

Engineering Risk Prevention and Control Strategies from the Perspective of Technical Management in the Field of Electromechanical Engineering

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Abstract: This study explores engineering risk prevention and control in electromechanical engineering from the technical management perspective. It elaborates on technical management's role, core concepts, critical risks, and various strategies like fail-safe design, predictive maintenance, ISO-compliant workflows. It also emphasizes future research areas such as AI - driven predictive risk modeling and cross-disciplinary management frameworks.

Keywords: Electromechanical engineering; Technical management; Engineering risk prevention

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1. Introduction

In the realm of electromechanical engineering, the prevention and control of engineering risks are of utmost importance. As projects in this field grow more complex and sophisticated, the potential risks multiply significantly. Technical management serves as a linchpin in effectively identifying, analyzing, and mitigating these risks. The 'New Energy Vehicle Industry Development Plan (2021–2035)' promulgated in 2020 emphasizes the importance of technological innovation and quality improvement in the electromechanical-related new energy vehicle industry, which further highlights the significance of technical management in risk control. By implementing strategies like formulating technical standards, conducting technical reviews, and controlling quality, technical management can enhance project reliability^[1]. Exploring risk prevention and control from the perspective of technical management not only benefits project implementation but also promotes the sustainable development of the electromechanical engineering industry.

1.1. Core concepts and principles

Technical management in electromechanical engineering encompasses several core concepts and principles.

Standardization is fundamental. In this field, it involves adhering to a set of well-defined industry standards and specifications ^[2]. These standards ensure that all electromechanical components and systems are designed, manufactured, and installed in a consistent manner. For example, standard electrical wiring colors and gauge specifications help in easy identification and maintenance, reducing the risk of errors during installation or repair.

Quality control is another crucial aspect. It aims to ensure that electromechanical products and systems meet or exceed predefined quality levels. This includes quality control during the design phase, where engineers verify that the design can withstand expected loads and environmental conditions. During manufacturing, inspections at various production stages, from raw material intake to the final product assembly, are carried out to detect and correct any quality issues promptly.

Resource allocation also plays a significant role. Adequate allocation of human, material, and financial resources is essential for the successful execution of electromechanical projects. Skilled engineers and technicians are needed to design, install, and maintain systems. Materials of appropriate quality and quantity must be sourced in a timely manner. And sufficient financial resources are required to cover all aspects, from research and development to production and after-sales service. All these core concepts and principles are inter-related and are vital for minimizing engineering risks in the electromechanical engineering field.

1.2. Role in engineering risk frameworks

Technical management plays a crucial and multi-faceted role in engineering risk frameworks within the realm of electromechanical engineering. It serves as the linchpin that integrates various aspects of risk governance. In electromechanical projects, technical management defines the parameters within which risks are identified, analyzed, and mitigated. For instance, it sets the technical standards and specifications that help in determining potential deviations, which are often sources of risk. By ensuring that all components and systems adhere to these standards, technical management reduces the likelihood of technical failures, a significant risk in electromechanical engineering.

In the context of decision-making hierarchies, technical management provides the expertise necessary for informed risk-related decisions. Technical managers, with their in-depth understanding of electromechanical systems, can assess the implications of different risk mitigation strategies on project outcomes. They can weigh the cost-effectiveness, feasibility, and long-term impacts of various options, guiding project teams towards the most appropriate decisions.

Regarding compliance mechanisms, technical management is responsible for ensuring that electromechanical projects comply with relevant industry regulations and standards. Non-compliance can lead to serious risks, such as legal issues, safety hazards, and reputational damage. By staying updated with regulatory changes and implementing necessary adjustments in project execution, technical management safeguards the project from these compliance-related risks ^[3]. Overall, technical management is fundamental to the effective functioning of engineering risk frameworks in electromechanical engineering.

2. Risk identification and assessment methodologies

2.1. Critical risks in electromechanical systems

In electromechanical systems, critical risks span multiple aspects. Technical failures are among the prominent ones. Mechanical wear, for instance, occurs due to continuous operation and friction between components.

Over time, parts like gears may experience tooth wear, which can gradually deteriorate the performance of the mechanical subsystem, potentially leading to component failure and system breakdown^[4]. Electrical faults are also common. Short-circuits can happen because of insulation damage, which may be caused by factors such as aging of electrical wires, high-voltage surges, or improper installation. These faults can disrupt power supply, damage electrical components, and even pose safety hazards like electric shock or fire.

Supply chain disruptions present another critical risk. Delays in the delivery of key components, such as motors or sensors, can halt production schedules. Natural disasters, geopolitical issues, or supplier-specific problems like financial distress can all contribute to these disruptions. A lack of alternative suppliers or insufficient inventory can exacerbate the impact on the electromechanical system's production and operation. Human factor risks are equally important. Inadequate training of operators may lead to improper use of electromechanical equipment, increasing the likelihood of accidents and system malfunctions. Designers' errors in the initial system design, such as miscalculating load-bearing capacities or overlooking electrical compatibility, can also cause long-term problems in the system's performance and safety.

2.2. Quantitative and qualitative evaluation tools

In the field of electromechanical engineering, for risk identification and assessment, both quantitative and qualitative evaluation tools play crucial roles. FMEA (Failure Mode and Effects Analysis) is a qualitative tool that systematically examines potential failure modes within electromechanical systems. It helps in identifying possible failures, their causes, and the potential effects, thus allowing engineers to prioritize risks based on severity, occurrence probability, and detectability^[5].

Fault tree analysis, on the other hand, can be both qualitative and quantitative. Qualitatively, it uses logic gates to represent the relationships between system failures and their underlying causes, providing a visual and systematic way to understand the fault propagation paths. Quantitatively, if failure probabilities of basic events are known, it can calculate the probability of top-level failures in complex electromechanical installations. Probabilistic risk assessment models are mainly quantitative tools. These models use probability theory and statistical methods to estimate the likelihood and consequences of various risks in electromechanical systems. By inputting data such as component failure rates, operating conditions, and human error probabilities, they can provide numerical values representing the overall risk level. These models are especially useful in complex electromechanical installations where multiple interacting factors contribute to risks, enabling decision-makers to make informed choices regarding risk prevention and control strategies.

3. Technical management strategies for risk prevention

3.1. System design optimization

3.1.1. Redundancy mechanisms and robust engineering

In the field of electromechanical engineering, designing fail-safe components and modular architectures is crucial for mitigating single-point failures in integrated electromechanical systems. Redundancy mechanisms play a vital role in this regard. By incorporating redundant components, such as backup power supplies, sensors, or actuators, the system can continue to operate even if a primary component fails^[6]. For example, in an electromechanical control system, having a redundant sensor can ensure that accurate data is still available if the main sensor malfunctions. This helps to prevent catastrophic failures and maintain the overall functionality of the system.

Robust engineering, on the other hand, focuses on designing systems that can withstand various operating

conditions and uncertainties. It involves considering factors like environmental variations, component wear-and-tear, and manufacturing tolerances. In electromechanical engineering, robust design ensures that the system performs reliably under different temperatures, humidity levels, and mechanical stresses. Modular architectures are an important aspect of robust engineering. They allow for easy replacement and maintenance of components. If a particular module fails, it can be quickly swapped out without affecting the entire system, reducing downtime and repair costs. Overall, through redundancy mechanisms and robust engineering in system design optimization, the risks associated with single-point failures in electromechanical systems can be effectively mitigated.

3.1.2. Predictive maintenance integration

Predictive maintenance integration involves implementing IoT-enabled condition monitoring and machine learning algorithms for proactive equipment health management in the field of electromechanical engineering. By integrating IoT into electromechanical systems, sensors can be deployed on various equipment components to continuously collect real-time data such as vibration, temperature, and pressure ^[7]. This data serves as a crucial indicator of the equipment's operating status.

Machine learning algorithms then come into play. They are capable of analyzing the large amounts of data collected by IoT sensors. These algorithms can identify patterns and trends that may indicate potential equipment failures long before they actually occur. For example, through historical data analysis, the algorithm can learn the normal operating patterns of a motor. When the real-time data shows deviations from these normal patterns, it can predict a possible breakdown in the near future.

This proactive approach to equipment health management has several benefits. It significantly reduces unplanned downtime, as maintenance can be scheduled in advance based on the predictions. This not only saves costs associated with sudden breakdowns, such as emergency repair expenses and lost production time, but also extends the lifespan of the equipment. By addressing potential issues promptly, the wear and tear on components can be minimized, ultimately enhancing the overall reliability and safety of electromechanical systems.

3.2. Process standardization and documentation

3.2.1. ISO-compliant workflow development

In the field of electromechanical engineering, developing ISO-compliant workflows is crucial for process standardization and documentation to prevent engineering risks. ISO standards provide a globally recognized framework that ensures consistency, quality, and safety in various processes.

For the installation phase, the ISO-compliant workflow clearly defines the step-by-step procedures. It starts with a detailed pre-installation inspection of equipment and site conditions, followed by proper handling and positioning of components. Each connection and fastening is precisely specified, ensuring that the installation meets the required mechanical and electrical specifications. This not only reduces the risk of improper installation, which could lead to equipment malfunction or safety hazards, but also makes it easier to troubleshoot in case of issues ^[8].

During the commissioning phase, the ISO-compliant workflow sets up a systematic testing regime. It includes power-on checks, functional tests, and performance verification. By following these standardized procedures, engineers can accurately identify and rectify any potential problems before the equipment is put into full-scale operation. This helps prevent risks such as sudden breakdowns during operation and ensures that the equipment functions as intended.

In the maintenance phase, the ISO-compliant workflow details preventive maintenance schedules, diagnostic procedures, and repair processes. Regular maintenance tasks are clearly defined, which can extend the equipment's lifespan and reduce the likelihood of unplanned downtime. The documentation requirements within this workflow also ensure that all maintenance activities are recorded, providing a historical record for future reference and analysis. Overall, ISO-compliant workflow development is an essential part of technical management strategies for effective risk prevention in electromechanical engineering.

3.2.2. Technical specification management

Technical specification management involves developing dynamic documentation systems to track component compatibility and performance thresholds across system lifecycles in the field of electromechanical engineering. These systems are crucial as they can effectively monitor the compatibility between various components. In electromechanical systems, different components need to work in harmony. For example, a motor's power output must be compatible with the load requirements of the mechanical components it drives. The dynamic documentation system can record and update information about these components continuously, ensuring that any changes in design, manufacturing, or operation are promptly reflected ^[9].

Moreover, tracking performance thresholds is another key aspect. Each component in an electromechanical system has its own performance limits, such as maximum temperature, voltage, or rotation speed. By accurately documenting these thresholds, engineers can anticipate potential risks. If the monitored performance parameters approach these thresholds, it serves as an early warning sign. This allows for timely preventive measures, like adjusting the operating conditions, performing maintenance, or replacing components, to avoid system failures. Overall, the establishment of such dynamic documentation systems for technical specification management is an essential strategy for preventing engineering risks in electromechanical engineering from a technical management perspective.

4. Technical control strategies for risk mitigation

4.1. Real-Time monitoring systems

4.1.1. Sensor network configuration

In the context of real-time monitoring systems for engineering risk prevention and control in the field of electromechanical engineering, sensor network configuration plays a crucial role. For critical machinery, multi-sensor arrays are designed to comprehensively monitor various aspects ^[10].

Vibration analysis sensors are an essential part of the sensor network. Vibration can indicate potential mechanical failures, such as misalignment, imbalance, or bearing wear in machinery. By precisely configuring vibration sensors at key positions of the machinery, like near the bearings and on the rotating shafts, the amplitude, frequency, and phase of the vibration can be accurately detected. This data provides early warning signs of impending problems, enabling timely maintenance and preventing catastrophic failures.

Thermal imaging sensors are also integrated into the network. Temperature is a significant indicator of the operational state of machinery. Overheating may result from excessive friction, electrical faults, or improper cooling. Thermal imaging sensors can detect temperature distributions across the machinery surface, identifying hotspots that may not be visible to the naked eye. This helps in diagnosing potential risks related to heat-induced component degradation or fire hazards.

Power consumption monitoring sensors complete the multi-sensor arrays. Power consumption reflects the

efficiency and performance of the machinery. Abnormal power consumption patterns can suggest issues such as motor inefficiencies, electrical short-circuits, or unbalanced loads. By accurately measuring power consumption in real-time, engineers can identify and address these problems promptly, optimizing the energy usage and overall operation of the machinery. This well-configured sensor network for critical machinery is thus fundamental to effective risk mitigation in electromechanical engineering.

4.1.2. Data fusion and anomaly detection

In the context of real-time monitoring systems for engineering risk prevention and control in electromechanical engineering, data fusion and anomaly detection play a crucial role. Edge computing and pattern recognition techniques are applied to achieve these objectives. Edge computing enables the processing of data closer to the source, reducing latency and bandwidth consumption. It allows for the quick collection and preliminary analysis of various types of data, such as sensor readings, equipment operation parameters, and environmental data related to electromechanical engineering projects ^[11].

Pattern recognition techniques, on the other hand, are used to identify normal and abnormal patterns within the fused data. By training models with historical data, these techniques can detect emerging technical anomalies at an early stage. For example, they can recognize subtle changes in the vibration patterns of motors or the temperature-related trends of electrical components. These anomalies, if left undetected, could lead to serious malfunctions or even safety hazards.

Data fusion combines multiple data sources to provide a more comprehensive view. In electromechanical engineering, this might involve integrating data from different sensors on a single piece of equipment or aggregating data from various components within a complex system. This integrated data is then analyzed by pattern recognition algorithms to accurately identify potential risks. Through the synergy of data fusion and anomaly detection, real - time monitoring systems can effectively mitigate engineering risks in the electromechanical engineering field, ensuring the smooth operation and safety of projects.

4.2. Adaptive response protocols

4.2.1. Automated safety interlocks

Automated safety interlocks play a crucial role in the technical control strategies for risk mitigation within the realm of electromechanical engineering. These interlocks are designed to safeguard systems by automatically halting operations when certain predefined conditions associated with potential risks are detected. For instance, in the context of developing PLC-controlled emergency shutdown systems triggered by predefined risk thresholds, the automated safety interlocks act as the final line of defense.

When specific parameters, such as abnormal temperature, pressure, or current levels in electromechanical equipment, approach or exceed the set risk thresholds, the interlocks are activated. This immediate response ensures that the system is stopped in a timely manner, preventing further damage, potential accidents, and minimizing the overall impact of the risk. The automated nature of these interlocks eliminates the reliance on human intervention during critical situations, reducing the possibility of human error ^[12]. They are integrated into the overall system architecture in a way that they can quickly sense changes in operating conditions and respond accordingly. By doing so, they enhance the reliability and safety of electromechanical engineering systems, contributing significantly to the overall goal of engineering risk prevention and control from a technical management perspective.

4.2.2. Human-machine interface optimization

In the field of electromechanical engineering, human-machine interface optimization plays a crucial role in engineering risk prevention and control. Designing ergonomic control panels is an essential approach. These control panels should be designed with the prioritization of risk visualization. By clearly presenting potential risks in a visual and intuitive manner, operators can quickly identify and understand the situation. For example, using color-coding systems where red indicates high-risk areas, yellow for medium-risk, and green for low-risk, can help operators make rapid judgments.

Furthermore, decision-support features are equally important. Incorporating intelligent algorithms into the control panels can provide real-time suggestions for risk mitigation based on the visualized risks. This could include recommended actions such as shutting down certain components, adjusting operating parameters, or initiating maintenance procedures. These decision-support features act as a guiding tool for operators, especially in complex and high-stress situations.

In essence, through human-machine interface optimization with risk visualization and decision-support features, the electromechanical engineering system can better adapt to various risk scenarios. This not only improves the efficiency of risk prevention and control but also reduces the likelihood of human-error-induced risks. By enhancing the interaction between humans and machines, the overall safety and reliability of the electromechanical engineering process can be significantly enhanced ^[13].

4.3. Competency development frameworks

4.3.1. Technical skill matrix development

Technical skill matrix development involves creating a comprehensive and detailed framework that maps out the specific technical skills required for various aspects of electromechanical engineering, especially in relation to risk mitigation. For electrical safety, it clearly defines the proficiency levels needed in areas such as electrical circuit analysis, grounding techniques, and the use of electrical safety equipment. This helps in identifying gaps in skills among engineers and technicians, enabling targeted training programs to enhance electrical safety knowledge and reduce risks associated with electrical malfunctions.

Regarding hydraulic system maintenance, the matrix specifies skills like hydraulic component identification, leak detection and repair, and system pressure regulation. By precisely outlining these skills, it becomes easier to assess an individual's ability to maintain hydraulic systems effectively, preventing potential failures that could lead to significant risks in electromechanical operations.

In automation programming, the matrix details skills in programming languages commonly used in the electromechanical field, such as ladder logic, PLC programming, and robotic control programming. It also includes aspects like system integration and troubleshooting of automated processes. This not only helps in ensuring the smooth operation of automated systems but also in quickly identifying and rectifying any programming-related issues that might pose risks to the overall engineering project. Overall, a well-developed technical skill matrix is a crucial tool for aligning technical capabilities with risk prevention and control in electromechanical engineering.

4.3.2. Scenario-based training simulators

Scenario-based training simulators play a crucial role in the technical control strategies for risk mitigation within the context of engineering risk prevention and control in electromechanical engineering. By implementing virtual reality platforms for risk scenario simulation and emergency response drills, these simulators offer a highly

immersive and practical training environment.

For instance, in electromechanical engineering projects, potential risks such as equipment malfunctions, electrical short-circuits, or system failures can be accurately replicated in a virtual setting. Trainees can then experience these scenarios firsthand, learning to identify the early signs of risks, understand the underlying causes, and most importantly, practice appropriate response measures.

Emergency response drills in the simulator help develop the necessary competencies among engineers and technicians. They learn how to quickly assess the situation, make rational decisions, and execute well-thought-out action plans to mitigate the risks. This not only improves their individual capabilities but also enhances the overall safety and reliability of electromechanical engineering systems. Moreover, the use of scenario-based training simulators allows for repeated practice without the real-world consequences of mistakes, ensuring that trainees can refine their skills and build confidence over time. Through these simulators, the industry can cultivate a workforce that is well-equipped to handle various risks, contributing to more efficient and secure electromechanical engineering operations.

5. Conclusion

In conclusion, this study has comprehensively explored engineering risk prevention and control strategies from the perspective of technical management in the electromechanical engineering field. The findings underscore the significance of systemically integrating technical management principles across design, operation, and human resource aspects to achieve holistic risk governance. By ensuring seamless coordination in these dimensions, potential risks can be effectively identified, analyzed, and mitigated, thereby enhancing the overall reliability and safety of electromechanical engineering projects. Looking ahead, future research holds great promise. AI-driven predictive risk modeling emerges as a crucial area. With the rapid development of artificial intelligence, leveraging its capabilities can enable more accurate anticipation of potential risks, allowing for proactive countermeasures. Additionally, the development of cross-disciplinary management frameworks for next-generation electromechanical systems is essential. As electromechanical engineering becomes increasingly intertwined with other disciplines, such frameworks will facilitate better collaboration and resource allocation, thereby fostering innovation and reducing risks in a complex technological landscape. Overall, continuous exploration and improvement in these areas will be key to advancing the field of electromechanical engineering and ensuring its sustainable development.

Disclosure statement

The author declares no conflict of interest.

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