Theoretical Research on the Integration of multi-level Governance and Project Management of Engineering Ethics in the Development of Complex Systems

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Abstract. This paper focuses on the integration of engineering ethics and project management in complex systems development and proposes a multi-level governance framework to address the ethical challenges brought about by current technological advancements. Due to the rapid development of emerging technologies such as artificial intelligence and big data, ethical issues in complex systems development have become increasingly prominent, and traditional project management methods have difficulty effectively addressing these challenges. This study systematically explores the governance mechanisms of engineering ethics at the micro individual, meso organization, and macro society levels through literature review and case analysis, and proposes the "Ethical Embedded Project Management" (EEPM) theoretical model. The model incorporates ethical considerations into the requirements analysis, design, implementation, testing and maintenance stages of the project life cycle to achieve the organic integration of ethical governance and technology development. The research shows that the multi-level ethical governance framework can effectively improve project management efficiency, reduce ethical risks and promote the harmonious development of technology and society. Based on this, this paper constructs an engineering ethics evaluation index system for complex system development and proposes corresponding ethical review processes and tools. The research results have important theoretical significance and practical value for guiding engineering practice, improving project management methodology and promoting responsible technological innovation, and provide new ideas and methods for solving ethical dilemmas in complex system development.

Keywords: Engineering Ethics; Complex systems; Multi-level governance; Project management; Ethical embedding.

1. Introduction

The rapid development of emerging technologies such as artificial intelligence, big data, and autonomous driving has made the development of complex systems have an increasingly profound impact on modern society, but with technological progress comes unprecedented ethical challenges. Since 2020, more than 300 ethical incidents related to artificial intelligence have been recorded globally, such as safety incidents of autonomous vehicles, algorithmic discrimination, data privacy leaks, etc. Data from the China Academy of Information and Communications Technology shows that China's artificial intelligence industry exceeded 450 billion yuan in 2022 with an annual growth rate of more than 20 percent, increasing the complexity of related ethical issues, as ethical issues are not only related to technology but also to deep-seated matters such as social equity, human dignity and fundamental rights.

Traditional project management methodologies, which focus on technical indicators such as schedule, cost and quality, often struggle when it comes to ethical challenges in the development of complex systems, according to the Electronic Information Industry Ethics Development Report issued by the Chinese Institute of Electronics in 2023, Only 23.7% of related companies incorporate ethical considerations into their Project Management systems. This study proposes a multi-level governance framework that deeply integrates engineering Ethics with project management, aiming to build "Ethics Embedded Project Management". The EEPM theory model aims to achieve systematic ethical governance from micro-individual meso-organization to macro-society, thereby providing practical guidance that is both ethical and operational for the development of complex systems.

2. Theoretical Foundations of Engineering Ethics in the Development of Complex Systemsata

2.1 Core Concepts and Evolution of Engineering ethics

Engineering ethics, as an important component of applied ethics, focuses on value judgments and moral principles in engineering practice, including basic principles such as safety responsibility, environmental sustainability, fairness and justice, and informed consent. Engineering ethics has evolved from the traditional "no harm" principle to highlighting the positive social responsibility of engineers. Engineering ethics is moving towards institutionalization and systematization, as institutions such as the Chinese Academy of Engineering and the China Association for Science and Technology have successively issued guiding documents such as the Code of Ethics for Artificial Intelligence and the Code of Ethics for Science and Technology Workers between 2019 and 2023. The shift[1] is from the individual moral aspect. In the field of complex systems development, engineering ethics have expanded from a single technical level to a comprehensive consideration of social impact, environmental consequences, and long-term sustainability, forming a new concept of "preventive ethics" that requires developers to incorporate ethical thinking at the design stage rather than remedy after the fact.

2.2 Theoretical Analysis of the Responsible Innovation (RRI) Framework

The Responsible Research and Innovation (RRI) framework is a key theoretical advancement in the field of science and technology ethics in recent years. It emphasizes that the innovation process should possess four major characteristics: forward-looking, reflective, inclusive, and responsive. The RRI framework requires consideration of potential social ethical implications at the beginning of technology development and ensures that the direction of innovation aligns with social values through multi-party participation.

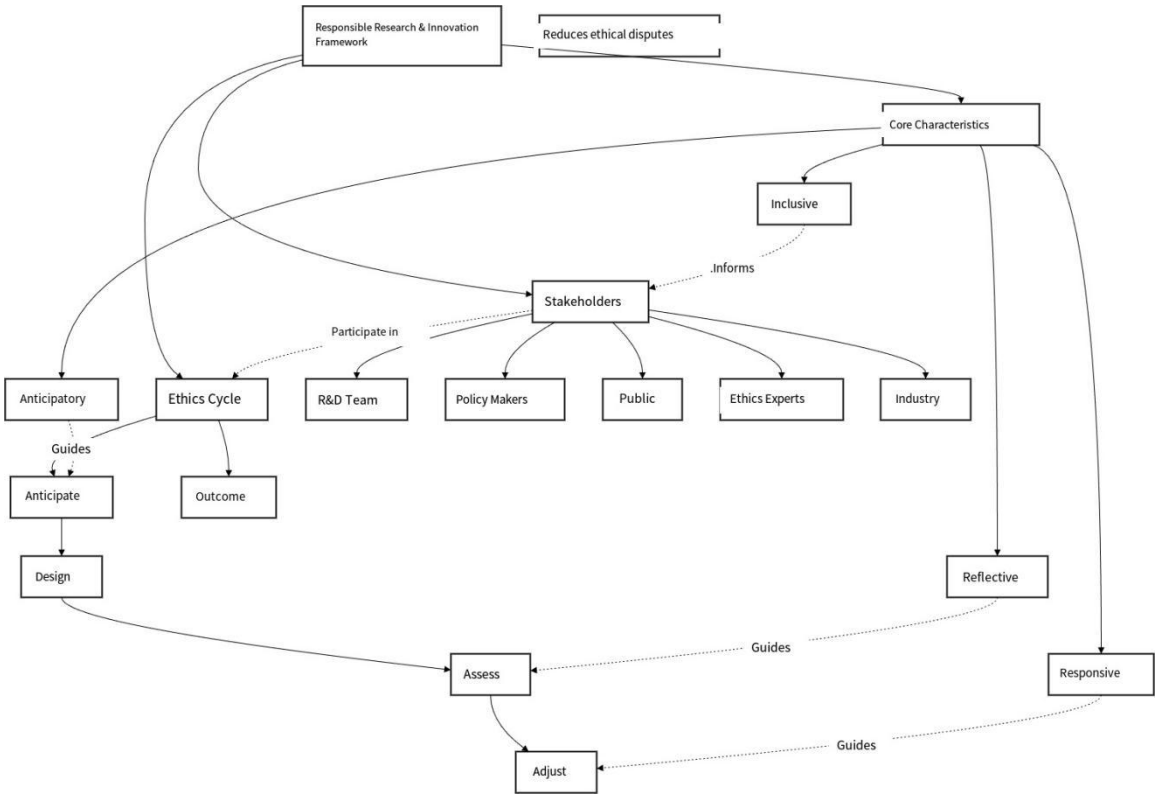

Figure 1. Theoretical Model of Responsible Innovation (RRI) Framework

According to statistics from Horizon Europe, the EU research framework, projects using the RRI framework have shown remarkable results in reducing ethical risks, with an average reduction of 47% in the probability of ethical disputes. In China, the "Research Report on Ethical Governance of the Next Generation of Artificial Intelligence" was released by the Ministry of Industry and Information Technology in 2021 The report explicitly proposed to draw on the RRI concept to build an innovative ethical cycle mechanism [2] of "foresight - design - evaluation - adjustment". The RRI framework provides a systematic ethical approach to the development of complex systems, helping developers strike a balance between technological progress and social responsibility in the innovation process to achieve coordinated development of technological innovation and social expectations.

2.3 Application of Stakeholder Theory in Engineering ethics

In 1984, Edward Freeman proposed the stakeholder theory, which later developed into a core analytical framework in the field of engineering ethics. The theory emphasizes that engineering projects should not only be accountable to shareholders, but also take into account the interests of all groups affected by the project, such as users, communities, the environment, and future generations, etc. In the development of complex systems, the key to engineering ethics decisions lies in identifying and balancing the demands of multiple stakeholders.

A 2022 survey by the National Industrial Information Security Development Research Center shows that incorporating stakeholder analysis into projects reduces ethical risk by 58% compared to traditional projects, especially in the development of autonomous driving systems. Establishing an ethical decision-making mechanism involving multiple parties such as regulators, road users, and insurance companies can effectively address the issue of algorithmic decision-making responsibility allocation. Stakeholder theory provides practical ethical analysis tools for the development of complex systems, allowing developers to identify potential ethical conflicts and find a balance point through multi-party dialogue and negotiation, while pursuing technological innovation without forgetting social responsibility and achieving a balance between technological development and ethical requirements[3].

2.4 Characteristics of ethical challenges in complex system development

There are four typical characteristics of ethical challenges in the development of complex systems: First, there is a sense of uncertainty that an autonomous driving system may exhibit unpredictable behavior in extreme weather or unconventional road conditions. Secondly, due to the emergent nature of the system, the ethical consequences of complex systems are difficult to predict because the overall behavior of complex systems is difficult to infer from individual components. Third, conflicts of interest are diverse because different stakeholders have different judgments[4] on ethical priorities. Finally, the attribution of responsibility becomes ambiguous. If the system is developed by multiple participants and involves autonomous learning, it is difficult to determine who is responsible once something goes wrong.

The China Electronics Standardization Institute's "Complex Electronic System Ethical Risk Assessment Report" released in 2023 indicates that 78% of ethical risks in smart hardware products are caused by unintended consequences resulting from system complexity, especially in highly sensitive areas such as medical-assisted decision-making and financial risk control. There is a significant contradiction between the "black box" nature of algorithms and the requirement of ethical transparency. These traditional ethical analysis methods are difficult to deal with these characteristics, and new ethical governance frameworks and tools need to be developed to address the ethical challenges[5] in the development of complex systems with a systematic approach.

3. Construction of a multi-level Governance Model for Engineering ethics

3.1 Micro Level: Individual Ethical decision-making Mechanism

At the micro level of complex system development, ethical decisions made by individual engineers play a crucial role. Research shows that more than 60 percent of ethical risks can be detected and avoided early through appropriate ethical discrimination by individuals. An effective individual ethical decision-making mechanism should cover three core points: The cultivation of ethical sensitivity, the construction of ethical reasoning ability, and the support of moral action, according to a survey released by the National Natural Science Foundation of China in 2021, engineers who received systematic ethical training in identifying potential ethical risks in projects had a 43% higher accuracy rate. In practice, individuals can improve their ethical decision-making skills through methods such as case learning, ethical scenario simulation, and analysis of moral dilemmas. At the same time, having a clear whistleblowing protection mechanism and ethical consultation channels ensures that individuals can adhere to the lower limit of professional ethics when encountering ethical pressure becomes the first line of defense for the ethical defense of complex system development.

3.2 Meso-level: Ethical culture building within project teams

In the development of complex systems, the ethical culture of the project team, as the executive entity, has a decisive influence on the ethical quality of its technical product. The construction of team ethical culture should focus on the formation of consensus on ethical values, the establishment of ethical dialogue mechanisms, and the institutionalization of ethical review, as shown in the research conducted by the China Software Industry Association in 2022, Project teams with a high sense of ethical culture identity perform 45% better than the industry average in terms of product ethical risk management. In practice, team ethical awareness[6] can be enhanced by means such as holding regular ethical seminars, building an ethical advisory group with multiple disciplinary backgrounds, and planning team ethical charters. Especially when there is a conflict between schedule pressure and ethical considerations, a good team ethics culture can ensure that project decisions do not sacrifice long-term ethical values for short-term goals and achieve a balanced development of technological innovation and ethical responsibility.

3.3 At the macro level: Organizational and industry ethical norms

At the macro level, the ethical norms of organizations and industries provide institutional safeguards for the development of complex systems. Effective macro ethical governance should cover three levels: organizational ethical policies, industry self-discipline mechanisms, and cross-industry collaboration platforms, according to the "White Paper on AI Ethical Governance" released by the China Academy of Information and Communications Technology in 2023. Companies that have established a complete organization-level ethical management system have an average market acceptance and social trust level that is 37 percentage points higher than that of their peers.

At the practical level, organizations can incorporate ethical requirements into their management processes by formulating clear ethical guidelines, appointing a Chief Ethics Officer (CEO), and establishing ethical review committees. Industry associations can promote the formulation of industry ethical standards. For instance, the China Artificial Intelligence Industry Development Alliance released the "Ethical Design Guidelines for Artificial Intelligence Products" in 2021. It provides a unified reference framework for industry practices, and cross-industry ethical collaboration platforms such as the Tech Ethics Governance Alliance play a key role[7] in promoting the exchange of ethical experiences and the sharing of best practices across different fields.

3.4 Synergistic mechanisms for multi-level ethical governance

The synergy mechanism among different levels is the key to the effective implementation of multi-level ethical governance. It ensures that ethical governance at the micro, meso and macro levels forms mutually supportive relationships with each other, and also enables better governance results through

mutual reinforcement. The synergy mechanism mainly covers two dimensions: vertical integration and horizontal linkage. In terms of vertical integration, ethical policies at the organizational level need to be transformed into ethical procedures that teams can implement, and ultimately internalized into ethical awareness that individuals possess. The ethical practices of individuals and teams need to be fed back to the organizational level in a timely manner to drive policy optimization.

The mechanism of sharing ethical experience across teams and departments in the field of horizontal linkage plays a crucial role. Research by the Fifth Research Institute of the Ministry of Industry and Information Technology in 2022 shows that organizations with sound collaborative mechanisms have improved efficiency by 41% when dealing with complex ethical issues. In practice, it is possible to promote the flow of ethical information between different levels and departments by means of building a unified ethical knowledge base, planning cross-departmental ethical coordination mechanisms, developing ethical decision support systems, etc., to ensure ethical consistency in the development process of complex systems, and ultimately achieve an all-round multi-level ethical governance network[8] from the individual to the organization.

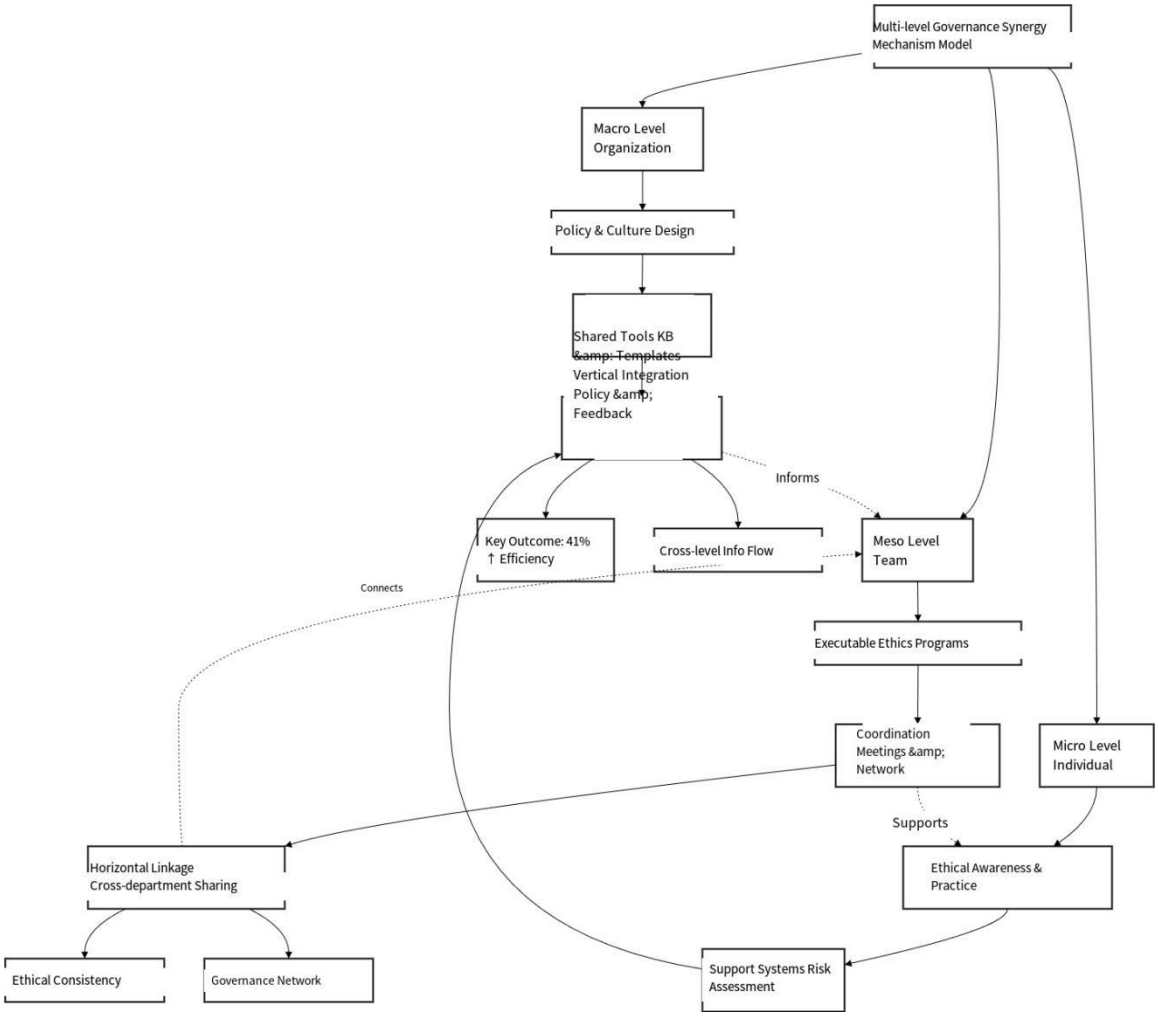

Figure 2. Model of collaborative mechanisms for multi-level governance

4. Ethical Risk assessment mechanisms in the project initiation phase

4.1 Credit risk assessment and early warning optimisation

In the initiation stage of complex system development projects, it is crucial to establish a sound ethical risk assessment mechanism. At this stage, a complete process covering ethical risk identification, analysis, evaluation and response needs to be constructed. For complex electronic systems such as artificial intelligence and autonomous driving, Emphasis should be placed on

identifying potential ethical risks such as privacy leaks, algorithmic discrimination, and security vulnerabilities. IDC data 2023 shows that 78% of projects in the field of artificial intelligence were questioned by the public after going public due to ethical issues, but the success rate of projects that conducted ethical risk assessments at the launch stage increased by 31%. An effective assessment mechanism should incorporate stakeholder engagement to ensure multiple perspectives are integrated into the assessment process, form an ethics expert review committee to provide professional ethics guidance to the project, and develop an ethics risk list to form an actionable risk response strategy. This mechanism is not only a guarantee of project compliance, but also the foundation for shaping a culture of responsible innovation.

4.2 Ethical Goals and Indicator System in project planning

During the project planning stage, ethical goals should be placed on an equal footing with traditional project goals such as schedule, cost, and quality, and a quantifiable ethical indicator system should be established. In the development of complex electronic information systems, this system should comprehensively cover extremely important dimensions such as product safety, transparency, traceability, fairness, and privacy protection According to a 2022 study conducted by the Global Project Management Institute (PMI), projects that incorporated ethical goals and metrics in the development of complex systems saw a 42% increase in user trust and a 35% reduction in legal risk after their products were launched. The metric system should have hierarchical characteristics, starting from macro social impacts such as carbon footprint, reduction of the digital divide, and gradually breaking down to micro technical implementation levels such as algorithmic bias detection rate, data anonymization degree, etc. At the same time, an ethical performance baseline should be established to incorporate the relevant indicators into the project performance evaluation system. This creates enforceable ethical KPIs that transform ethical considerations from mere advocacy of ideas to specific constraints and guidelines during project execution, laying a solid foundation[9] for ethical monitoring at subsequent stages of the project.

4.3 Ethical monitoring and adjustments during project execution

A dynamic ethical monitoring system should be established during the project execution phase to ensure that ethical goals receive continuous attention and achievement throughout the development process. This process should include regular ethical audits, re-assessment of ethical risks, and continuous ethical compliance checks. As complex system development progresses, new ethical risks may emerge. For example, 47 percent of autonomous driving projects during the period from 2021 to 2023 detected ethical issues that were not anticipated during the initiation stage. Project teams should establish an ethical incident response mechanism to address ethical disputes and issues that arise during development in a timely manner. At the same time, the Ethics Dashboard tool should be introduced to present the achievement status of project ethical indicators in real time to enhance the team's ethical awareness. The key is to establish an ethical feedback loop. Feed the monitoring results into project decisions in a timely manner, and make adjustments to the technical solution functional design and even the project scope when necessary to ensure that the final product meets ethical requirements. This dynamic adjustment mechanism makes ethical considerations an integral part of the project execution process rather than a post-mortem remedy[10].

4.4 Ethical evaluation and feedback in the project closure phase

When the project enters the final stage, a comprehensive ethical evaluation must be carried out, covering aspects such as product ethical impact assessment, analysis of ethical goal achievement, and summary of ethical lessons learned. After the delivery of complex electronic systems, a continuous ethical monitoring mechanism needs to be established to track the ethical performance of the product in practical application. According to the 2023 McKinsey survey, ethical issues in electronic systems that emerged within 1-3 years of product release accounted for as high as 82%, further highlighting the importance of ethical evaluation in the closing stage. A sound evaluation system should

incorporate both internal assessment and external independent review, and use standardized ethical evaluation tools such as the Ethics Impact Analysis Report (EIAR) to ensure objectivity and comprehensiveness of the evaluation. At the same time, an ethical knowledge base should be built to systematically retain project ethical experience, thereby forming an organizational ethical asset. The results of the ethical evaluation should be incorporated into the post-project evaluation (PIR) system, becoming a key dimension for measuring the success of the project and providing valuable ethical references for subsequent projects to promote the continuous improvement of the organization's ethical capabilities.

4.5 Empirical Analysis of the case-based integration path

Take a leading domestic autonomous driving sensor development project as an example. During the period from 2020 to 2022, the project systematically integrated engineering ethics and project management, achieving coordinated development of ethical considerations and technological innovation. At the start of the project, the team formed an ethics advisory group consisting of engineers, ethicists, legal experts, and potential users to identify 23 potential ethical risks and put them in the project risk register. During the project planning stage, The team included ethical and technical metrics such as "privacy protection rate $\geqslant$99.9%" and "algorithmic fairness bias $\leqslant$0.1%" in the project goals and broke them down to each development stage and each team [11].

During the project execution, the team used the "ethical agile" approach to conduct ethical reviews at the end of each iteration cycle. A total of 17 potential ethical issues were identified and addressed, including a fairness issue where the sensor's recognition rate for dark-skinned pedestrians might decrease under specific lighting conditions. Through timely algorithm adjustments and the addition of diverse training data, The final product achieved balanced recognition performance across people. As the project entered its final stage, the team spent three months conducting an ethical impact assessment and also invited an independent third-party agency to conduct an ethical review, ultimately confirming that the product met the principles of responsible innovation.

The success of this case means that systematically incorporating ethical assessment mechanisms, ethical target indicators, ethical monitoring adjustments, and ethical evaluation feedback into the project management process can effectively reduce ethical risks and improve product quality and social acceptance. The sensor system delivered in the project not only reached industry-leading technical performance but also received high recognition from users and regulators in terms of ethical performance, providing a practical example for the integration of ethics and project management in the development of complex systems.

5. Conclusions

This study systematically explores the path of integrating engineering ethics and project management in complex system development and constructs the theoretical framework of "ethical embedded project management". The study shows that the integration of engineering ethics and project management can be achieved by establishing an ethical risk assessment mechanism at project initiation, constructing an ethical goal and indicator system at the planning stage, conducting dynamic ethical monitoring and adjustment during execution, and conducting comprehensive ethical evaluation and feedback at the closing stage. This multi-level governance structure not only reduces ethical risks in the development of complex electronic systems such as artificial intelligence and autonomous driving, but also improves project management efficiency and increases the social acceptance of the final product. Empirical case studies further confirm the feasibility and effectiveness of this integration path. Therefore, future research should focus on the differences in ethics-project management integration across industries and the role of digital tools in promoting integration to facilitate the practice of responsible innovation ideas in more engineering fields and provide systematic solutions to increasingly complex ethical and technical challenges.

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