Engineering Construction and Risk Management Practice of Intelligent Rail-Logistics System in Multi-Building Tertiary-A Hospital

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Abstract

To meet the requirements for the high-quality development of public hospitals and solve practical problems such as low efficiency of in-hospital material transportation, high labor costs and heavy pressure of nosocomial infection control in multi-building tertiary-A hospitals, Chengdu Hospital of Integrated Traditional Chinese and Western Medicine has launched the reconstruction-and-expansion project of an intelligent rail-logistics system. As an intelligent renovation project constructed under the premise of uninterrupted medical services, it is restricted by multiple factors including existing building conditions, nosocomial-infection control requirements and extreme weather, with engineering risks running through the whole project lifecycle. Combined with project practice, this paper carries out whole-lifecycle risk identification and assessment, establishes a risk matrix, formulates corresponding countermeasures, and builds a closed-loop management system of “risk identification-assessment-disposal-review”. Risk control is implemented through multi-party collaboration, phased construction, on-site operation and maintenance, special training and emergency disposal. A total of 48 stations are planned with a total rail length of 2567 m, among which 32 stations have been put into operation. The system completes an average of 320 delivery tasks per day, with a 30-minute task completion rate of 93 %. The labor cost for full-time delivery staff is reduced by 50 %. The construction objectives of cost reduction and efficiency improvement, nosocomial-infection prevention and refined operation of intelligent logistics support have been achieved. Practice proves that whole-lifecycle engineering risk management is critical to the successful implementation of hospital intelligent reconstruction-and-expansion projects, and can provide practical references for similar domestic hospital intelligent-logistics projects.

Keywords

Intelligent Rail-Logistics; Hospital Intelligent Engineering; Reconstruction and Expansion; Engineering Risk Management; Intelligent Logistics Support.

1. Introduction

With the continuous advancement of the high-quality development of public hospitals, the construction of smart hospitals has gradually extended to the field of refined intelligent management. Internet-of-Things-driven in-hospital automatic logistics has become an important approach to realize refined management of logistics support for logistics services. For large-scale tertiary-A hospitals with a multi-building layout, there is a large demand for the cross-building circulation of medicines, laboratory specimens and medical consumables. The traditional manual transportation mode of “nursing staff + handcart + public elevator” occupies elevator resources and consumes a large amount of manpower. Without a full-process traceability mechanism for material circulation, potential safety

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hazards such as nosocomial infection and passage occupation may occur, which cannot meet the operational demands of modern hospitals.

Hospital rail-logistics is a reconstruction-and-expansion project integrating electromechanical equipment and Internet-of-Things technologies. Hospitals must maintain normal medical services during project construction. Old buildings are generally subject to inherent constraints including insufficient floor height, dense pipelines and the lack of dedicated logistics shafts, resulting in numerous potential risk points in the construction, commissioning and operation-maintenance phases. Most of the existing literature focuses on the application effects of such systems, while few studies discuss whole-lifecycle risk management for renovation projects with uninterrupted medical services. Taking the intelligent rail-logistics project of a hospital as the research object, this paper analyzes the whole process of whole-lifecycle risk identification, risk assessment, countermeasures and review management, and summarizes practical experience in engineering risk management.

2. Project Overview and Constraints for Reconstruction-Expansion

This tertiary-A general hospital adopts a multi-building centralized layout with more than 2400 open beds and strong demand for cross-building material transportation. This project plans to build 48 logistics stations with a total rail length of 2567 m, equipped with 85 transport trolleys and 42 rail switches. The ceiling-hung magnesium-aluminum alloy rail system covers pharmacy, pharmacy intravenous admixture service (PIVAS),[1] clinical laboratory, operating rooms and all clinical wards. It realizes point-to-point automatic transportation for small-and-medium-size materials such as infusions, specimens, small-sized surgical instruments and medical documents. Large-size articles including bed linens and large equipment still adopt original transportation modes to form a multi-mode complementary material guarantee system.

The project started construction in November 2023 under the principle of “overall planning, phased construction and phased commissioning”. By June 2026, 32 stations had been put into operation with 51 transport trolleys, accomplishing 48118 transportation tasks in total.

Main drawbacks of traditional manual logistics are listed as follows: (1) Material transportation occupies passenger elevators and aggravates elevator congestion in peak hours; (2) Material handling consumes a large number of nursing staff; (3) Manual transportation is restricted by shift arrangement with poor 7 × 24-h emergency support capacity, resulting in occasional mis-delivery, missing-delivery and specimen damage; (4) Transport carts shuttle in wards and bring risks of nosocomial infection and fire-exit occupation; (5) Cross-building material circulation lacks data support, and logistics support management depends on experience.

This reconstruction-expansion project faces prominent on-site constraints: no additional external logistics shaft can be constructed;[2-4] partial zones have limited floor height; operating rooms require strict cleanliness standards; partial outdoor rails lack canopy protection; all construction activities shall not interfere with routine medical services, which puts forward high requirements for engineering risk management.

3. Whole-Lifecycle Risk Identification, Assessment and Countermeasures

According to project schedule, the whole lifecycle is divided into four phases: scheme design, on-site construction, commissioning-and-phased-operation,and operation-maintenance-and-emergency-response. Risk identification is conducted via field investigation and expert discussion. Risk levels are comprehensively evaluated combining occurrence probability and consequence severity.[5] Corresponding response strategies and control measures are defined, as shown in Table 1.

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Table 1. Whole-lifecycle risk matrix and countermeasures for hospital intelligent rail-logistics engineering

Phase	Risk No.	Risk description	Risk level	Response strategy	Specific risk-control measures
Scheme design phase	R1-1	Insufficient assessment of building conditions; conflict between rail routes and existing pipelines / fire-safety codes	High	Risk avoidance	Carry out multiple rounds of site survey and scheme review based on architectural & pipeline drawings; verify fire-protection clear-height specifications for outdoor passages
	R1-2	Ambiguous business boundary; over-expectation for system load capacity and applicable material types	Medium	Risk mitigation	Define system positioning for small-and-medium-size materials only; keep original transportation mode for large articles and conduct internal publicity
	R1-3	Lack of protection for outdoor rails; short-circuit and equipment damage caused by extreme rainfall	High	Risk avoidance	Install steel-structure canopy for outdoor rails; equip fire-proof, wind-proof and overload-weighing devices and optimize electrical waterproof design
	R1-4	Absence of fire-linkage and nosocomial-infection-control design, violating medical-building specifications	High	Risk avoidance	Implement fire-protection linkage control; enclose rails in clean operating-room zones with 304 stainless-steel sheets to meet cleanliness requirements
Non-interrupt on-site construction phase	R2-1	Construction noise, dust and enclosures interfere with inpatient & outpatient medical services	High	Risk mitigation	Adopt zoned and staggered-hour construction; implement closed enclosure for nurse-station construction and restrict operation time windows
	R2-2	Inadequate dust-proof protection during construction in clean operating-room zones, damaging cleanliness level	High	Risk avoidance	Arrange operating-room construction on weekends with non-operation status; lay dust-proof protective films and implement cleanliness protection measures
	R2-3	Complex pipelines in suspended ceiling; rail installation damages original electrical and ventilation pipelines	Medium	Risk mitigation	Hold regular meetings for all participating parties to check pipeline layout; implement sample-first procedure for key processes before mass construction
	R2-4	Poor coordination among multi-participants for cross-work, causing rework and schedule delay	Medium	Risk mitigation	Set up a hospital-led special project team; organize multi-party coordination meetings to unify civil-work, decoration and equipment-installation schedules
Commissioni	R3-1	Unfamiliar operation by medical	Medium	Risk	Carry out practical training

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Phase	Risk No.	Risk description	Risk level	Response strategy	Specific risk-control measures
ng & phased-operat ion phase		and logistics staff; mis-operation leading to wrong delivery or trolley jamming		mitigation	before commissioning of each batch; establish training files and implement regular retraining for staff turnover
	R3-2	Full-scale simultaneous commissioning leading to concentrated failures and poor clinical adaption	Medium	Risk avoidance	Adopt the phased-commissioning principle of "commission after construction & training"; avoid full-scale simultaneous launch
	R3-3	Mass task submission in morning peak hours, resulting in trolley queuing and transportation delay	Medium	Risk mitigation	Arrange manufacturer engineers on-site in early operation stage; explore staggered-sending strategy to relieve peak-hour pressure
Operation-ma intenance & emergency-re sponse phase	R4-1	Defective operation-maintenance response mechanism; system long-time shutdown due to delayed fault disposal	High	Risk mitigation	Deploy on-site operation-maintenance team with clear response requirements: respond within 10 min and arrive at fault location within 15 min during working hours
	R4-2	Building leakage and ceiling dampness erode electrical components of rails and cause partial system breakdown	High	Risk mitigation	Add building-leakage and ceiling-dampness inspection into routine check-list; formulate extreme-rainfall emergency plan and cut-off power supply once hazard occurs
	R4-3	Absence of backup scheme; material guarantee interruption under emergency conditions	High	Risk transfer & backup guarantee	Establish manual-transportation backup workflow; activate manual mode to guarantee emergency medicines and specimen delivery under large-scale system failure
	R4-4	Over-emphasis on hardware investment while ignoring data application; logistics big-data fails to support logistics management optimization	Low	Risk acceptance & continuous improveme nt	Collect logistics operational data continuously; explore data value for scheduling and process optimization in follow-up work

Note: For formal journal submission in Word, set this table as standard three-line table: 1.5 lb top & bottom lines, 0.5 lb header separator line, remove all vertical lines and inner horizontal lines.

4. Implementation of Risk Control Measures

If you follow the "checklist" your paper will conform to the requirements of the publisher and facilitate a problem-free publication process.

4.1 Implementation in Scheme and Construction Phase

The special project team coordinates hospital, general contractor and equipment manufacturer to complete overall scheme review. Outdoor rails for fire-access passages strictly comply with clear-height requirements. Steel-structure canopies are installed for outdoor rails of pharmacy intravenous admixture service without original shelter. Rails inside operating rooms are enclosed by stainless-steel sheets. Enclosed enclosure is adopted for ceiling construction near nurse stations, and all operating-room construction works are scheduled on weekends. Sample processes are verified before mass installation to minimize disturbance to clinical services.

4.2 Implementation in Commissioning and Phased-Operation Phase

Phased commissioning is strictly performed. The third inpatient building, emergency building and second inpatient building are commissioned successively. Stations of the first inpatient building and outpatient building go online along with department relocation. Single-machine and joint debugging are completed before commissioning of each batch. Practical training is provided for nurses and logistics administrators with complete training records; retraining is arranged for new employees. Manufacturer engineers keep on-site duty in early operation stage to handle trolley jamming and mis-operation in time.

4.3 Implementation in Operation-Maintenance and Emergency-Response Phase

Three after-sales staff and one full-time technical-support engineer are assigned for on-site service with 7 × 24-h mobile communication guarantee. Routine inspection is performed for rails, electrical components and ceiling leakage points. Heavy rainfall once caused water intrusion into rail equipment. The project team activated flood-prevention emergency plan immediately: cut off power supply, block leakage points and replace damaged components for recovery. The extreme-weather emergency plan and inspection checklist were revised afterwards. Manual backup mechanism is implemented to guarantee continuous supply of critical clinical materials in emergencies.

5. Implementation Effects and Improvement Suggestions

5.1 Operational and Economic Benefits

Thirty-two stations have been commissioned, accomplishing 48118 transportation tasks in total, with 320 daily delivery tasks on average. The average on-rail time for single transportation task is 13.9 min and the 30-min task completion rate reaches 93 %. The number of full-time delivery staff decreases from 6 to 3, with labor cost reduced by 50 %. Closed automatic transportation lowers damage risk for specimens and medicines. Collected logistics data supports scheduling optimization for pharmacy and PIVAS, promoting logistics-support management from experience-driven mode to data-driven mode.

5.2 Clinical and Safety Benefits

Materials are transported by dedicated rails instead of passenger elevators, relieving elevator congestion in peak hours. Fewer handcart movements inside wards guarantee accessibility for first-aid passages and fire exits. Full-process traceability significantly reduces mis-delivery and missing-delivery. Trolleys are equipped with ultraviolet disinfection and closed transportation function to lower cross-infection risks. The 7 × 24-h running capability fills the gap of night-time emergency material support. Medical staff are released from repetitive material-handling work and can focus on clinical diagnosis and treatment. Clinical departments give high recognition for this system. This project avoids the common industry defect of “emphasizing hardware while neglecting operation-maintenance and training”, and provides reference for peer hospitals.

5.3 Existing Risks and Continuous Improvement

Partial stations can only be commissioned after department relocation, so full system capacity is not released yet. Occasional trolley queuing exists in morning peak hours. Building leakage and dampness risks of old buildings require long-term routine inspection. Retraining shall be continuously arranged for staff turnover. In the future, the hospital will accelerate commissioning of remaining stations, optimize dispatching strategy, improve inspection and emergency plans, dig value from logistics big-data, and iterate risk-management measures continuously. In terms of medium-and-long-term planning, the hospital intends to further extend logistics network to connect the fourth inpatient building and the fifth outpatient department. Hybrid logistics modes (rail + robot, rail + pneumatic tube) will be explored. Taking rail-logistics as backbone network and multiple intelligent devices as terminal extensions, a modern intelligent medical logistics system with full coverage and high efficiency will be constructed.

6. Conclusion

Intelligent rail-logistics for multi-building tertiary-A hospitals is a reconstruction-expansion engineering integrating electromechanical and IoT technologies. Under the condition of non-interrupt medical services, risks exist in scheme design, construction, commissioning and operation-maintenance phases. If only hardware selection is emphasized while whole-lifecycle risk management is ignored, negative consequences including schedule delay, clinical service disturbance, frequent equipment failure and unsatisfactory practical performance may occur.

The practice of this project indicates that hospital intelligent reconstruction-expansion projects shall establish a hospital-led multi-party coordination team, and fully identify risks brought by building constraints, medical infection-control requirements and non-interrupt construction. Phased planning and phased commissioning can greatly reduce project implementation risks. Clinical training, on-site operation-maintenance, emergency plan and review after risk events are indispensable components for successful project operation. Risk management shall run through the whole lifecycle of design-construction-commissioning-operation-maintenance to realize closed-loop management of risk identification-assessment-disposal-review. This practice can provide reference for reconstruction-expansion projects of intelligent logistics support in public hospitals and facilitate high-quality development of hospitals.

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