

## 超大规模城市轨道交通网络的车辆高质量运维管理模式

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地铁作为城市公共交通的重要组成部分,其运营效率和运行安全性直接关系到市民的日常出行和城市的整体运行。截至2024年底,上海轨道交通运营的线路里程达896 km(运营里程数目前居全国第一),车辆保有量超过7 500辆,2024年全线网日均安全运送乘客1 028.11万人次,面对超大规模网络下复杂的车辆、设备配置和大客流压力,运营需求与设备现状,质量需求与成本控制,以及专业人员能力、数量与精细化管理等多方面的矛盾日益凸显,车辆运维的高质量发展和转型已逐渐成为行业内的重要课题。

高质量发展不仅意味着提高产品和服务的质量,更意味着提高生产效率和创新能力。为了实现这一目标,上海轨道交通在列车技术、管控体系和生态链三个方面进行了深入研究和探索。

### 一、高质量的技术创新是提升列车可靠性和降低运维成本的关键

列车作为地铁系统的核心设备,其技术性能直接影响运维管理的效果。上海轨道交通在列车技术方面进行了深入的探索和创新,回归列车设计的本质,以“RAMS+”为核心,即在可靠性、可用性、可维修性、安全性的基础上,还要考虑到列车的可操作性和可乘坐性。通过从装备的全进口到国产化,再到绿色环保、数字化、多系统融合等方面的探索,通过零救援列车设计、列车设备模块化设计以及低频次运维列车设计等创新手段,有效降低了列车的故障率和维修成本。此外,上海轨道交通还积极推动列车技术的标准化、集成化和数字化。通过制定统一的列车标准和运维规范,实现了不同车型间的兼容性和互换性;通过集成化设计,提高了列车的整体性能和运维效率;通过数字化手段,实现了对列车运行状态的实时监控和智能预警。

### 二、高质量的管控体系是确保列车安全运营和高效运行的关键

从最初的计划修到均衡修,再到状态修和全寿命均衡维修,上海轨道交通不断探索更适合超大规模网络的检修模式。同时,在保持成本基本不变的前提下,通过优化检修计划和流程、提高检修效率和质量等手段,上海轨道交通首次提出列车架大修模式从传统的“架大架大架”优化至“架架大架架”的探索,配合车辆的延寿改造工作,实现列车全寿命周期可靠性提升的目标。

在设备状态监控和检验检测能力建设方面,上海轨道交通通过建设7大类检测实验室和焓差实验室,实现了对列车材料级、部件级、系统级和整车级的全面检测能力。这不仅提高了设备的可靠性和安全性,也为运维工作提供了有力的技术支持。

### 三、高质量的行业生态链是实现车辆运维管理可持续发展的关键

上海轨道交通在培育生态链方面进行了积极的探索和实践,通过加强与上游部件供应商和中游整车制造商的合作,推动技术创新和产业升级,通过优化下游运维服务网络布局和提高服务水平,确保列车的安全、高效运行。同时,通过ISO 22163质量管理体系、RCM(以可靠性为中心的维修)理论等管理标准的引入和实施,提高了全产业链的协同效率和运维质量,积极推动列车标准化和多系统融合发展,为运维工作提供了更加便捷和高效的解决方案。

展望未来,上海轨道交通将继续坚持高质量发展的理念不动摇,不断创新和实践高质量的车辆运维管理模式。一方面,将继续加强列车技术的研究和创新力度的提升,推动列车技术的标准化、集成化和数字化进程;另一方面将不断完善管控体系和生态链建设,提高运维管理的质量和效率。同时,还将积极探索智能化、绿色化等新的发展方向,为打造更加安全、高效、环保的地铁系统贡献更多的智慧和力量。

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## High Quality Vehicle Operation and Maintenance Management Mode for Ultra-large-scale Urban Rail Transit Networks

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Metro systems is a critical component of urban public transportation, the operational efficiency and safety of which directly impact the daily commutes of citizens and the city overall functioning. By the end of 2024, the operational mileage of Shanghai rail transit had reached 896 km (the longest in China at the moment), with a fleet exceeding 7 500 vehicles. The network safely transported an average of 10.28 million passengers per day in 2024. Amidst the challenges posed by an ultra-large-scale network, complex vehicle and equipment configurations, and high passenger volume pressure, contradictions between operational demand and equipment conditions, quality requirements and cost control, as well as capability, volume, and refined management of specialized workforce, have become increasingly prominent. Achieving high-quality development and transformation in vehicle operation and maintenance (O&M) is becoming the critical topic within the industry.

High-quality development entails not only improving product and service quality but also enhancing production efficiency and innovation capacity. To achieve this, Shanghai Rail Transit has conducted in-depth research and exploration in three key areas: train technology, management and control systems, and industry eco-chains.

### 1. High-quality technological innovation is the key to enhancing train reliability and reducing O&M costs.

Trains is the core equipment of metro systems, the technological performance of which directly impacts the effectiveness of O&M management. Shanghai Rail Transit has carried out extensive exploration and innovation in train technology, focusing on the essence of train design under the concept of 'RAMS + ', including train operability and passenger comfort beyond reliability, availability, maintainability, and safety. Through the exploration of evolutionizing fully imported equipment to localized production, green and digital innovations, and multi-system integration, as well as groundbreaking solutions such as zero-rescue train design, modular train equipment design, and low O&M frequency train design, the train failure rates and maintenance costs are effectively reduced. Additionally, Shanghai Rail Transit actively promotes standardization, integration, and digitalization of train technology. By formulating unified train standards and O&M regulations, compatibility and interchangeability across various vehicle types are achieved. Integrated design improves overall train performance and O&M efficiency, while digital tools enable real-time monitoring and intelligent early warning for train operation status.

### 2. High-quality management and control systems is the key to ensuring safe and efficient train operations.

Shanghai Rail Transit continuously refines its maintenance strategies, from the initial planned maintenance to balanced maintenance, and further to condition-based and full-lifecycle balanced maintenance, constantly exploring for the more suitable maintenance modes for an ultra-large-scale network. Meanwhile, under the premises of generally keeping the same costs, through optimizing maintenance planning and workflows, and enhancing both maintenance efficiency and quality, Shanghai Rail Transit proposes a shift from the traditional 'standard overhaul, major overhaul, major overhaul' cycle to optimized 'standard overhaul, standard overhaul, major overhaul' cycle for the first time, coupled with vehicle life-extension projects to achieve the goal of train full-lifecycle reliability enhancement.

In terms of equipment condition monitoring and inspection capabilities, Shanghai Rail Transit has established testing laboratories for seven major components and an enthalpy difference laboratory, capable of comprehensive testing at the material, component, system, and whole-vehicle levels. This not only enhances equipment reliability and safety but also strengthens the technical foundation for O&M operations.

### 3. High-quality industry eco-chains is the key to realizing vehicle O&M management sustainable development.

Shanghai Rail Transit is actively exploring and implementing strategies to foster robust industry eco-chains. By strengthening collaboration with upstream component suppliers and midstream whole-vehicle manufacturers, technological innovation and industrial upgrades are promoted; through optimizing the downstream O&M service network layout and enhancing service quality, safe and efficient train operation is ensured. Furthermore, the introduction and implementation of ISO 22163 quality management systems and RCM (reliability-centered maintenance) methodologies significantly improve coordination efficiency and O&M quality across the entire industrial chains, proactively advancing train standardization and multi-system integration development and providing more efficient and convenient solutions for O&M work.

Looking ahead, Shanghai Rail Transit will remain committed to the philosophy of high-quality development, continuously innovating and implementing high-quality vehicle O&M management modes. On one hand, the research and innovation in train technology shall keep strengthening, progressing the standardization, integration, and digitalization of train systems. On the other hand, the management and control systems shall be further optimized, and industry eco-chains constructed, improving O&M management quality and efficiency. Simultaneously, new frontiers such as intelligent and green transit solutions shall be proactively explored, contributing wisdom and power to the development of safer, more efficient, and more environmentally friendly metro systems.

Translated by ZHANG Liman