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Designing Functional Carriage of High-Speed Medical Train – Systematic Analysis and Evaluation of Tasks, Functions and Flow Routes

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ABSTRACT
This paper proposes a functional carriage design and an evaluation index system to improve the operational efficiency of high-speed medical trains. Hierarchical task analysis and human-machine-environment analysis were applied to model the transfer task and the functional modules of the medical train. The functional module configuration was obtained by performing a correlation analysis between the task and function. The relationship between carriages was elucidated by analysing material, personnel and information flow, and an optimal grouping diagram was obtained. Based on this design method, an innovative 6-carriage grouping design scheme was proposed. A functional evaluation index system for the carriage design was constructed, and the 6-carriage design was compared with the conventional 8-carriage design to verify the usability of the design method. The results showed that the 6-carriage high-speed trains can be flexibly configured to suit the changing task environment and are generally better than the 8-carriage design. This study provides theoretical and methodological support for constructing efficient and rational functional carriages for high-speed medical trains.

KEYWORDS
high-speed medical trains; flow routes; task-functional relevance; functional carriage.

1. INTRODUCTION

Medical trains, also known as hospital trains, are a special type of train equipped with medical facilities, equipment and medical staff to provide medical services [1]. Medical trains use rail trains as transportation platforms, equipped with professional medical staff, facilities and equipment. They are essential means of transportation for war security, emergency disaster relief and general medical care [2]. After being first used in the Crimean War in the 1850s, medical trains were widely used on various battlefields during World War II, making positive contributions to the war effort. Since the founding of the People’s Republic of China, China’s medical trains have carried out 276 casualty evacuation missions in the Korean War and self-defence counter-attack operations on the China-Vietnam border and transported a total of 77,924 people in major natural disaster events such as the Tangshan and Wenchuan earthquakes [3].

Medical trains can serve as a universal, affordable health care platform, providing medical services to the general public along the railway. Since 2005, Health Express has established 15 Health Express Eye Centres in less developed areas to train ophthalmologists and provide equipment and technical support to primary care hospitals. In 2016, Health Express launched the “Diabetes and Retinal Disease Screening and Prevention Program” to provide early prevention and treatment of diabetes. In recent years, China, India, and other countries have set up the Lifeline Express project to provide specialised surgical services for people in remote areas, such as ophthalmologic, nose and throat and oral cavity surgeries [4].

Based on the G25 train platform, China's existing medical trains have insufficient medical equipment and facilities and have unreasonable spatial layouts and inflexible grouping. They are not conducive to the efficient transport and treatment of the sick and wounded [5, 6]. As China's high-speed rail network gradually expands, the medical trains based on the G25 platform will not fit into China's future railway transportation planning in terms of operating speed and routes. The China standard EMU trains are technologically advanced and are manufactured with new materials. These latest EMU trains have large passenger capacity, good stability, low noise and pressure wave, and will become the optimal platform for the development of high-level medical trains [7]. However, research on high-speed medical trains based on China standard EMU platform is still lacking, with most existing literature still focusing on feasibility studies and design basis discussions. Currently, only the Chinese Army Medical University has developed the first functional surgical emergency carriage for medical trains [8], allowing the train to carry out medical treatment in transit. However, there is still a gap in terms of a fully functional medical train formation.

Functional carriage is the most basic unit of train marshalling. The functional carriage design of high-speed medical trains involves two core issues. The first is the module configuration of functional carriages. The number of functional modules involved in high-speed medical trains is large, and their relationship is complex. Li et al. [9] provided a reference for the wartime construction of a medical train operating room based on the actual needs made apparent in the 2009 medical logistics drill. However, the existing research lacks a systematic review of the functional requirements of a high-speed medical train. It lacks the systematic allocation basis of functional modules, which cannot guide the configuration of functional carriages. The second issue is the arrangement layout design of functional carriage. High-speed medical train carriages are arranged with longitudinal marshalling, and the routes in the internal space are single-line round-trip, with a long distance between the first and the last single-line. Chen et al. [10] used ergonomic principles to analyse and propose that the layout of the surgical area should reduce the repeated movements of personnel and cross traffic to ensure the smooth passage of operators and the compactness and fluidity of operations. At the same time, the vertical space should be divided into different functional spaces at different levels. It is of great practical significance to reduce operating costs and improve operating efficiency to determine the functional carriage design of medical trains according to the task nature and demand [6].

Given the important impact of tasks and flow routes on the functional carriage design of high-speed medical trains, a method based on task analysis and flow route analysis is proposed to study the functional carriage design of high-speed medical trains (module configuration and layout design). The overall research framework is shown in *Figure 1*. This research framework focuses on two aspects: functional carriage design and task flow analysis. On the one hand, this research analysed the main influencing factors of the transfer and treatment tasks, such as the urgency of medical treatment, medical equipment and consumables, and staffing arrangements. On

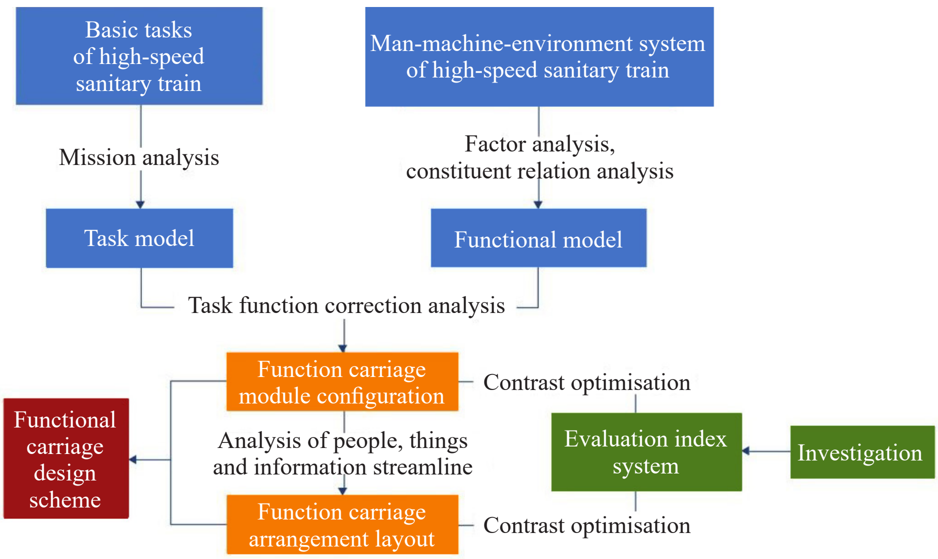

Figure 1 – Research framework for this work

the other hand, it addressed the movement routes of personnel and the flow efficiency of medical resources and daily supplies. By analysing these two factors, a layout is proposed as a reference for optimising the carriages of high-speed medical trains and for improving the operational efficiency of patient transfer and treatment in emergencies. The research framework consists of the following three main parts:

(1) Based on the task model, the correlation between tasks and function modules is analysed to guide the configuration and allocation of function modules.

(2) Human-machine-environment analysis is performed regarding the relationships among the functional carriages by considering their material, personnel and information flow. This is used to guide the arrangements of the functional carriages.

(3) The objectives of the configuration and layout design of functional carriages of high-speed medical trains are investigated and an evaluation index system is proposed to guide the evaluation and optimisation of design schemes.

2. RELATED WORKS

A high-speed medical train consists of three systems: human, machine and environment. These three systems are interconnected and interact to maintain the operation of the high-speed medical train and ensure the smooth execution of medical transfer and rescue missions. Human-machine-environment system engineering provides important theoretical support for correctly dealing with the relationship between the three elements in complex systems [11]. In a human-machine environment system, "human" refers to the people performing tasks in the system, "machine" is the general term for all equipment in the system, and "environment" includes both the physical and social environment in the system [12].

The execution of medical tasks on high-speed medical trains involves factors like personnel, which includes medical personnel, management personnel and patients; equipment, which includes medical equipment, consumables and daily supplies; and environments, which includes carriage layout, movement routes and the exterior environment of the carriage. Amongst these factors, people use equipment to accomplish medical tasks, and the task environment is affected by the layout of functional carriages. Therefore, it is possible to optimise carriage design specific to a medical task by identifying the constituting parts of the human-machine-environment model and understanding their interactions and interdependencies.

2.1 Task analysis

Task analysis methods help clarify the flow of complex tasks by breaking down the target tasks into smaller sub-tasks. Describing and illustrating these subtasks one by one can help establish a clear and systematic view of the overall task model [13]. Commonly used task analysis methods include hierarchical task analysis (HTA), variance partitioning analysis (VPA), subgoal template method (SGT) and tabular task analysis (TTA). Hierarchical task analysis (HTA) is a structured and objective way to describe the task and its sub-task hierarchy. In user experience design, hierarchical task analysis is used to analyse and describe how users perform a series of tasks to achieve a goal. HTA is more suitable for analysing multi-step, branching tasks with specific goals than other task analysis methods. Therefore, HTA has been widely used in train-related research. Wang et al. analysed the critical operations of high-speed railroad dispatchers during turnout failures and used HTA to investigate task attributes and potential human errors in railroad dispatching operations [14]. Naweed et al. conducted a comprehensive task analysis of two-driver freight railroad driving operations through HTA to investigate the feasibility and safety risks of shifting from a two-driver to a single-driver operation [15]. Although there are examples of HTA being used for train-related studies, the subjects studied were only for single-subject and single-task analysis or multi-subject and single task analysis. On top of that, there were few discussions related to its application to health train tasks. Therefore, it is very urgent and necessary to analyse the hierarchical tasks in the context of high-speed health trains, particularly medical transport and treatment tasks after natural disasters. The HTA method can help break down the complex tasks of high-speed medical trains and build a comprehensive, reasonable and hierarchical task model to provide reliable theoretical support for optimising the arrangement of functional carriages and the layout of each carriage in health trains.

2.2 Facility layout planning

Facility layout planning is a design method to map out the location of facilities and equipment based on their functions or tasks and to plan behaviour flows to improve workflow efficiency and ensure the safety of personnel, material and information flows [16]. A good layout plan ensures a compact and smooth operational process, which is an important basis for facility and equipment layout [16]. Sun et al. classified the frequency and importance of facility use based on personnel flow and their function and arranged equipment based on this [17]. Suhardi et al. studied the system layout planning method, analysed the relationship between material flows and non-material flows to map out the location of operational units and functional modules, and explained the optimal layout of each module [18]. Goecks et al. considered the correlation and importance between modules and determined the location and height of related facilities based on their correlation or flow intensity [19].

Currently, the design of high-speed train carriages is mainly based on ergonomics. The flow routes of human activities, carriage arrangement and the arrangement of functional modules are studied to improve passenger experience and increase carrying capacity. Jung et al. looked at the human-machine-environment system of high-speed train carriages and analysed the passenger-related facilities and layouts. They also studied data on the environment's physiological and psychological influence on the passengers and proposed a method for high-speed train carriage design [20]. Zhang et al. divided the interior space of the carriage by analysing passenger behaviour and completed the facility and access design based on general design theories [21]. Xiang et al. investigated the riding tasks, key riding motions, routes and impacts of other passengers on wheelchair users travelling by railroads to support the development of railroad carriage layouts [22]. Xiang et al. proposed the most efficient carriage layout based on the relationship between passenger behaviours and space across time [23].

Compared with the layout design of ordinary high-speed train carriages, the layout and sequence of functional carriages of high-speed medical trains need to take into account the degree of urgency of tasks, the relevance of carriage modules and the flow routes of material and personnel, which is why they have more complex functional modules than ordinary high-speed trains. The medical train mainly performs medical tasks, which differs from the single-purpose use of ordinary high-speed trains. The medical train has more complex tasks and personnel composition than high-speed passenger trains. As specialised equipment is required on medical trains, the carriage functions and carriage arrangement of high-speed medical trains must be designed with its task characteristics in mind. Compared with the layout design of ordinary high-speed train carriages, the special nature of medical tasks means that the layout design of high-speed medical train cars has more urgent and higher requirements.

3. FUNCTIONAL CARRIAGE DESIGN METHOD ON CARRIAGE LAYOUTS

3.1 Task model of high-speed medical trains based on HTA

High-speed medical trains are constructed with wartime medical service as their primary application scene. Its basic task is to carry out the transportation of patients and to provide medical treatment while ensuring the basic living needs of personnel. The transport objective is to complete the transportation of the wounded from the field hospital to the base hospital; the goal of medical treatment is to diagnose, treat and nurse the wounded during transit.

HTA helps break down the tasks of high-speed medical trains. In order to ensure the stability of the patient's condition in the long-distance transport process, it is necessary to carry out diagnoses and treatments during transport according to the level of acuity and severity of the condition. These include examination, surgery, intensive care and resuscitation for the most high-risk patients. For patients with complex conditions, these include ICU monitoring to avoid deterioration. For low-risk patients, these may include simple nursing care and rehabilitation training to speed up recovery. Therefore, the five subtasks of the high-speed medical train include: ① patient acuity assessment; ② patient transfer to the medical train according to their acuity level; ③ diagnosis and treatment plan formulation to treat the patients; ④ patient transfer out of the medical train upon arrival; ⑤ providing medical supplies such as medicines, consumables and disinfectant as well as access to other daily supplies. The above subtasks can be further broken down into secondary and tertiary tasks. A hierarchical task model of the high-speed medical train can then be obtained, as shown in *Figure 2*. The basic task flow is as follows: after completing task 1, tasks 2.1, 2.2 and 2.3 are completed according to the injury severity level. Then tasks 3.1, 3.2 and 3.3 are carried out, respectively. Task 4 is completed after reaching the destination, and task 5 can be performed concurrently with other tasks.

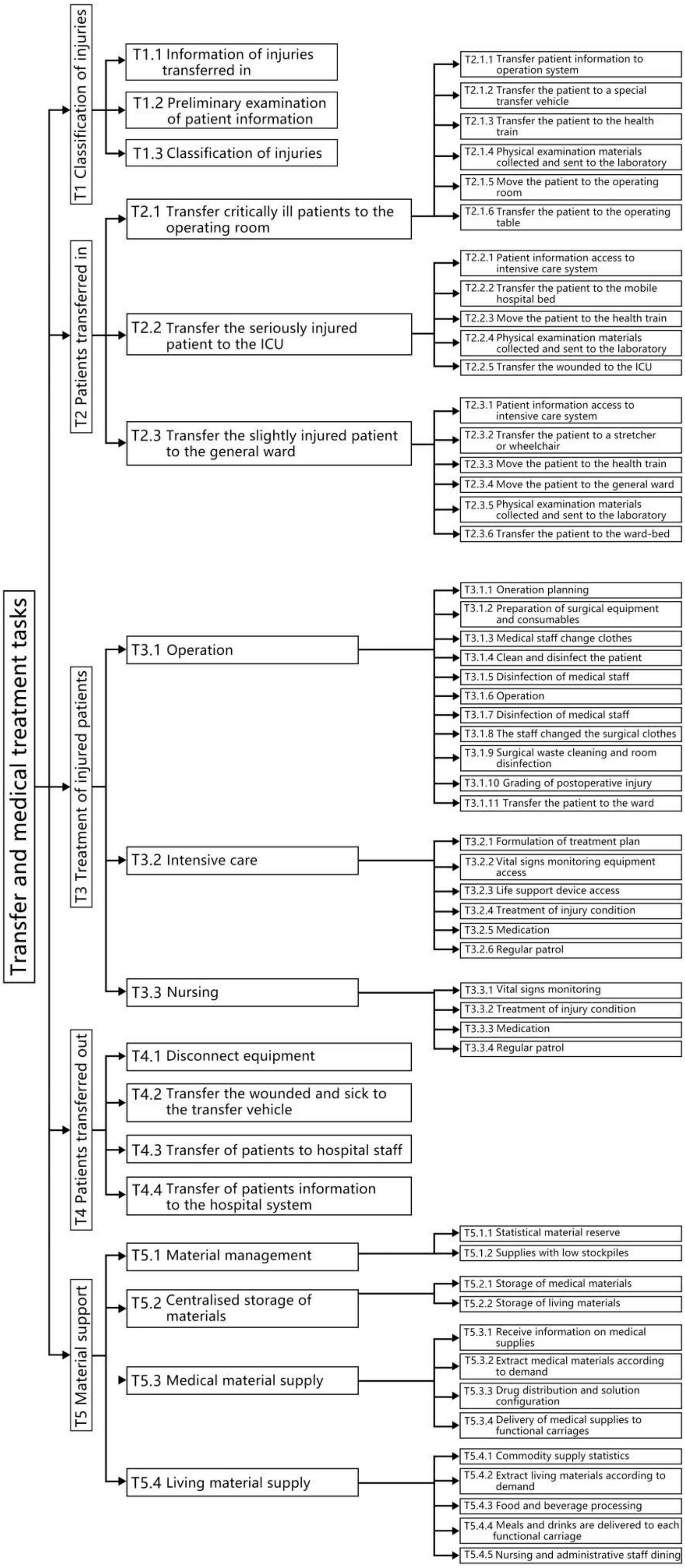

Figure 2 – High-speed medical train task model based on HTA

3.2 Functional modules of high-speed medical train

There are three types of 'human' in high-speed medical trains: medical staff, wounded and sick patients and management. The medical staff includes doctors and nurses with medical qualifications and skills, as well as carriers who assist medical staff in moving the patient to and from the stretcher, the surgical table and the bed. The sick and wounded include critically ill patients, unconscious patients, inactive patients, patients with severe injuries and sometimes patients with relatively milder injuries and clearer consciousness. The management includes medical system management, life system management and train system management. The medical system management staff is in charge of medical supplies, medical staff roster and medical equipment. The life system management personnel are in charge of the dining car, the dormitory car and their supplies. The train system management is responsible for the mechanical operations of the train, monitoring its status and keeping its maintenance.

The 'machine' in high-speed medical trains consists of medical equipment, materials, and information systems. Medical equipment includes transport equipment, which is used to move the patient from outside to the medical train, inspection equipment, testing equipment, fixture equipment, life support equipment, monitoring equipment and medical consumables. Materials include medicines, IV fluids, food, beverages, nutritional supplies, laundry and bedding. The information system includes the patient EHR, medical staff information, transfer record, staff duty roster and the driver information system (DIS), which includes task record, speed, time and other information relating to the train operation.

The 'environment' in the high-speed medical train includes the medical environment for providing medical services such as injury examination, surgery, intensive care and nursing; the living environment for medical staff and managers to eat and rest; the storage environment for storing medicines, medical equipment and consumables, machines and daily supplies; and the management environment for personnel, materials and information management. *Figure 3* shows a conceptual flowchart of a human-machine-environment system analysis in high-speed medical trains.

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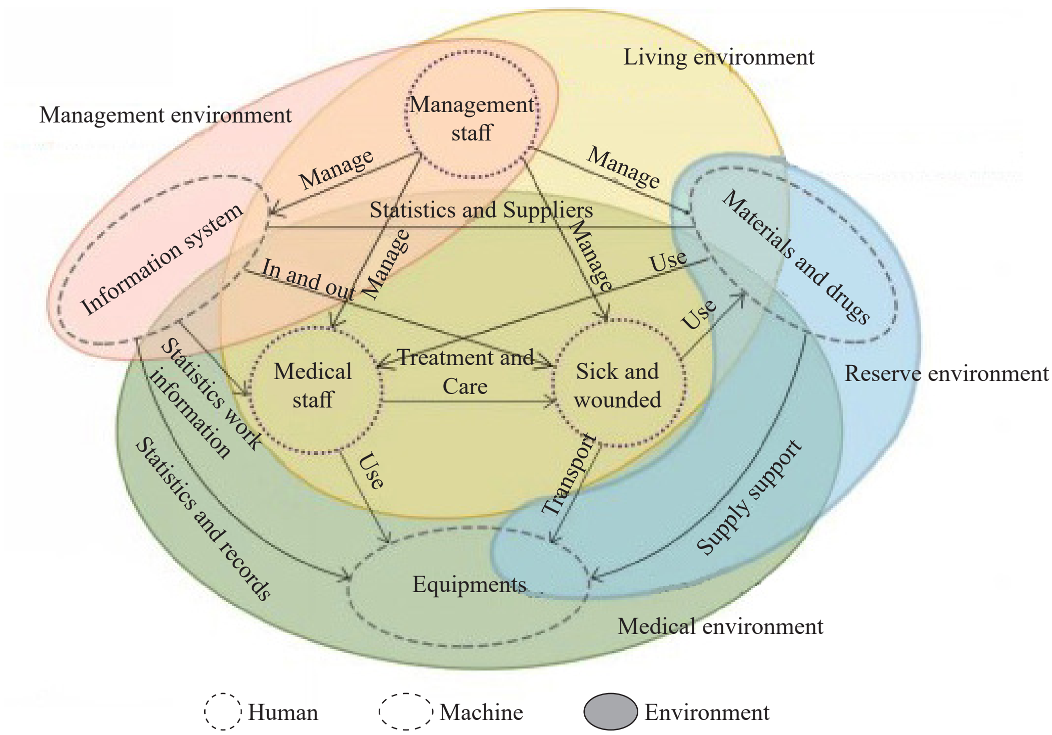


Figure 3 – Human-machine-environment system analysis of high-speed medical trains

By analysing the elements of the human-machine-environment system of high-speed medical trains and understanding their relationships, it is clear that high-speed medical trains can be divided into four functional modules: medical module, life module, storage module and management module. These functional modules are further divided into 10 main modules and 28 submodules.

The medical module can be divided into F_1 examination submodules (f_{11} radiology module, f_{12} ultrasound, ECG module, f_{13} blood test module, f_{14} biochemical laboratory module), F_2 surgery submodules (f_{21} changing room module, f_{22} disinfection module, f_{23} surgery module, f_{24} dirt collection), F_3 intensive care submodules (f_{31} vital sign monitoring module, f_{32} life support module, f_{33} emergency module), F_4 minor injury nursing submodules (f_{41} bed nursing module, f_{42} emergency call module).

The life module is the dining and rest area for medical and nursing managers, including F_5 catering submodules (f_{51} food storage module, f_{52} food processing module, f_{53} dining module) and F_6 rest submodules (f_{61} dormitory module, f_{62} washing module).

The storage module stores the necessary materials and equipment. The module includes the F_7 medical material storage submodules (f_{71} medicine storage module, f_{72} medical equipment, and consumables management module, f_{73} liquid preparation module) and the F_8 living material storage submodules (f_{81} daily supplies storage module, f_{82} food and beverage storage module).

The management module is the space for medical tasks, information, material access and communication. It can be divided into F_9 medical management submodules (f_{91} EHR management module, f_{92} treatment plan discussion module) and F_{10} train operation management submodules (f_{101} train status monitoring module, f_{102} external communication module, f_{103} material management module).

3.3 Correlation analysis of task and function

Functional correlation is an important reference for designing system function configuration and layout [21]. For the function configuration of the carriage to meet the requirements of the operation and to ensure the shortest travel of materials and people during an operation, it is necessary to divide the function modules according to the correlation between the task and the function. The function modules with strong correlations are placed adjacently to form a functional carriage, and the function modules with weak correlations are spread out into different function carriages.

Task function correlation describes the correlation between functional modules and tasks, which refers to the correlation between functional modules required to complete a task T. The correlation calculations of task functions are as follows:

Experts are invited to evaluate the correlation between the two functional modules based on the correlation grade according to the medical train task model and the secondary task process. Correlation grade and score included ‘strong correlation between two functional modules due to task X (0.8-1.0) ‘, ‘moderate correlation between two functional modules due to task X (0.4-0.7)’, ‘weak correlation between two functional modules due to task X (0.1-0.3)’ and ‘no correlation between two functional modules due to task X (0)’.

The correlation scores of all function modules are set and a function module correlation matrix M_k is established based on task T. M_k is an $n \times n$ matrix with principal diagonals as symmetric points. The values of principal diagonal elements are all at 1, indicating that the correlation between the same functional module is 1. k is the number of subtasks of high-speed medical trains, m_{ij} ($i, j = 1, 2, \ldots, n$) is the degree of correlation between function modules i, j in task T.

$$M_k = \begin{bmatrix} m_{11} & m_{12} & \ldots & m_{1n} \\ m_{21} & m_{22} & \ldots & m_{2n} \\ \ldots & \ldots & \ldots & m_{ij} \\ m_{n1} & m_{n2} & \ldots & m_{nn} \end{bmatrix} \tag{1}$$

Considering all the secondary tasks in the medical train task model, the correlation matrices of all the task function modules are joined together. Considering that all secondary tasks of the medical train are of equal importance, the correlation between each pair of functional modules is added together, and the correlation value of function modules is calculated by taking the mean value. The comprehensive correlation between each pair of functional modules in the task model is determined and expressed by the comprehensive correlation matrix *TM*. As the formula:

$$TM = \sum_{k=1}^{k} (M_k) / k \tag{2}$$

where M_k represents the functional module correlation matrix for the k-th subtask.

3.4 Module configuration of functional carriages

Three experts engaged in military medical service, medical treatment and train design and development are invited to score respectively the correlation of the main functional modules using the above procedures and methods. Weights average of the expert scores is taken to obtain the comprehensive correlation matrix *TM* of the functional modules, as shown in *Table 1*. Function modules are divided according to the correlation of all function modules in *TM* in the overall task model, integrating highly relevant functional modules into one carriage.

Table 1 – Correlation degree of main functional modules

Functional modules	F_1	F_2	F_3	F_4	F_5	F_6	F_7	F_8	F_9	F_{10}
F_1	1	0.35	0.35	0.4	0.01	0.01	0.53	0	0.88	0
F_2		1	0.38	0.23	0.05	0.05	0.35	0.05	0.33	0
F_3			1	0.03	0.05	0.03	0.35	0	0.30	0
F_4				1	0.05	0.05	0.35	0.08	0.30	0
F_5					1	0.03	0	0.83	0	0.23
F_6						1	0	0.78	0	0.21
F_7							1	0.05	0.15	0.79
F_8								1	0.03	0.81
F_9									1	0.02
F_{10}										1

The functional carriage configuration Scheme One of an 8-carriage high-speed medical train is put forward as follows: examination carriage (f_{11} radiology module, f_{12} ultrasound and ECG module, f_{13} blood test module, f_{14} biochemical laboratory module), surgery carriage (f_{21} changing room module, f_{22} disinfection module, f_{23} surgery module, f_{24} diet collection module, f_{31} vital signs monitoring module, f_{32} life support module, f_{33} first aid module), intensive care carriage (f_{31} vital signs monitoring module, f_{32} life support module, f_{33} first aid module, f_{41} hospital bed nursing module, f_{42} emergency call module), minor injury nursing carriage (f_{31} vital signs monitoring module, f_{41} hospital bed nursing module, f_{42} emergency call module), dining carriage (f_{51} food storage module, f_{52} food processing module, f_{53} dining module, f_{82} meals and drinks storage module), sleeping carriage (f_{61} beds module, f_{62} wash module, f_{81} daily supplies storage module), storage and preparation of medical materials carriage (f_{71} medicine storage module, f_{72} medical equipment and consumables management module, f_{73} medical fluid preparation module), management carriage (f_{91} EHR management module, f_{92} diagnosis and treatment planning module, f_{101} train status monitoring module, f_{102} external contact and docking module, f_{103} material management module).

The functional carriage configuration Scheme Two of a 6-carriage high-speed medical train is put forward as follows: examination carriage (f_{11} radiology module, f_{12} ultrasound and ECG module, f_{13} blood test module, f_{14} biochemical detection module), surgery carriage (f_{21} changing room module, f_{22} disinfection module, f_{23} surgery module, f_{24} diet collection module, f_{31} vital signs monitoring module, f_{32} life support module, f_{33} first aid module, f_{71} medicines storage module, f_{73} medical fluid preparation module), intensive care carriage (f_{31} vital signs monitoring module, f_{32} life support module, f_{33} first aid module, f_{41} hospital bed nursing module, f_{42} emergency call module), minor injury nursing carriage (f_{31} vital signs monitoring module, f_{41} hospital bed nursing module, f_{42} emergency call module, f_{71} medicine storage module, f_{73} medical fluid preparation module), living carriage (f_{51} food storage module, f_{52} food processing module, f_{53} dining module, f_{61} beds module, f_{62} wash module, f_{81} daily supplies storage module, f_{82} meals and drinks storage module), management carriage (f_{91}

EHR management module, f_{92} diagnosis and treatment planning module, f_{101} train status monitoring module, f_{102} external communication module, f_{103} material management module).

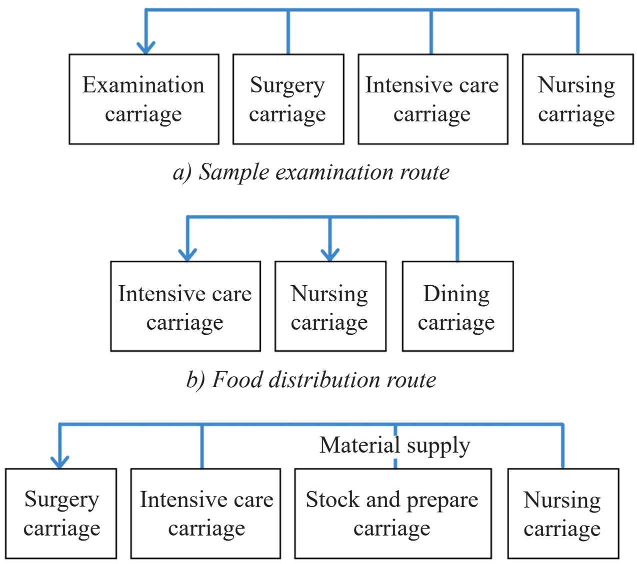
The main difference between the two schemes is that in Scheme One the storage and preparation of medical materials carriage is independent. At the same time, the dining and sleeping functions are divided into two independent carriages. Scheme Two divides the storage and preparation of medical materials module into the associated operation, critical care and nursing carriages, and the living carriage integrates the functions of dining and sleeping.

4. FUNCTIONAL CARRIAGE DESIGN METHODOLOGY ON CARRIAGE ARRANGEMENTS

Based on the definition of a high-speed medical train, its function module, and its task, this paper looks at different material flow routes, personnel flow routes, and information flow routes and comprehensively considers the occurrence of each task flow route to obtain the relationships between functional carriages. Then, an arrangement and layout scheme of functional carriages can be put forward.

4.1 Relationship of functional carriages based on material flow route

The sample submission flow route is part of the examination task, which mainly involves the examination carriage, surgery carriage, intensive care carriage, and nursing carriage. To prevent patients from crowding into the examination carriage for the collection of samples, the biosamples of the patients are collected at bedside in the order of decreasing patient acuity level (first surgical patients, then intensive care patients, and finally patients with minor injuries). Then, the nurse will send the test samples to the examination carriage for tests, as shown in *Figure 4a*. Sample submission is only performed once after a patient is transferred to the vehicle.



a) Sample examination route

b) Food distribution route

c) Medical material supply route (Scheme One)

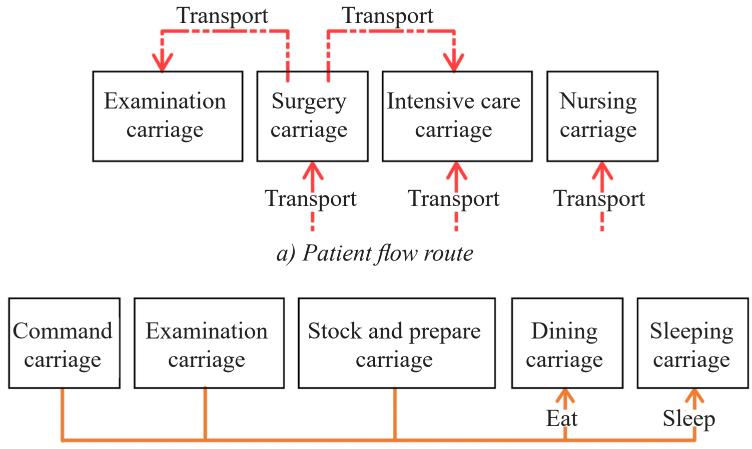
Figure 4 – Relationship of functional carriages based on material flow route

4.2 Relationship of functional carriages based on personnel flow route

Two groups of personnel flow routes are proposed based on the task flow of high-speed medical trains, including patient and staff flow routes.

The patient flow is shown in *Figure 5a*, which includes three types of tasks: in the transfer task, the patient is transferred to the surgery carriage, intensive care carriage and nursing carriage for corresponding medical treatment based on the severity of the injury. In the examination task, the patient in the surgery carriage must go to the examination carriage for X-ray and ultrasonic examinations if their doctors require it. Patients are transferred to intensive care carriage for monitoring in the surgery task. The above procedures are only performed once after a patient board the medical train.

Meals and rest tasks mainly generate the flow of medical management staff: medical management personnel move from each functional carriage to the dining carriage for meals and to the sleeping carriage for rest. The bedtime flow route happens once a day. The mealtime dining flow happens three times a day and is the most frequent staff flow, as shown in *Figure 5b*.



a) Patient flow route

b) Medical staff flow route

Figure 5 – Relationship of functional carriages based on personnel flow route

4.3. Relationship of functional carriages based on information flow route

The information flow route involves examination, patient diagnosis and treatment tasks. The examination carriage collects the sample results into the command carriage. The command room formulates a surgical and treatment plan according to the sample results and assigns tasks to each medical carriage, as shown in *Figure 6*. The task dispatch flow route shall be executed when the patient first boards the medical train and once per day after that.

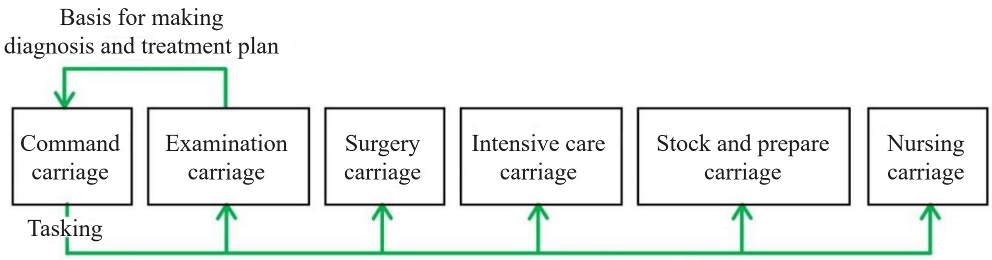
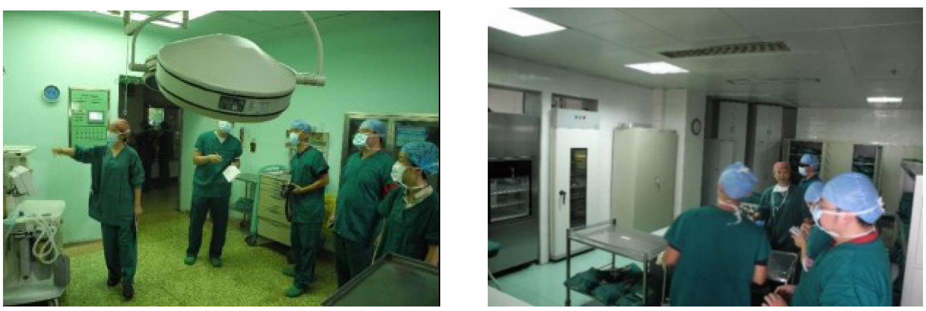


Figure 6 – Relationship of functional carriages based on information flow route

5. EVALUATION INDEX SYSTEM OF FUNCTIONAL CARRIAGE DESIGN

More than 20 experts in the fields of transportation vehicle design, health services and medical equipment were invited to discuss the task flow, operations, teamwork and other practical problems of the medical train after conducting field studies on the environment and tasks such as operating rooms and medical equipment storage rooms (see *Figure 7*). These field studies and research helped the experts gain insight into the conditions required for medical operations. The objectives of the medical train functional carriage design include: enhancing the flexibility of carriage grouping schemes, ensuring a comprehensive and reasonable functional configuration,



a) Operating room *b) Medical instrument stocking cabinet*

Figure 7 – Pictures of field research

simplifying material management, minimising the cross interference between different functions, reducing the crossover of task processes, reducing the travel distances in each task and avoiding the congestion caused by personnel crowding into a small area. Based on the above objectives, this paper compiles an evaluation index system for the design and arrangement layout of functional carriages of high-speed medical trains, which contains six primary and 15 secondary indicators, as shown in *Table 2*.

Table 2 – Evaluation index system of functional carriage design of the high-speed medical train

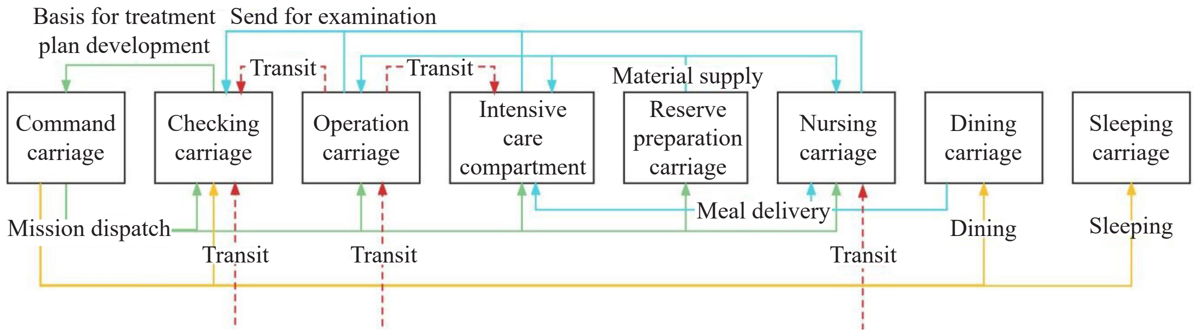
Primary indicators	Secondary indicators	Interpretation
Carriage grouping	A_1 Grouping flexibility	The adaptability of different carriage groupings to different tasks
Function configuration	A_2 Function configuration comprehensiveness	Variety of functions that can be achieved
	A_3 Function configuration rationality	Whether the design meets the demands of medical treatment and daily operations
Space arrangement	A_4 Spatial independence	Operational independence of functional space
	A_5 Space utilisation	Utilisation level of cabin space
Material management	A_6 Material management difficulty	Difficulty in purchasing and selling, storing and transporting and accessing medical and living materials
	A_7 Supply security difficulty	Difficulty in replenishing supplies when supplies are scarce or reserves are low
Load capacity	A_8 Material stockpile	Number of medical supplies in storage
	A_9 Trains shipment capacity	Number of patients and casualties that can be accommodated
	A_{10} Medical care capacity	Number of health care workers that can be accommodated
	A_{11} Task load capacity	Accommodating task types and numbers
Operational efficiency	A_{12} Task flow crossover	Number of other functional carriages involved in the task execution process
	A_{13} Task line distance	Distance travelled to perform the task
	A_{14} Logistics route distance	Material transfer and delivery distance
	A_{15} People movement distance	Staff and patient flow distance

6. DESIGN AND EVALUATION

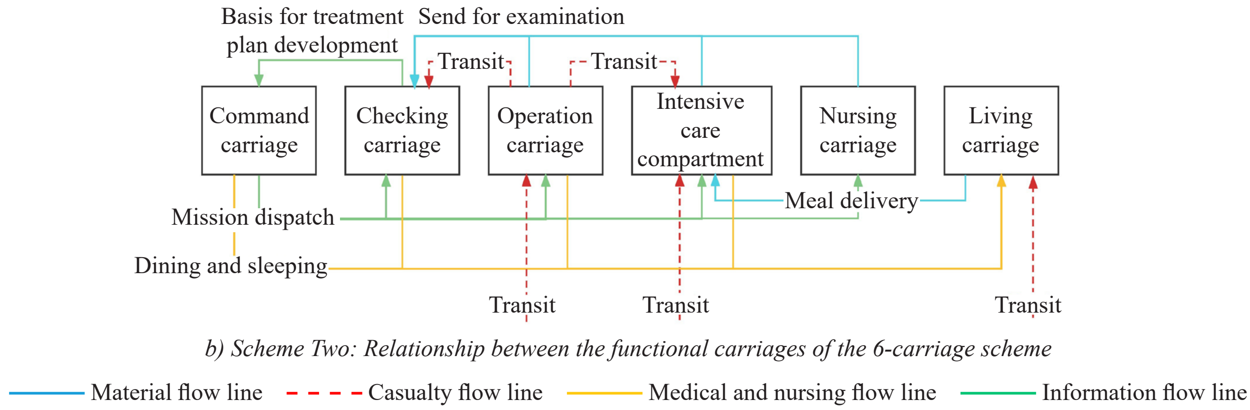
6.1 Arrangement layout of functional carriages based on task flow

Based on the carriage relationship analysis of logistics, personnel and information flow, a comprehensive diagram of the functional carriage interrelationship of high-speed medical trains is constructed, shown in *Figure 8*. It provides a basis for the design of the arrangement and layout of functional carriages of high-speed medical trains. The design idea is introduced by taking the arrangement layout of the 8-carriage scheme as an example. The layout of the 6-carriage scheme is consistent with the philosophy behind the 8-carriage scheme.

The command carriage of the high-speed medical train is responsible for the real-time monitoring of the train status and communications. The relevant systems are currently integrated with the head carriage, so the head carriage is set as the command carriage. For the rest of the carriages, the medical area and living area are distributed at both ends. The medical area includes a command carriage, an examination carriage, a surgery carriage, an intensive care carriage, a medicine storage and preparation carriage and a nursing carriage. The living area includes a catering carriage and a sleeping carriage. The meal distribution flow involving the above two areas and the dining and sleeping flow for medical and nursing managers occurs infrequently. Thus, there will be no conflict with other task flows and there will be no congestion on traffic routes. In the medical area, medical personnel in the command carriage develop surgical plans and treatment plans based on information reported by the examination carriage, which means they should be placed as closely as possible. In addition to examining the samples sent to the examination carriage, the carriage is also used for ECG, ultrasound and radiology examinations. In order to reduce the moving distance of the patients before surgery, the surgery



a) Scheme One: Relationship between the functional carriages of the 8-carriage scheme



b) Scheme Two: Relationship between the functional carriages of the 6-carriage scheme

Figure 8 – Interrelationship of the functional carriages of high-speed medical trains

carriage is placed adjacent to the examination carriage. Due to the patient flow routes between the surgery and intensive care carriages, they have strong functional correlation. To reduce the movement distance of patients after surgery, the two carriages are arranged next to each other. The storage and preparation carriages need to frequently provide medical equipment, consumables and drugs for surgery, intensive care and nursing carriages. There is a frequent flow of medical materials to and from each medical carriage. In order to reduce the delivery distance of medical materials, the storage and preparation carriages are placed between the intensive care carriage and the minor injury nursing carriage. In the living area, the dining car is set close to the medical area because of the more frequent flow of personnel and materials between the dining car and each functional carriage.

The above layout determines the workflow of the high-speed medical train as follows. ① The patients are transferred to the surgical carriage, the intensive care carriage and the nursing carriage of the high-speed medical train according to their acuity levels. ② The medical staff of each carriage collect and send samples of the patients to the examination carriage to avoid overcrowding of the sick and wounded in the examination carriage. ③ The examination carriage sends the examination results to the immediately adjacent command carriage. ④ The command carriage sends the medical treatment plan and tasks to the surgery carriage, intensive care carriage and nursing carriage, respectively. ⑤ The storage and preparation carriage supply materials to the adjacent intensive care carriage and nursing carriage. ⑥ The surgical carriage transfers the patient to the neighbouring intensive care carriage after completing the surgery. ⑦ Catering carriage distributes ready meals to the intensive care carriage and nursing carriage. ⑧ Command carriage personnel go to the dining car for meals three times a day. ⑨ The medical staff goes to the adjacent sleeping carriage for rest after meals.

6.2 Comparison of the design schemes of the functional carriages

Based on the evaluation index system, the results of comparing Scheme One and Scheme Two are shown in *Table 3*. As the material storage module is placed adjacent to the functional carriages highly related to it, the transportation distances of medical materials are shorter in Scheme Two; however, that increases material management difficulty. Compared to Scheme One, Scheme Two has better spatial independence and space utilisation; the task process crossover is reduced because there is no medical material supply route; the task route distance, logistics route distance and personnel flow distance are reduced, and the overall operational

Table 3 – Comparison of functional carriage design options for high-speed medical trains

Primary indicators	Secondary indicators	Scheme One (8-carriage)	Scheme Two (6-carriage)
Carriage grouping	A_1 Grouping flexibility	Poor	Excellent
Function configuration	A_2 Functional configuration comprehensiveness	Same	
	A_3 Functional configuration rationality	Same	
Space arrangement	A_4 Spatial independence	Poor	Excellent
	A_5 Space utilisation	Poor	Excellent
Material management	A_6 Material management difficulty	Excellent	Poor
	A_7 Supply security difficulty	Excellent	Poor
Load capacity	A_8 Material stockpile	Excellent	Poor
	A_9 RPM capacity	Excellent	Poor
	A_{10} Medical care capacity	Excellent	Poor
	A_{11} Task load capacity	Same	
Operational efficiency	A_{12} Task flow crossover	Poor	Excellent
	A_{13} Mission line distance	Poor	Excellent
	A_{14} Logistics route distance	Poor	Excellent
	A_{15} People movement distance	Poor	Excellent

efficiency is improved. In addition, the load capacity of Scheme Two is reduced by using a 6-carriage grouping; however, as it breaks away from the traditional 8-carriage grouping, it can achieve more flexible configurations of functional carriages and enables task-specific functional carriage grouping schemes. Overall, the convenience brought by eliminating separate material storage carriages far outweighs the disadvantages and is better than Scheme One. Therefore, subsequent studies should be based on Scheme Two for adjustment and modification as a basis for further research.

7. DISCUSSION

Scheme One is an 8-carriage design, and Scheme Two is a 6-carriage design, both designed according to the correlation between the task model and the functional modules. Although the 6-carriage scheme reduces the carrying capacity due to fewer carriages, it allows greater flexibility and adaptability in the configuration of functional carriages when facing different medical tasks because it breaks the limitation of the 8-carriage scheme for high-speed trains. Generally speaking, the advantages of the 6-carriage scheme far outweigh the disadvantages, so this innovative scheme is better than the traditional 8-carriage scheme. The results of this study can provide a basis for further optimisation of the configuration and arrangement of medical train carriages.

The analysis method based on task and flow route and the evaluation method proposed in the paper provide sufficient design basis to help ensure scheme rationality and provide theoretical and methodological support for the design of functional carriages for high-speed medical trains. However, the design solution is a theoretical-based research result, which still needs to be revised and improved in the subsequent influence of technical and social related factors.

The analysis method proposed in this paper provides sufficient theoretical and methodological support for designing functional carriages for high-speed medical trains. We have achieved a reasonably optimised layout of high-speed medical trains through the combination of task and flow analysis and discussions of task and functional configuration relevance. More importantly, through analysing the results, this paper proposes an innovative design scheme that breaks away from the traditional grouping scheme and concludes that the optimised scheme is feasible and effective. Therefore, the analysis method proposed in this paper can be more widely applied to tasks involving complex personnel compositions and procedures. On top of that, the evaluation index system can decide whether the optimised design meets the requirements. However, the design solution is a theoretical-based research result, which still needs to be revised and improved in the subsequent influence of technical and social factors.

8. CONCLUSION

This paper studies two important issues: functional carriage configuration and arrangement layout of high-speed medical trains. Based on the HTA method, we constructed a task model for medical transfer on high-speed medical trains, and we proposed four major functional modules and 28 submodules of high-speed medical trains based on the analysis of the human-machine-environment system. We used the correlation between the task model and the functional modules as the basis for the division of functional modules of high-speed medical train carriages. The three task flow routes of the high-speed medical train are the basis for the arrangement and layout of functional carriages. We summarised the evaluation indexes of the functional carriage design for the evaluation and comparison of the two functional carriage configuration schemes, summarised the pros and cons of the two solutions and provided a basis for further optimisation of the design.

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高速医疗列车功能车厢设计：任务、功能和流动路线的系统分析与评价

摘要

为提升高速医疗列车运行效率，提出了功能性车厢设计和评价指标体系。运用层次任务分析和人-机-环境分析方法，对医学培训的交接任务和功能模块进行建模。通过任务与功能的相关性分析，得到功能模块的配置。通过对物资流、人员流和信息流的分析，阐明了车厢之间的关系，得到了最优分组图。基于该设计方法，提出了一种创新性的6车厢分组设计方案。构建了车厢设计功能评价指标体系，并将6节车厢设计与传统的8节车厢设计进行了对比，验证了设计方法的可用性。研究结果表明，6节车厢高速列车可灵活配置，以适应不断变化的任务环境，总体上优于8节车厢设计。本研究为构建高效合理的高速医疗列车功能车厢提供了理论和方法支持。

关键词：

高速卫生列车；流线分析；任务功能相关性；功能车厢