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The Balance Between Value and Risk: A Study on Engineering Philosophy and Practice Based on the Hong Kong-Zhuhai-Macao Bridge

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ABSTRACT

As human engineering capabilities enter the era of "mega-projects," the value created by engineering activities and the accompanying risks have reached unprecedented scales and complexity. How to maximize engineering value under high-risk environments has become a key issue in major project management. Using the iconic Hong Kong-Zhuhai-Macao Bridge (HZMB) as the research subject, this paper conducts a systematic case study to deeply explore its embodiment within multi-dimensional value systems and complex risk spectra. Focusing on the dynamic decision-making process of "acceptable risk," this paper reveals how engineering decision-makers, guided by strategic, economic, technological, social, and environmental values, utilize technological innovation, meticulous management, and system synergy to reduce various risks from unacceptable levels to the lowest reasonably practicable level of acceptability. This study indicates that risk management for major projects is essentially an art of dynamic balance guided by value rationality. Its successful practice offers significant theoretical insights and practical references for future major project management. This study not only systematically summarizes the innovative practices in risk management during the HZMB project but also reflects on the value realization paths of modern mega-projects from the perspective of engineering philosophy, providing useful references for the decision-making and implementation of similar major infrastructure projects.

KEYWORDS

Engineering Value; Engineering Risk; Risk Control; Acceptable Risk; Hong Kong-Zhuhai-Macao Bridge; Major Project Management

1. INTRODUCTION

1.1. Research Background and Significance

The world today is in an era of booming mega-projects, with human engineering capabilities reaching unprecedented heights. According to statistics from the International Project Management Association, the number of major infrastructure projects worldwide with investments exceeding ten billion US dollars has shown exponential growth over the past decade. These mega-projects are constantly pushing physical limits while achieving new heights in technical complexity, system integration, and social impact. From massive bridge-tunnel clusters spanning seas to aerospace systems exploring space and global digital infrastructure networks, major projects have become vital carriers for driving regional development and demonstrating comprehensive national strength.

However, alongside the immense value created by these projects is a corresponding accumulation of significant risks. Mega-projects generally feature large investment scales, long construction cycles, high technical difficulty, and numerous stakeholders, leading to more complex risk spectra and far-reaching consequences. Traditional engineering risk management methods, primarily based on probabilistic risk assessment, focus on quantifying and controlling known risks but often fall short when facing systemic risks unique to mega-projects and "unknown unknowns." This tension between value creation and risk assumption constitutes the fundamental contradiction in modern engineering management.

Against this backdrop, the Hong Kong-Zhuhai-Macao Bridge, as the most representative mega-project under the "One Country, Two Systems" framework, provides an invaluable research sample for studying the value realization and risk control of major projects. This 55-kilometer cross-sea passage connecting Hong Kong, Zhuhai, and Macao is the longest sea-crossing bridge in the world, setting multiple world records. More importantly, it not only connects three locations geographically but also achieves innovative breakthroughs in legal systems, technical standards, and management models. Its effective risk management during construction, particularly the successful experiences in ecological protection, technological innovation, and cross-regional coordination, holds significant reference value for future major engineering projects.

The significance of this study is manifested on three levels:

Theoretical Level: Through in-depth analysis of this extreme case, it helps enrich and develop major project risk management theory, particularly promoting the innovation and improvement of "acceptable risk" decision-making theory.

Practical Level: By systematically summarizing the successful risk management experiences of the HZMB, it provides replicable practical paradigms for similar projects.

Methodological Level: It explores the innovation of interdisciplinary research paradigms, organically integrating perspectives from engineering, management, sociology, and other disciplines, offering new ideas for complex engineering system research.

1.2. Research Background and Significance

This study focuses on the HZMB case to construct a systematic "Value-Risk" balance analysis framework. Specifically, the research content includes the following three aspects: First, it analyzes the composition and internal logic of the value system of major projects to reveal the interrelationships between different value dimensions. Second, it systematically identifies the special risk spectra faced by mega-projects and their evolution patterns to establish a framework for risk classification and assessment. Finally, based on the value-risk balance perspective, it explores the decision-making mechanisms and innovative management models for major projects.

In terms of research methodology, this paper adopts a mixed-methods approach combining case studies and theoretical analysis. By collecting extensive primary data during the HZMB construction—including technical documents, management records, and research reports—it uses grounded theory methods to conduct an in-depth analysis of the specific practices of engineering value realization and risk control. Simultaneously, combined with systems engineering thinking and management theory, it refines practical experience into theoretical frameworks with universality. Additionally, comparative analysis is used to compare the HZMB with other similar major projects to enhance the reliability and generalizability of the research conclusions.

The structure of the thesis follows the logical thread of "Theory-Practice-Implications": Chapter 2 establishes the theoretical framework, elaborating on the multiple compositions of engineering value, systematic methods of risk identification, and the theoretical basis of acceptable risk. Chapter 3 conducts empirical case analysis, detailing the value pursuits, risk challenges, and coping strategies of the HZMB. Chapter 4 summarizes practical implications and proposes recommendations for future major project management. This arrangement seeks to integrate theory with practice, ensuring scientific rigor and utility.

2. THEORETICAL FRAMEWORK: ENGINEERING VALUE, RISK, AND ACCEPTABILITY

2.1. The Multi-dimensional Composition of Engineering Value Research Background and Significance

Major projects, as material practices of human transformation of the world, exhibit inherent multiplicity and complexity in their value manifestations. From the perspective of value forms, the value system of modern major projects can be divided into four interrelated yet relatively independent dimensions, which together constitute the foundational basis for the existence of the project.

Economic Value: This is the most direct manifestation of engineering value, but its connotation has transcended traditional ROI calculations. Modern engineering economic value includes three levels: Direct economic value (operational revenue and asset appreciation); Indirect economic value (regional economic stimulus and industrial upgrading effects); Potential economic value (social cost savings and development opportunities created through efficiency improvements). For the HZMB, its economic value lies not only in direct operating income but, more importantly, in deepening the economic integration of the Guangdong-Hong Kong-Macao Greater Bay Area and optimizing regional industrial layouts.

Strategic Value: This is a unique dimension of major projects, often transcending purely economic considerations. Such value may involve national security, regional coordinated development, and enhancing national competitiveness. Strategic value requires a long-term perspective, considering the project's impact on regional development patterns, national strategic layouts, and even global competition. The strategic value of the HZMB lies not only in improving regional transportation infrastructure but also in promoting the construction of the Greater Bay Area and fostering the integrated development of Hong Kong, Macao, and the Mainland—a value that, though difficult to quantify, cannot be ignored.

Technological Value: This reflects the knowledge accumulation and capability enhancement brought by engineering as a carrier of technological innovation. Technological innovations and knowledge accumulation generated during major projects often drive technological progress across entire industries and related fields. This spillover effect may far exceed the value of the project itself. The multiple technological innovations produced during the HZMB construction not only ensured the smooth implementation of the project but also made significant contributions to the technological advancement of China's bridge construction industry; this accumulation of technological value is long-term and sustainable.

Social and Environmental Value: This is a dimension increasingly emphasized in modern engineering. Social value includes improving livelihoods, promoting social equity, and enhancing national cohesion; environmental value is reflected in ecological protection and the enhancement of sustainable development capabilities. It is important to note that social and environmental values often involve complex trade-offs. Balancing development with protection is a critical issue for modern engineering. During the HZMB construction, the protection of the Chinese white dolphin reflects the project's emphasis on environmental value, and such value choices in turn influenced the project's social acceptance.

2.2. Identification and Classification of Engineering Risks

Corresponding to the multiplicity of values, the risks faced by major projects also present complex spectral characteristics. Based on the source and nature of risks, a systematic risk classification framework can be constructed, encompassing four interrelated dimensions.

Technical Risk Dimension: This covers technical uncertainties throughout the entire process of design, construction, and operation. For mega-projects like the HZMB, technical risks are particularly prominent, mainly manifesting in three aspects: Technical maturity risk (e.g., lack of precedent for innovative technologies like deep-sea immersed tunnels); Technical integration risk (complexity and compatibility issues between multiple subsystems); and Technical reliability risk (material durability and structural safety assurance under a 120-year design life). These technical risks intertwine, forming the core technical challenge of project implementation.

Management Risk Dimension: This involves the organizational system, coordination mechanisms, and control processes of the project. Mega-projects typically feature numerous participating units, complex organizational interfaces, and long management chains, significantly increasing management risks. Specifically, management risks include Organizational coordination risk (decision-making efficiency under multi-party participation); Schedule control risk (the cascading effect of delays in critical nodes); and Cost overrun risk (budget pressure from design changes and price fluctuations). The HZMB involved collaboration among Guangdong, Hong Kong, and Macao, making its management complexity unprecedented and requiring innovative management models and coordination mechanisms.

External Risk Dimension: This includes external factors beyond the project's direct control that may have a significant impact. Such risks usually include: Natural disaster risk (extreme weather events like typhoons and earthquakes); Policy environment risk (changes in laws/regulations and administrative approval issues); Market fluctuation risk (changes in raw material prices and financing environments); and Public opinion risk (pressure from public attention and media scrutiny). External risks often possess strong uncertainty, necessitating flexible and effective response mechanisms.

Ethical Risk Dimension: This is a type of risk requiring special attention in modern engineering, often overlooked by traditional risk management. Ethical risks involve Safety ethics (impact of engineering decisions on the safety of construction personnel and the public); Environmental ethics (impact of engineering construction on ecosystems and biodiversity); Intergenerational ethics (impact of current decisions on the development space of future generations); and Social ethics (fairness of resource distribution and stakeholder participation). In the HZMB construction, balancing engineering construction with ecological protection and ensuring fairness in decision-making were ethical issues requiring careful consideration, directly relating to the project's social legitimacy and moral justification.

2.3. Theoretical Basis and Analysis Models of Acceptable Risk

"Acceptable risk" is the core concept connecting engineering value and risk practice. Its theoretical development has evolved from technical rationality to value rationality. In modern engineering practice, acceptable risk decision-making has developed into a systematic theoretical framework and methodological system.

The ALARP Principle: As the foundational framework for acceptable risk decision-making, its core lies in establishing a zoned management model for risk levels. This model divides risk levels into three characteristic regions:

Unacceptable Region: Risk levels exceed societal tolerance limits; mandatory measures must be taken to reduce risk.

ALARP (As Low As Reasonably Practicable) Region: This is the core area of risk decision-making, requiring all reasonably practicable measures to minimize risk.

Broadly Acceptable Region: Risk levels are sufficiently low that no specialized control measures are required.

The key to this framework lies in the judgment standard of "reasonably practicable," requiring comprehensive consideration of multiple factors such as technical feasibility, economic reasonableness, and social acceptability.

Risk Matrix: An important tool for acceptable risk analysis, it establishes a matrix model for risk level assessment through two dimensions: likelihood of occurrence and severity of consequences. The value of this tool lies not only in risk grading but also in providing a methodological basis for risk comparison and priority ranking. In modern engineering practice, the risk matrix has evolved into a comprehensive assessment system containing multiple parameters, enabling more precise description of risk characteristics to support risk decision-making.

Decision-making Basis for Acceptable Risk: This is a multi-criteria trade-off process requiring comprehensive consideration of four aspects: Legal standards (mandatory norms and technical standard requirements); Social consensus (reflecting public risk perception and acceptance, requiring effective risk communication); Cost-benefit analysis (providing a basis for judging economic reasonableness, but needing to avoid pure economism); and Technical feasibility (determining the implementation space for risk control measures, requiring a balance between technical advancement and reliability). These factors collectively constitute the constraints and judgment criteria for acceptable risk decision-making.

In the context of mega-projects, acceptable risk decision-making exhibits three important characteristics: First, dynamic decision-making, where acceptable risk standards need timely adjustment as the project progresses and the environment changes; second, value orientation, where the priority order of different value objectives directly influences the direction of risk decisions; and third, iterative process, where risk decisions require continuous optimization based on implementation effects. These characteristics make acceptable risk decision-making a complex adaptive process requiring corresponding institutional safeguards.

3. CASE STUDY: VALUE REALIZATION AND RISK CHALLENGES OF THE HZMB

3.1. Case Background

The conception of the Hong Kong-Zhuhai-Macao Bridge began in the 1980s. After nearly 30 years of planning and preliminary preparation, formal construction commenced in 2009, and it was fully opened to traffic in 2018. As a super-large sea-crossing transportation project connecting the Hong Kong SAR, Zhuhai City, and the Macao SAR, its construction background possesses distinct characteristics of the times and strategic significance.

Geographical Dimension: The 55-kilometer-long bridge adopts a bridge-island-tunnel cluster design, including a 6.7-kilometer undersea immersed tunnel and two artificial islands of 100,000 square meters each. This complex engineering structure was designed to simultaneously satisfy multiple requirements such as navigation clearance, aviation height restrictions, and environmental protection, reflecting the art of balancing engineering design with multiple constraints. Particularly, the tunnel section crossing the main channel of the Lingdingyang needed to ensure the passage of 300,000-ton ships, posing extremely high requirements for tunnel burial depth and alignment design.

Political Dimension: The bridge is a major infrastructure project promoted under the "One Country, Two Systems" framework, involving three administrative regions with different legal systems, technical standards, and governance models. This unique institutional background not only brought coordination difficulties but also spurred institutional innovation. A coordination body composed of representatives from the three governments was established, creating an innovative management model of "coordinated decision-making, separate implementation, and unified operation," providing important experience for cross-regional major project collaboration.

Technical Dimension: The bridge faced a series of world-class engineering challenges. Technologies such as rapid artificial island construction on thick soft marine foundations, design and installation of deep immersed tunnels, and durability assurance for a 120-year design life were technical bottlenecks requiring breakthroughs. The project team, through industry-university-research collaborative innovation, overcame multiple technical difficulties, forming an independent intellectual property rights system and laying a solid foundation for China's transition from a bridge-building country to a bridge-building powerhouse.

3.2. Core Value Analysis of the HZMB

The value realization of the HZMB is manifested in multiple dimensions, which mutually support each other and collectively constitute the foundational basis for the project's existence.

Strategic and Political Value: This is the core value dimension of the bridge, embodied on three levels: At the national strategy level, it is a landmark project for infrastructure connectivity in the Guangdong-Hong Kong-Macao Greater Bay Area, strengthening the physical link for regional coordinated development; at the regional development level, it effectively resolved the traffic bottleneck of the Pearl River Estuary, promoting the regional economic integration process; at the institutional innovation level, it explored coordination mechanisms for cross-regional major projects under "One Country, Two Systems," providing important references for similar projects. These strategic values transcend the attributes of mere transportation infrastructure, making the bridge a vital national strategic asset.

Economic Value: This is the most direct manifestation of value, but its connotation is much richer than traditional cost-benefit analysis. Direct economic value includes toll revenue and related operating income, which is relatively easy to quantify. Indirect economic value is reflected in multiple aspects: Firstly, the spatial-temporal convergence effect—the bridge reduced land travel time between Hong Kong, Zhuhai, and Macao from 3 hours to 30 minutes, greatly reducing regional logistics and personnel costs; secondly, the industrial driving effect—construction and operation drove the development of building materials, equipment manufacturing, tourism, and other industries; finally, the regional synergy effect—promoting economic integration in the Greater Bay Area and optimizing regional industrial layouts. Although difficult to measure precisely, these economic values are profound and lasting.

Technological and Innovation Value: This represents the important wealth contributed by the bridge to the industry's development. In terms of technological innovation, the project achieved multiple breakthrough results: independently developed design and construction technology for offshore immersed tunnels, realizing the precision installation of the world's longest highway immersed tunnel; innovative rapid artificial island construction technology, creating the engineering miracle of "island completion in the year of commencement"; and breakthroughs in the 120-year durability technology system, providing important references for long-life design of major projects. Regarding knowledge accumulation, the project formed a complete knowledge system including 55 technical standards and over 600 patents. These achievements not only supported the bridge's construction but also made significant contributions to industry-wide technological progress. More importantly, the project cultivated a large number of professional technical talents, reserving important strength for China's transportation infrastructure construction.

3.3. Analysis of Typical Risks Faced by the HZMB

The risk spectrum faced by the HZMB during construction and operation was extremely complex, with risks interconnected and dynamically changing, posing major challenges to project management.

Technical Risks: The most direct challenge, whose complexity is mainly reflected in three aspects: Deep-sea immersed tunnel technology was the largest source of technical risk. Installing 33 giant immersed tubes under complex hydrogeological conditions at depths of over 40 meters required overcoming significant uncertainties. The 120-year design life requirement posed extremely high standards for material durability and structural reliability, necessitating responses to material degradation and performance deterioration in the marine environment. Large-scale artificial islands on deep soft foundations required rapid construction and long-term settlement control, lacking referenceable engineering experience. These technical risks involved not only individual technical links but, more importantly, the complexity of system integration and interface coordination.

Ecological Risks: A special challenge characterized by: The project traversing the Pearl River Estuary Chinese White Dolphin National Nature Reserve, where construction activities could potentially impact the habitat and behavior patterns of this endangered species; the long-term and uncertain impact of large-scale marine engineering on hydrodynamic environments and ecosystems; and the distribution of important marine fishery resources and ecologically sensitive areas around the project, requiring full consideration of ecological protection requirements in engineering activities. These ecological risks involved not only technical levels but also the project's legitimacy and social acceptance, requiring particularly prudent handling.

Economic and Operational Risks: Characterized by long-term nature and uncertainty. At the investment level, the over 100-billion-yuan project investment brought huge financial pressure, and investment control faced significant challenges. At the operational level, traffic flow forecasts were uncertain, affected by multiple factors such as license plate policies, customs clearance convenience, and regional economic development. Regarding financial sustainability, it was necessary to balance operating income with maintenance costs to ensure the project's long-term financial health. These risk factors interacted with each other, requiring the establishment of dynamic risk monitoring and response mechanisms.

Cross-regional Coordination Risks: Unique management challenges stemming from differences in legal systems, technical standards, and management models among the three regions under "One Country, Two Systems." Specific manifestations included: Differences in engineering construction standards and technical specifications among the three regions, requiring the establishment of a unified technical standard system; different project management procedures and approval processes, necessitating innovative coordination mechanisms; and the need for collaborative working mechanisms for traffic management and emergency response during the operation period. These coordination risks not only affected engineering efficiency but also directly related to the overall effectiveness of the project.

4. RISK CONTROL AND "ACCEPTABLE RISK" DECISION-MAKING PRACTICES OF THE HZMB

4.1. Whole-process, Systematic Risk Control System

The HZMB project established a risk control system covering the entire lifecycle. Guided by engineering value realization and centered on risk process management, this system embodies advanced concepts and methods of modern engineering risk management.

Technical Risk Control: The project innovatively proposed a risk management model of "research-led, experimental verification, and dynamic optimization." Addressing the core technical risk of the deep-sea immersed tunnel, the project assembled an expert team including academicians and design masters, conducting years of technical research and experimental studies. Through large-scale physical model tests, numerical simulation analysis, and prototype observation, the mechanical characteristics and deformation laws of the immersed tunnel under complex marine environments were systematically mastered. Particularly noteworthy is the innovative "semi-rigid" immersed tube structural system, which successfully solved the adaptability problems of traditional rigid and flexible structures under deep-sea buried conditions. During implementation, dedicated equipment and monitoring systems for immersed tube floatation and installation were developed, achieving millimeter-level precision docking of 33 immersed tubes, setting a new world record for subsea tunnel construction.

Ecological Risk Control: This reflected the project's profound practice of the sustainable development concept. The project constructed a "three-pronged" ecological protection system of "Avoidance-Mitigation-Compensation." In the planning and site selection phase, route optimization maximized avoidance of the core habitat and breeding areas of the Chinese white dolphin. During construction, special funds were invested to develop low-noise construction equipment and processes, establish a marine mammal observer system, and implement seasonal protection measures. During the operation period, a special protection fund was established for continuous marine ecological monitoring and conservation research. Commendably, the project invested over 1.7 billion yuan in ecological protection, implementing more than 300 environmental measures, achieving coordinated development between engineering construction and ecological protection. Monitoring data showed that the number of Chinese white dolphins in the reserve remained stable during construction, a result fully recognized by domestic and international environmental organizations.

Management Risk Control: The project innovatively established a "Three-tier Coordination, Two-tier Management" governance structure. At the decision-making level, a project coordination leadership group composed of government representatives from the three regions was responsible for decision-making and coordination of major issues. At the execution level, a project legal entity was established to implement professional management. At the operational level, participating units implemented project management according to unified standards. To address the differences in standards among the three regions, the project innovatively adopted the principle of "aligning with the higher standard," compiling and promulgating the Hong Kong-Zhuhai-Macao Bridge Technical Specifications. This specification system integrated the highest requirements of the three regions' standards, providing a unified technical basis for project construction. In terms of schedule and cost control, modern information technology was used to establish a whole-process dynamic monitoring system, ensuring the project remained controlled. This innovative management model provided important experience for cross-regional major project management.

4.2. Decision Analysis of "Acceptable Risk"

The practice of the HZMB in "acceptable risk" decision-making provides an enlightening case for major project risk governance.

Case of Ecological Risk Decision-making: The project successfully applied the ALARP principle, achieving the optimal balance between engineering construction and ecological protection. The decision-making process first clarified that "zero impact" was an unrealistic goal, then set the risk control target at the "reasonably practicable minimum" level. Through cost-benefit analysis, it was confirmed that investing 1.7 billion yuan in environmental protection was reasonable and feasible. Although this accounted for 1.5% of the total project investment, compared to the project's total investment of hundreds of billions and its enormous strategic value, this investment was reasonable and necessary. In terms of measure selection, all feasible means were adopted, including acoustic deterrence during construction, seasonal protection, and a full-time observer system, minimizing ecological impact. Ultimately, this decision ensured the smooth implementation of the project while effectively protecting the ecological environment, achieving a win-win situation for multiple parties. This case demonstrates that acceptable risk decision-making is not a simple technical judgment but a rational choice based on value trade-offs.

Case of Technical Risk Decision-making: The project demonstrated the wisdom of proactively managing risks in pursuit of higher value. The selection process for the immersed tunnel scheme fully embodied this. Decision-makers faced two choices: one was a shallow-buried scheme with relatively mature technology and lower risk, but it would restrict waterway development; the other was a deep-buried scheme with high technical difficulty but capable of ensuring smooth navigation. Through systematic analysis, decision-makers recognized that although the deep-buried scheme had high technical risk, its strategic value—ensuring the unobstructed main channel of Guangzhou Port and promoting regional economic development—far outweighed the risk costs. Therefore, the project team reduced the failure probability of the immersed tube joints to an extremely low level of 10^{-6}/year through technological innovation. At this point, decision-makers judged that this residual risk level was acceptable relative to the enormous value brought by the scheme. This decision not only reflected technical rationality but also demonstrated the guiding role of value rationality.

These two cases reveal several important characteristics of acceptable risk decision-making: First, risk acceptability is not an absolute standard but a trade-off result relative to engineering value. Second, risk decision-making is a dynamic process requiring continuous adjustment as understanding deepens and technology advances. Finally, risk decision-making needs to establish a multi-party participation mechanism to ensure the scientific nature and legitimacy of decisions. These understandings hold important implications for improving the risk governance system for major projects.

4.3. Analysis of Typical Risks Faced by the HZMB

The successful practice of the HZMB in risk management has accumulated valuable experience for major project management.

Experience: A value-oriented decision-making mechanism was the fundamental guarantee for the project's success. The project always took the realization of national strategic value as the core objective; this clear value orientation provided the basic adherence for risk decision-making. When facing major risk decisions, the project was able to transcend simple technical-economic comparisons and conduct value judgments from a broader strategic perspective—a decision-making mindset worth emulating. Forward-looking investment was an important foundation for risk control. The project invested substantial resources in preliminary research and experimental verification. Although this increased upfront costs, it laid a solid foundation for subsequent risk control. Particularly in technological innovation, the project broke through multiple technical bottlenecks through independent R&D; this spirit of innovation was a crucial support for the project's success.

Reflection: There are aspects worthy of reflection. Regarding operational risk estimation, the project's forecast for traffic flow in the initial stage of opening was overly optimistic, and actual traffic flow was lower than expected. This was partly due to external factors such as license plate policies and customs clearance convenience, but it also reflects that the project could have been more cautious in estimating operational risks. Regarding dynamic risk management, the project established a sound risk control system during the construction period, but the risk monitoring and response mechanism during the operation period needs strengthening. Particularly, the emergency response capability for unexpected events requires a more robust mechanism. Regarding public communication, while the project focused on communication with professional institutions and communities during construction, there is room for improvement in broader social communication. The social acceptance of major projects directly affects their sustainability, necessitating a more open and transparent communication mechanism.

These experiences and reflections offer important insights for future major project management. First, establish a value-oriented risk decision-making mechanism to ensure risk control serves the realization of the project's core value. Second, emphasize whole-lifecycle risk management, particularly risk monitoring and response during the operation period. Third, strengthen stakeholder participation and establish a more open and transparent decision-making mechanism. Finally, focus on knowledge management and experience inheritance, transforming project practices into common wealth for the industry.

5. CONCLUSION

The construction practice of the Hong Kong-Zhuhai-Macao Bridge provides rich insights for understanding value realization and risk control in major projects. Research shows that the success of major projects depends not only on technological innovation and resource investment but also on the organic unity of value rationality and instrumental rationality. At the value level, a multi-value coordination mechanism should be established to achieve balanced development of economic, social, environmental, and other diverse values. At the risk level, the concept of "acceptable risk" should be embraced, utilizing systematic measures to control risks at a reasonable level. At the governance level, project management models should be innovated to establish governance structures adapted to the characteristics of complex projects.

In the future, as engineering construction expands into deeper, farther, and more complex domains, the value-risk balance challenges facing projects will become more severe. Particularly under new backgrounds such as climate change and digital transformation, major projects need to innovate development concepts and management models. On one hand, greater emphasis should be placed on resilience construction to enhance the ability of engineering systems to cope with uncertainty; on the other hand, the application of digital technologies should be actively promoted to improve risk control levels through means such as digital twins. More importantly, a people-centered value orientation should be adhered to, ensuring that the fruits of engineering development benefit broader social groups.

The practice of the HZMB demonstrates that major project management is essentially an art of balance, requiring the search for an optimal solution under multiple constraints. This balance is reflected not only at the technical-economic level but also at the level of value rationality. Only by adhering to the correct value orientation, applying scientific management methods, and establishing sound governance mechanisms can we achieve the unity of maximizing engineering value and controllable risks, thereby promoting the high-quality development of engineering construction.
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REFERENCES

[1] Van I. Poel, D. (2025). Acceptable risk under moral uncertainty. Journal of Risk Research, 28(11), 1320–1337. https://doi.org/10.1080/13669877.2025.2584028

[2] Alqahtani, A. D., Ahmed, M., Mallick, J., et al. (2026). Integrated risk priority assessment of engineering and non-engineering factors influencing Saudi Arabian construction projects. Buildings, 16(8), 1518. https://doi.org/10.3390/buildings16081518

[3] Liu, W., Luo, X., Feng, Z., et al. (2026). Research on risk propagation mechanism and control strategy of prefabricated building supply chain: based on complex network model and dynamic simulation analysis. Engineering, Construction and Architectural Management, 33(7), 5901–5933. https://doi.org/10.1108/ecam-10-2024-1480