicator System for Evaluating Megaproject Social Responsibility. *Int. J. Proj. Manag.* **2017**, *35*, 1415–1426. [CrossRef]
11. Jia, F.; Zeng, S.; Gao, X. Can the Digital Economy Empower the Transportation Sector to Improve Green Total Factor Productivity? *Int. J. Sustain. Transp.* **2024**, *18*, 871–886. [CrossRef]
12. Zhong, C.; Cai, H.; Liu, L.; Xue, R.; Shan, Y. Unveiling the Green Path: How Urban Openness Reduces Pollution and Paves the Way to Sustainability. *J. Environ. Manag.* **2024**, *370*, 122378. [CrossRef]
13. Ma, H.; Liu, Z.; Zeng, S.; Lin, H.; Tam, V.W.Y. Does Megaproject Social Responsibility Improve the Sustainability of the Construction Industry? *Eng. Constr. Archit. Manag.* **2020**, *27*, 975–996. [CrossRef]
14. Chen, Y.; Zhou, Z.; Zhu, J.; Deng, X. Megaproject Branding on Social Media from the Lens of Information Content and Information Diffusion. *J. Manag. Eng.* **2024**, *40*, 04023049. [CrossRef]
15. Loew, S.; Lützenkirchen, V.; Hansmann, J.; Ryf, A.; Guntli, P. Transient Surface Deformations Caused by the Gotthard Base Tunnel. *Int. J. Rock Mech. Min. Sci.* **2015**, *75*, 82–101. [CrossRef]
16. Chen, H.; Jin, Z.; Su, Q.; Yue, G. The Roles of Captains in Megaproject Innovation Ecosystems: The Case of the Hong Kong-Zhuhai-Macau Bridge. *Eng. Constr. Archit. Manag.* **2021**, *28*, 662–680. [CrossRef]
17. Larsson, J.; Eriksson, P.E.; Olofsson, T.; Simonsson, P. Industrialized Construction in the Swedish Infrastructure Sector: Core Elements and Barriers. *Constr. Manag. Econ.* **2014**, *32*, 83–96. [CrossRef]
18. Li, L.; Luan, H.; Yuan, M.; Zheng, R. Knowledge Fusion-Driven Sustainable Decision-Making for Mega Transportation Infrastructure Projects. *Eng. Constr. Archit. Manag.* **2024**. [CrossRef]

19. Jin, Z.; Saixing, Z.; Gao, X. Unpacking the Paradox of Openness in Megaproject Innovation Ecosystems. *Technol. Anal. Strateg. Manag.* **2023**, *37*, 217–233. [CrossRef]
20. Zeng, S.X.; Ma, H.Y.; Lin, H.; Zeng, R.C.; Tam, V.W.Y. Social Responsibility of Major Infrastructure Projects in China. *Int. J. Proj. Manag.* **2015**, *33*, 537–548. [CrossRef]
21. Yuan, M.; Liu, H.; Wang, H.; Dou, Y.; Yin, X. Exploring the Evolution of Collaborative Innovation in the Con-struction and Demolition Waste Management Industry: Evidence From China. *IEEE Trans. Eng. Manag.* **2025**, *72*, 2978–2994. [CrossRef]
22. Yang, K.; Wang, W.; Xiong, W. Promoting the Sustainable Development of Infrastructure Projects through Responsible Innovation: An Evolutionary Game Analysis. *Util. Policy* **2021**, *70*, 101196. [CrossRef]
23. Arici, H.E.; Uysal, M. Leadership, Green Innovation, and Green Creativity: A Systematic Review. *Serv. Ind. J.* **2022**, *42*, 280–320. [CrossRef]
24. Gao, Q.; Cheng, C.; Sun, G. Big Data Application, Factor Allocation, and Green Innovation in Chinese Manufacturing Enterprises. *Technol. Forecast. Soc. Change* **2023**, *192*, 122567. [CrossRef]
25. Luo, Y.; Salman, M.; Lu, Z. Heterogeneous Impacts of Environmental Regulations and Foreign Direct Investment on Green Innovation across Different Regions in China. *Sci. Total Environ.* **2021**, *759*, 143744. [CrossRef]
26. Luo, S.; Yimamu, N.; Li, Y.; Wu, H.; Irfan, M.; Hao, Y. Digitalization and Sustainable Development: How Could Digital Economy Development Improve Green Innovation in China? *Bus. Strategy Environ.* **2023**, *32*, 1847–1871. [CrossRef]
27. Fang, Z.; Razzaq, A.; Mohsin, M.; Irfan, M. Spatial Spillovers and Threshold Effects of Internet Development and Entrepreneurship on Green Innovation Efficiency in China. *Technol. Soc.* **2022**, *68*, 101844. [CrossRef]
28. Kangmin, W.; Yuyao, Y.; Xiangyu, W.; Zhengqian, L.; Hong'ou, Z. New Infrastructure-Lead Development and Green-Technologies: Evidence from the Pearl River Delta, China. *Sustain. Cities Soc.* **2023**, *99*, 104864. [CrossRef]
29. Mäkitie, T.; Hanson, J.; Damman, S.; Wardeberg, M. Digital Innovation's Contribution to Sustainability Transitions. *Technol. Soc.* **2023**, *73*, 102255. [CrossRef]
30. Chen, H.; Yi, J.; Chen, A.; Peng, D.; Yang, J. Green Technology Innovation and CO2 Emission in China: Evidence from a Spatial-Temporal Analysis and a Nonlinear Spatial Durbin Model. *Energy Policy* **2023**, *172*, 113338. [CrossRef]
31. Zhang, M.; Ma, X.; Liu, J. Can Infrastructure Upgrading Achieve the Synergistic Effect of Pollution Reduction and Carbon Reduction? Evidence from the High-Speed Rail and "Broadband China" Strategies. *Sustainability* **2024**, *16*, 1628. [CrossRef]
32. Zhang, Y.; Sun, J.; Yang, Z.; Wang, Y. Critical Success Factors of Green Innovation: Technology, Organization and Environment Readiness. *J. Clean. Prod.* **2020**, *264*, 121701. [CrossRef]
33. Grafius, D.R.; Varga, L.; Jude, S. Infrastructure Interdependencies: Opportunities from Complexity. *J. Infrastruct. Syst.* **2020**, *26*, 04020036. [CrossRef]
34. Jin, Z.; Zeng, S.; Chen, H.; Shi, J.J. Explaining the Expansion Performance in Technological Capability of Participants in Megaprojects: A Configurational Approach. *Technol. Forecast. Soc. Change* **2022**, *181*, 121747. [CrossRef]
35. Ling, S.; Jin, S.; Wang, H.; Zhang, Z.; Feng, Y. Transportation Infrastructure Upgrading and Green Development Efficiency: Empirical Analysis with Double Machine Learning Method. *J. Environ. Manag.* **2024**, *358*, 120922. [CrossRef]
36. Singh, S.; Upadhyay, S.P.; Powar, S. Developing an Integrated Social, Economic, Environmental, and Technical Analysis Model for Sustainable Development Using Hybrid Multi-Criteria Decision Making Methods. *Appl. Energy* **2022**, *308*, 118235. [CrossRef]
37. Tian, Z.; Zhou, S.; Yin, X.; Yao, Q.; Zhao, Y. A Bayesian Pressure-inversion–Driven Method for Establishing Mechanically Grounded Digital Twins of In-service Tunnel Linings. *Reliab. Eng. Syst. Saf.* **2026**, *265*, 111633. [CrossRef]
38. Ji, H.; Miao, Z. Corporate Social Responsibility and Collaborative Innovation: The Role of Government Support. *J. Clean. Prod.* **2020**, *260*, 121028. [CrossRef]
39. Lin, H.; Sui, Y.; Ma, H.; Wang, L.; Zeng, S. CEO Narcissism, Public Concern, and Megaproject Social Responsibility: Moderated Mediating Examination. *J. Manag. Eng.* **2018**, *34*, 04018018. [CrossRef]
40. Naji, K.K.; Gunduz, M.; Hamaidi, M.F. Major Factors Affecting Construction Waste Management in Infrastructure Projects Using Structural Equation Model. *J. Constr. Eng. Manag.* **2022**, *148*, 04022101. [CrossRef]
41. Li, R.; Du, J.; Wu, J.; Chen, X. Government Carbon Reduction Policies and the Shift to Green Lifestyles: The Role of Innovation, Incentive, Driving and Economic Effect. *J. Environ. Manag.* **2025**, *374*, 124056. [CrossRef]
42. Liu, J.; Ma, G. Study on Incentive and Supervision Mechanisms of Technological Innovation in Megaprojects Based on the Principal-Agent Theory. *Eng. Constr. Archit. Manag.* **2021**, *28*, 1593–1614. [CrossRef]
43. Ma, H.; Lv, K.; Zeng, S.; Lin, H.; Shi, J.J. Climbing the Pyramid of Megaproject Social Responsibility: Impacts of External Stakeholders and Project Complexity. *J. Constr. Eng. Manag.* **2022**, *148*, 04022116. [CrossRef]
44. Xie, L.; Xu, T.; Han, T.; Xia, B.; Chen, Q.; Skitmore, M. Influence of Institutional Pressure on Megaproject Social Responsibility Behavior. *J. Civ. Eng. Manag.* **2022**, *28*, 177–195. [CrossRef]

45. Chi, Y.; Hu, N.; Lu, D.; Yang, Y. Green Investment Funds and Corporate Green Innovation: From the Logic of Social Value. *Energy Econ.* **2023**, *119*, 106532. [CrossRef]
46. Kyriacou, A.P.; Muinelo-Gallo, L.; Roca-Sagalés, O. The Efficiency of Transport Infrastructure Investment and the Role of Government Quality: An Empirical Analysis. *Transp. Policy* **2019**, *74*, 93–102. [CrossRef]
47. Zeng, S.; Liu, Z.; Sun, D. How Do Highways Enable Firm Productivity? The Role of Innovation. *IEEE Trans. Eng. Manag.* **2024**, *71*, 2350–2363. [CrossRef]
48. Xie, L.; Xu, T.; Ju, T.; Xia, B. Explaining the Alienation of Megaproject Environmental Responsibility Behavior: A Fuzzy Set Qualitative Comparative Analysis Study in China. *Eng. Constr. Archit. Manag.* **2023**, *30*, 2794–2813. [CrossRef]
49. Li, C.; Song, L. Regional Differences and Spatial Convergence of Green Development in China. *Sustainability* **2022**, *14*, 8511. [CrossRef]
50. Shang, Y.; Niu, Y.; Song, P. Regional Differences and Influencing Factors of Green Innovation Efficiency in China's 285 Cities. *Sustainability* **2024**, *16*, 334. [CrossRef]
51. Li, Y.; Yao, Z.; Wu, J.; Zeng, S.; Wu, G. Toward Ecological Environmental Risk for Spoil Ground Group Management in Mega Projects. *Eng. Constr. Archit. Manag.* **2024**, *31*, 3706–3726. [CrossRef]
52. Antunes, J.; Tan, Y.; Wanke, P.; Jabbour, C.J.C. Impact of R&D and Innovation in Chinese Road Transportation Sustainability Performance: A Novel Trigonometric Envelopment Analysis for Ideal Solutions (TEA-IS). *Socioecon. Plann. Sci.* **2023**, *87*, 101544. [CrossRef]
53. Dalvi-Esfahani, M.; Niknafs, A.; Kuss, D.J.; Nilashi, M.; Afrough, S. Social Media Addiction: Applying the DEMATEL Approach. *Telemat. Inform.* **2019**, *43*, 101250. [CrossRef]
54. Wu, W.-W.; Lee, Y.-T. Developing Global Managers' Competencies Using the Fuzzy DEMATEL Method. *Expert Syst. Appl.* **2007**, *32*, 499–507. [CrossRef]
55. Liu, W.; Hu, Y.; Huang, Q. Research on Critical Factors Influencing Organizational Resilience of Major Transportation Infrastructure Projects: A Hybrid Fuzzy DEMATEL-ISM-MICMAC Approach. *Buildings* **2024**, *14*, 1598. [CrossRef]
56. Alqershy, M.T.; Shi, Q. Barriers to Social Responsibility Implementation in Belt and Road Mega Infrastructure Projects: A Hybrid Fuzzy DEMATEL-ISM-MICMAC Approach. *Buildings* **2023**, *13*, 1561. [CrossRef]
57. Umar, T. Applications of Drones for Safety Inspection in the Gulf Cooperation Council Construction. *Eng. Constr. Archit. Manag.* **2021**, *28*, 2337–2360. [CrossRef]
58. Umar, T. Key Factors Influencing the Implementation of Three-Dimensional Printing in Construction. *Proc. Inst. Civ. Eng. Manag. Procure. Law* **2021**, *174*, 104–117. [CrossRef]
59. Galvin, R. How Many Interviews Are Enough? Do Qualitative Interviews in Building Energy Consumption Research Produce Reliable Knowledge? *J. Build. Eng.* **2015**, *1*, 2–12. [CrossRef]
60. Burillo, P.; Bustince, H. Entropy on Intuitionistic Fuzzy Sets and on Interval-Valued Fuzzy Sets. *Fuzzy Sets Syst.* **1996**, *78*, 305–316. [CrossRef]
61. Umar, T. Challenges of BIM Implementation in GCC Construction Industry. *Eng. Constr. Archit. Manag.* **2022**, *29*, 1139–1168. [CrossRef]
62. Wang, Z.-X.; Niu, L.-L.; Wu, R.-X.; Lan, J.-B. Multicriteria Decision-Making Method Based on Risk Attitude under Interval-Valued Intuitionistic Fuzzy Environment. *Fuzzy Inf. Eng.* **2014**, *6*, 489–504. [CrossRef]
63. Chang, K.-H.; Cheng, C.-H. Evaluating the Risk of Failure Using the Fuzzy OWA and DEMATEL Method. *J. Intell. Manuf.* **2011**, *22*, 113–129. [CrossRef]
64. Chacón, R.; Ramonell, C.; Posada, H.; Sierra, P.; Tomar, R.; Martínez de la Rosa, C.; Rodriguez, A.; Koulalis, I.; Ioannidis, K.; Wagmeister, S. Digital Twinning during Load Tests of Railway Bridges-Case Study: The High-Speed Railway Network, Extremadura, Spain. *Struct. Infrastruct. Eng.* **2024**, *20*, 1105–1119. [CrossRef]
65. Zhu, J.; Hertogh, M.; Zhang, J.; Shi, Q.; Sheng, Z. Incentive Mechanisms in Mega Project-Risk Management Considering Owner and Insurance Company as Principals. *J. Constr. Eng. Manag.* **2020**, *146*, 04020120. [CrossRef]
66. Hammar, J.; Grünberg, I.; Kokelj, S.V.; van der Sluijs, J.; Boike, J. Snow Accumulation, Albedo and Melt Patterns Following Road Contruction on Permafrost, Inuvik-Tuktoyaktuk Highway, Canada. *Cryosphere Discuss.* **2023**, *17*, 1–22.
67. Umar, T.; Opoku, A.; Umeokafor, N.; Ahmed, S. The Built Environment's Contribution to the Progress of the Sustainable Development Goals. In *The Elgar Companion to the Built Environment and the Sustainable Development Goals*; Edward Elgar Publishing: Gloucestershire, UK, 2024; pp. 58–82. ISBN 1-0353-0003-6.
68. Cavallaro, F.; Costa, C.; De Biasi, I.; Fabio, A.; Nocera, S. Sustainable Pathways for Mitigating Externalities in Long-Distance Terrestrial Transport. *Transp. Policy* **2024**, *154*, 207–221. [CrossRef]
69. Zarbakhshnia, N.; Ma, Z. Critical Success Factors for the Adoption of AVs in Sustainable Urban Transportation. *Transp. Policy* **2024**, *156*, 62–76. [CrossRef]

70. Naccari Carlizzi, D.; Rindone, C.; Quattrone, A.; D'Errigo, F. Decision Making and E-Democracy: Archimede, a Tool to Support the Data-Driven Process. In *Innovations and Economic and Social Changes due to Artificial Intelligence: The State of the Art*; Springer: Berlin/Heidelberg, Germany, 2023; pp. 39–53.
71. Tonn, G.; Reilly, A.; Czajkowski, J.; Ghaedi, H.; Kunreuther, H. US Transportation Infrastructure Resilience: Influences of Insurance, Incentives, and Public Assistance. *Transp. Policy* **2021**, *100*, 108–119. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.