Research on Teaching Reform of Cruise Emergency Drill Based on Virtual Simulation — Against the Background of Safety Supervision Requirements for Cruises in Hainan Free Trade Port

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Abstract: *There is a problem of cognitive overload in teaching cruise emergency drills due to the coordination of many systems, a short time window and a large number of people. A special shipping Area has been added to the Hainan Free Trade Port to reduce the length of the navigation Area and thus shorten the emergency response time. The old scripted drill mode is not very realistic in imitating real life, and generally has low branch coverage and a long feedback period. With the help of virtual simulation technology, this paper has developed a teaching model for cruise emergency drills that includes hierarchical modelling and interaction mechanisms for immersive emergency scenarios, a logical parametric design method for teaching-oriented emergency event chains, and a distributed virtual environment architecture for multi-role collaborative drills. Therefore, the teaching plan in this paper will be revised according to the regulations mentioned above. Modular deconstruction and dynamic rearrangement have been employed to build quantitative mapping rules for operational standardisation based on regulatory indicators, a multi-dimensional evaluation index system and formative feedback have been established, and thus, the adjustability and traceability of drill teaching have been achieved. Organise the theoretical basis and technical roadmap for teaching emergency drills in light of the safety supervision requirements of cruises in the Hainan Free Trade Port in this paper.*

Keywords: *Cruise emergency drill, Virtual simulation, Teaching model construction, Hainan Free Trade Port, Safety supervision constraints, Multi-dimensional evaluation*

Introduction

The emergency response ability of a cruise ship directly affects the safety of life at sea and the continuous operation of the vessel; thus, good teaching and training will be provided to improve this aspect in the shipping industry. With the development trend of large cruise ships and more complicated routes, the cognitive tasks in emergency drill teaching, such as information perception, state diagnosis, action decision-making and execution verification, have shown characteristics of nonlinear coupling and thus have higher demands on the basic operational skills and advanced coordination skills of trainees. Given that there are many ports in the Hainan Free Trade Port, various kinds of weather all year round, and strict time windows for port entry and exit, the time available for emergency response is also limited. The old drill mode is a combination of scripted scenarios and fixed-point practical exercises; it is not easy to create many different scenarios with a high probability of branching, and there is no real-time behaviour correction or personalised feedback diagnosis. Therefore, virtual simulation technology should be introduced and the teaching model for emergency drills needs to be reformed. Hierarchical Models and Distributed Virtual Environments can reconstruct the spatial topological structure of cruise cabins and the evolution process of disaster physical fields, and at the same time, based on the capability profile of the trainees, modifications can be made to the difficulty gradient and training focus, and parametric event chain design and modular process reorganization can also be carried out. Based on the problems mentioned above, this paper proposes a teaching model and an evaluation system for it to provide a good technical solution to the teaching of cruise emergency drills in special shipping environments.

1. Theoretical Basis and Practical Problems of Cruise Emergency Drill Teaching

1.1 Cognitive Task and Skill Decomposition of the Cruise Emergency Response Process

The attributes of the cruise emergency response process are that it involves many systems, has a limited time, and many people are concerned. According to the view of cognitive task analysis, the four recursive stages of the emergency response process are information perception, state diagnosis, action decision-making and execution verification. All the stages have different kinds of cognitive loads. For example, the first two are to find the location and filter noise, and the latter two are to know when to use resources and which risks are relatively high. Based on the above tasks, they need to be combined with the specific cabin arrangement and passenger flow of a cruise ship to form a quantifiable set of subtask nodes[1].

Based on the results of cognitive task decomposition, the corresponding skill system can be divided into two levels: basic operation skills and advanced coordination skills. The first few skills are those that are easy to observe, such as how to use the emergency equipment and cabin isolation. Good coordination skills refer to the information-sharing system of the emergency command centre, rules for communication among different roles, and the ability to think and make decisions in the face of missing information about the situation. There is a nonlinear coupling between the two levels of skills; that is, the proficiency in basic skills directly affects the response latency and error recovery efficiency of advanced coordination. Based on the above analysis, the more regular the operation sequence of basic skills is, the lower the demand for communication bandwidth in advanced coordination; therefore, training in basic skills should be conducted at the beginning of the teaching process.

1.2 Characteristics of Safety Supervision Constraints in the Special Shipping Environment of Hainan Free Trade Port

The cruising routes of the Hainan Free Trade Port generally have several port stops and areas with different seasonal weather, so they are not the same as those along the traditional coast. Constraints on safety supervision in this area refer to the restrictions on the accessibility of navigation areas, the requirements for the accuracy of the port entry and exit window period, and the need to promptly verify the qualifications of foreign shipboard personnel. The mapping of the above constraints in the teaching of emergency drills is as follows: The drill cases need to have some geometric parameters for the ports and tidal curve data so that trainees can be exposed to the operating limits in line with actual navigation in virtual environments.

Based on the above analysis, it has been decided to reduce the time basis for emergency response systematically. For example, in some waters under the jurisdiction of the Hainan Free Trade Port, the window for the arrival of search and rescue forces is shorter than the standard value recommended by the International Maritime Organization, so the emergency organisation on board needs to complete the entire chain of response from detection to action in less time. Given the reduction in space, the new teaching goals should consider that students have less time and fewer resources for study, so decisions need to be made more promptly. Modify the multiplier of the scenario clock and the information update frequency according to the constraint conditions listed above in the virtual simulation platform parametrically. At the same time, the system will also record the distribution of trainees' decision delays in the short period of high demand and quantify how much this time pressure has affected the accuracy of operations.

1.3 Limitations in the Adaptability of the Traditional Drill-Teaching Model for Dynamic Scenario Simulation

Most of the traditional cruise emergency drills are in line with the structure of the organisation, use scripted reasoning and fixed-point practical operations, and the logic for creating scenarios is based on preset event sequences and fixed personnel trigger nodes. Given that emergency evolution is non-linear and irregular, and there may be many simultaneous failures or changes in personnel behaviour due to expectations, this method may not cover all the circumstances and will fail to find some response paths. The first characteristic of dynamic Scenarios is that there are probabilistic branches in the causal chain of events, and scripted mode is not suitable for producing a large number of variations in branch logic at an increased labour cost[2].

The old way of increasing the speed of feedback is to have people observe movement and then manually record and summarise what they have learned; thus, the trainees do not receive timely feedback on correcting their behaviour during the training. In the course of an emergency that requires teamwork, the trainees will not know how to coordinate communication at different times about the results they have achieved. Behavior recording and assessment modules have been added to the virtual simulation technology, and the feedback delay is now in the millisecond range; traditional drill methods do not have such a kind of real-time diagnosis at the level of technical architecture and are therefore less suitable for teaching in highly dynamic emergency situations. The old way is not good at generating all kinds of feedback reports for different trainees; everyone receives the same evaluation information and cannot identify their own weak links in cognitive task decomposition.

2. Construction of a Teaching Model for Emergency Drills Based on Virtual Simulation

2.1 Hierarchical Model and Interaction Mechanism for Immersive Emergency Scenarios

The hierarchy of immersive emergency scenarios is created by adding behaviour rules to the bottom of scenario primitives. At the bottom is the static environment layer; it contains the spatial topological structure of the cruise cabins, locations of equipment distribution, emergency signage systems, etc., all of which are geometric and semantic information that do not change with time. In the middle is a dynamic event layer that contains physical process models with patterns of spatiotemporal evolution, such as the spread of fire, the speed of waterlogging and smoke diffusion, etc. At the top is the interaction response layer; it saves the operation input of the trainees and modifies the scenario state variables. The three layers are connected by event-triggering functions; for instance, when the open state of a cabin door changes, it will update the boundary conditions for smoke diffusion in the middle layer.

The Design of Interaction Mechanisms should meet the demands of teaching regularity and situational realism. Therefore, a discrete-event-driven system will be used; that is to say, every operation carried out by the trainee will be recorded as a state-change command and a timestamp. Therefore, based on the above, the interaction response should be in line with the actual physical delays and feedback characteristics of cruise emergency operations, such as the non-linear rise curve of water pressure after opening a fire hose. To solve the problem of spatial disorientation in the virtual world, haptic proxies and spatial audio cues have been added to help trainees feel their surroundings and judge the distance to equipment. The interface for interaction is also a combination of many ways; that is to say, controller operation, voice commands and head movement tracking can all be used together to simulate all channels of information processing required in an actual emergency.

2.2 Teaching-oriented Parametric Design Method for Emergency Event Chain Logic

Parametric Design of the Emergency Event Chain Logic is Based on the Skill-Level Decomposition of Teaching Objectives. Every chain of events has a starting trigger, some intermediate development steps, and a final result, and both the probability distribution and the time duration of the intermediate stages can be set as parameters. A rule-based logic generator is used to construct a parametric expression, and then, by taking the Cartesian product of different accident types, various scenarios such as engine room fires, passenger overboard incidents and public health events are created according to the current navigation stage of the cruise (including berthing, departure and sea navigation) to build the initial condition matrix of the event chain. The range of the parameter value is based on the statistical data of event evolution times in the relevant training manual of the International Maritime Organization. Parametric methods can also take the external environment into account, such as wind speed, visibility and the condition of the sea, and thus change the development path of the event chain according to the actual conditions at sea[3].

The way of teaching in this Design Method is to adjust the gradient of difficulty. By altering the three-dimensional parameters of the event chain, that is, the presentation delay of information, the insertion frequency of disruptive events and the length of the crucial decision period, many scenarios based on different abilities of trainees can be created. Parametric Design can be employed to address the problems in teaching as well. For example, if the basic skill decomposition shows that trainees have a relatively high error rate in the "information perception" stage, then we can reduce the branch complexity of the intermediate nodes and shorten the information refresh interval to focus training on the cognitive processing efficiency of that stage. All the parameter settings can be saved as preset templates, and then these templates can be used, modified, etc. The library of parameter configurations has been versioned, and based on the teaching data accumulated so far, the range of parameters will be automatically optimised to reduce the subjectivity of manual parameter tuning.

2.3 Distributed Virtual Environment Architecture for Multi-role Collaborative Drills

The Structure of a Distributed Virtual Environment is a Client-Server Model with Permission Gradients. The server has one database to store the current attitude of all ship motion, the development of disaster physical fields and operation records for all roles. Based on the type of the logged-in role, a different interaction interface and information area will be shown to the client. For example, the commander has a general view of the situation from the cabin and a map of resource distribution, but the view of the on-site response personnel is only local information and communication channels in the deck area where they are located. A stable transmission mode with state synchronization has been added to the network communication protocol, so all clients will have the same virtual timestamps and will not have action sequence disorder due to latency differences. A timeline management module on the server side can be used to stop all operations, step through them, and play back some parts of the teaching for review and analysis[4].

The reason for the multi-role cooperation is that there is some interdependence among all these roles. Authorisation Chains and Reporting Paths for the Roles have been set up in the system. Only the commander can operate the general alarm public address system of the ship; the other stations can only send information request messages to their superiors. At the same time, the system will also record how often messages are sent by different roles and how quickly they are replied to. There is a problem of resource contention in a multi-user environment, and thus a priority-based operation lock mechanism has been introduced. When the two trainees issue different commands to the same virtual device, the system will determine which one is correct according to the order of post authorities in the accident handling rules. It is also compatible with many kinds of end devices, so some students can participate in the same activity using virtual reality glasses, and others can do so on a computer; thus, the hardware requirements are relatively low.

3. Reconstruction of the Teaching Process and Evaluation System in Light of Regulatory Requirements

3.1 Modular Deconstruction and Dynamic Reorganisation of the Virtual Drill Teaching Process

Modular Deconstruction of the Virtual Drill Teaching Process divides all the stages of the emergency drill into separate teaching modules. Each unit is a relatively simple task that has a clear start and end, such as confirming the fire alarm, issuing the first alarm, guiding passengers to the assembly area, and so on. The two levels of deconstruction are the time sequence of emergency response operations and the responsible posts; that is to say, different units should have a logical predecessor-successor relationship and be able to operate independently when separated from the original sequence. All the necessary parts of the virtual scenario, role permission settings and evaluation indicators have been added to each teaching unit, and they are now complete sets of teaching materials.

The division of the group can be based on how capable the trainees are at present. The Rules of Organisation are based on the decision tree for cruise emergency response, and some non-critical path units have been designated as skippable or adjustable in sequence. For example, after the trainees have learned all the components of communication protocols, that part can be omitted and only the logical connections to the other parts need to be shown. Add a particular constraint for the navigation environment in the Hainan Free Trade Port, such as reducing the window for personnel evacuation in narrow waterways, and another judging factor is to have the trainees rank the two evacuation plans in a short time. The restructured teaching process will automatically generate new weights for assessment, and we do not need to leave out any part of the evaluation[5].

3.2 Quantitative Mapping Rules for Operational Standardisation Based on Regulatory Indicators

The Regulation Index is the specific list of cruise emergency response requirements published by the Navigation Water Safety Management Office. The above indices are in the form of qualitative or semi-quantitative norm documents, such as the time limit for the emergency communication response, the accuracy rate of the passenger muster station headcount, and the completion sequence of fire-fighting equipment operation. First, the rules of quantitative mapping convert the normative texts above into operational factors and clear observable variables. Every link in the chain is a behaviour that can be recorded by the virtual simulation system, such as pressing the alarm button, sending a command on a particular channel, or carrying out a series of protective equipment donning operations. The granularity of the operation element should be set according to the triggering frequency of the sensor in the virtual system, and there should be no unobservable ambiguous indicators.

The first aim of the mapping rule is to change the permitted deviation range in the regulations into the boundary conditions of the scoring function. Emergency communication is a typical case, so the time to detect an emergency and issue an alarm should be short. The mapping rule set the upper bound for the start of the linear penalty function, and if it exceeds this limit, the penalty rate is divided into several sections according to the overtime multiplier. For example, in order to operate in a certain way, ventilation must be off before a fire extinguisher can be used; therefore, a mapping rule called a sequence constraint matrix can be used to specify which sequences are allowed and which are not. The relationship of all pairs of operational elements in the matrix is given by binary judgment values (allowed or not allowed). At that time, the system will record the operation steps of the trainees and compare them with the matrix. If there is a forbidden sequence, a warning will be issued immediately. The mapping rules shown above are in an editable configuration file, and they will be updated automatically after changing the regulatory indicators.

3.3 Multi-dimensional Evaluation Index System for Formative Feedback in Drill Teaching

The index system for formative feedback is different from that of summative assessment, and its purpose is to offer a reference for correcting behaviour during the process of drilling, not after the drilling has been completed. The three parts of the index system are: the time index stores the time it takes for the trainee to complete each sub-task and the standard time window; the sequence index is the edit distance between the operational path and the reference path; and the state index is the difference in instantaneous values of key variables in the virtual scenario, such as the area spread by fire and the number of evacuated passengers, and the target control ranges. The indices of the three dimensions are taken at the same time along the time axis, and the sampling frequency is changed according to the time sensitivity of each subtask; a high sampling rate is used in periods of high sensitivity, such as before and after decision points.

Generally speaking, the form of the output for the multi-dimensional indicators is a combination of a real-time display window and a post-event heatmap. The live dashboard will show how far each trainee is from the norm, and to avoid disturbing them, all sorts of non-verbal cues will be used to draw attention, such as changes in colour gradients or shifts in the contour of graphics. A post-hoc heatmap of the three dimensions of the spatial arrangement in the virtual world is shown below. For example, if all three indicators of high temporal deviation, high sequential deviation and state variable exceedance occur at the same time in a particular cabin, it can be concluded that there is an organised problem with the teaching module for that area. An index system will be established to determine whether the increase in the deviation of one area of the indices is due to a decrease in another. For instance, if the accumulation of deviations in a row of operations reaches a certain threshold, the time deviation will start to increase rapidly, and an early warning of teaching intervention will be issued.

Conclusion

According to the division of cognitive tasks, this paper will systematically analyze the hierarchical structure of skills in the cruise emergency response process and the effect of safety supervision constraints on drill teaching in the Hainan Free Trade Port to uncover the adaptation limits of the current traditional model in dynamic scenario simulation. Based on the above, this paper proposes a teaching model for emergency drills based on virtual simulation and introduces the hierarchical model of immersive scenarios, parametric design of event chain logic, and a multi-role distributed collaboration architecture. Modular deconstruction and dynamic rearrangement of teaching can be employed to set up quantitative mapping rules for operational standardisation based on regulatory indicators and establish a multi-dimensional evaluation index system for formative feedback. Based on the above results, the theoretical basis and Design Model for using virtual simulation technology in cruise emergency education have been established. First, based on the behaviour data of the trainees in the future, adaptive parameter optimisation algorithms need to be developed that can change the level of cognitive load for individuals dynamically according to the branch probabilities and difficulty gradients of event chains. Second, add eye-tracking and other physiological indicators to the evaluation system to obtain more detailed information on the efficiency of cognitive processing at the time of information perception and state diagnosis. Third, the large-scale concurrency capacity of the distributed virtual environment should be increased to support the construction of joint drill scenarios with multi-ship coordination or ship-shore linkage.

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