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Risk assessment model and application of COVID-19 virus transmission in closed environments at sea

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\textbf{ARTICLE INFO}

\textbf{A B S T R A C T}

This paper focuses on the risk assessment methods of novel coronavirus pneumonia virus (COVID-19) pneumonia virus spreading in closed marine environment. Firstly, the possibility of the spread of new coronavirus in closed environments at sea and the consequences of the harm caused by the epidemic are classified into five levels, and the corresponding risk assessment framework is constructed, and the risk assessment model of the spread of COVID-19 pneumonia virus in closed environment at sea is established taking the Japanese “Diamond Princess” as an example, the model is applied and its output is analysed. Finally, the proportion of the cumulative confirmed cases on the Diamond Princess is calculated, and the possibility of viral infection of Diamond Princess passengers in this COVID-19 pneumonia epidemic in four different risk transmission stages are assessed, and the corresponding risk assessment is undertaken. Through the calculation of risk assessment value, the five stages of the epidemic are established to assess the risk of the “Diamond Princess” outbreak. The research method in the present work helps to provide a risk assessment and analysis idea for the risk of spread of the COVID-19 epidemic in a closed environment at sea.

1. Introduction

In the early study of novel coronavirus, research focused on the pathological phenomenon and transmissibility. Some scholars analysed 41 hospitalised patients with COVID-19 infection, and studied the epidemiology and symptoms of virus transmission. Confirmed cases with COVID-19 were infected by transmitted through the indoor air in hospital wards, leading to a further increase in the number of hospital with COVID-19 were infected by transmitted through the indoor air in

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1. Introduction

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effects on confirmed cases in infection clusters (Li et al., 2021). Facing the COVID-19 epidemic crisis, enterprises in the society are faced with complex and changeable challenges, especially affecting the business model and strategy of business (Ritter & Pedersen, 2020). Environmental analysis shows that the severity of the epidemic directly or indirectly affects the demand for energy (Norozi, de Rubens, Chouhanpishehzafar, & Enevoldsen, 2020). Using the data from an automatic identification system, the movement of all ocean cruise ships around the world from January to March 2020 was tracked, and it was found that the infection rate of COVID-19 in cities accepting cruise ships was higher than that in cities not accepting cruise ships (Hirohito et al., 2020). According to the airborne transmission characteristics of COVID-19 virus, the effect of airborne transmission of COVID-19 virus in the hospital is limited, but the possibility of infection can be decreased by keeping a certain distance from the patients infected by COVID-19 (Vosoughi et al., 2021). As the key member of the sustainable consumption and production system network, human beings need to make behavioural changes in response to the COVID-19 epidemic, which can provide effective insights to promoting sustainable supply and production (Sarkis et al., 2020). The risk impact of norovirus in Marine cruise ships was evaluated. The risk degrees of different regions of the cruise ship differ: they can be classified into three types which are slight impact area, general impact area and major impact area (Widdowson et al., 2004). The influences of infectious diseases in different regions are different, and the number of affected people in different regions are classified according to the the area infected by norovirus (Zhang et al., 2015). Depending on medical, environmental, and engineering factors, it is of practical guiding significance to study the distance and ventilation quantity, so as to ensure the normal order of the city (Sun & Zhai, 2020). Using on-line data to detect confirmed cases of COVID-19, using a multiple vector regression model to predict the number of infected people in Shenzhen, and assessing the risk of cities during the pandemic is key to scientific decision-making and promoting the sustainable development of cities (Huang et al., 2020). Based on the principles of thermodynamics, the COVID-19 virus in 17 cities in Hubei Province was analysed, and the risk assessment of each city was emphasised, and the risk level was determined, which provided technical support for the prevention and control of this urban epidemic (Pang, Wu, & Lu, 2021). Similarly, we calculate the risk of spread of the COVID-19 epidemic in a closed environment based on epidemic data; different from other studies, we systematically evaluate the risk holistically and at each stage.

There is a certain correlation between the enclosed environment and virus transmission. The transmission process of the Ebola virus was analysed using remote sensing technology (Olivero et al., 2017). Using mathematical analysis and modelling, the virus transmission path in a suitable environment is analysed, and the virus transmission path in closed environment is specifically studied (Nicholas et al., 2008). The neural network module was extended to the classic SIR epidemiological model, and the published online COVID-19 epidemic data were studied by machine learning algorithm to evaluate the level of risk in each region (Dandekar, Rackauckas, & Barbashitis, 2020). It is found that the isolation effect is limited in the presence of a high proportion of symptomatic patients, and other preventive measures should be taken to prevent and control the spread of the virus (Huang et al., 2020). COVID-19 transmits in the closed environment of sea cruises, so monitoring of relevant aspects of sea cruises, use of relevant detection and early warning algorithms, and protective measures were proposed (Benvenuto et al., 2020). In addition, the infectivity and severity of new crown pneumonia in different stages of the first five months of the epidemic in most countries in the western Pacific region (WPR) were evaluated and compared; this provided new ideas for preventing and controlling the further expansion and spread of the epidemic (Yeoh et al., 2020).

At present, the novel coronavirus pneumonia research focuses on the medical research and risk communication research of the virus itself, involving the etiology, transmission, symptoms, and preventive measures pertinent thereto; however, the risk of novel coronavirus in the closed marine environment has not been analysed, and the quantitative analysis of risk in a breeding environment is lower. In addition, there are five characteristic features of the existing research: first, we study the transmission of the COVID-19 virus and the serious consequences of the viral infection. Second, we study the pathology of COVID-19 and the effect of drugs from the medical point of view. Third, we study mathematical models for, or statistics pertaining to, COVID-19. Fourth, we study the transmission characteristics of COVID-19 in a closed environment. Fifth, we study the spread and severity of COVID-19 on the Diamond Princess. Based on the existing research, we further studied the new issues: The risk characteristics and the risk assessment model of COVID-19 spread in closed environment at sea, and the model application of “Diamond Princess’. The structure of the article is as follows: Section 2 covers the method used: the novel coronavirus can be classified into five levels by the possibility of transmission in the marine closed environment and the harm caused. We construct the corresponding risk assessment framework and establish a risk assessment model. In Section 3 we demonstrate the application results, taking Japan’s “Diamond Princess” as an example to analyse transmission of novel coronavirus pneumonia in closed marine cruise sites, calculating the proportion of the confirmed cases and analysing the transmission speed of the epidemic in different stages; furthermore, a risk assessment is conducted through application of the model. In Section 4 we draw the conclusions.

### 2. Methods

#### 2.1. Risk factors and classification of infectious diseases in enclosed places on cruise ships

Risk identification and assessment of infectious diseases allows a comprehensive qualitative and quantitative evaluation of the possibility, and severity of harm, of infectious disease events. Under the background that the new epidemic affects people’s lives worldwide, its spread on cruise ships has attracted more attention. Therefore, based on the medical research into the COVID-19 epidemic, combined with the characteristics of the spread of large-scale cruise ship epidemic, this allows risk identification and risk assessment under the condition of insufficient medical resources on cruise ships without considering

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Table 1

Assessment of infectious disease risk factors in closed places on cruise ships.

| Evaluation factor | Observational index                                                                 |
|-------------------|--------------------------------------------------------------------------------------|
| Transmission route| How difficult it is to spread.                                                       |
| Susceptible population | Problems caused by crowds gathering in enclosed places on cruise ships.          |
| Size of enclosed environment | The overall level of immunity of the population, the proportion of susceptible and non-susceptible populations in the population, and their spatial distribution. |
| Natural factors   | The size of the closed environment can determine the speed of virus transmission. Large environment, slow spread. Small environment, fast spread. |
| Social factors    | Factors such as season, climate, geography and natural disasters at ports of call. |
| Human factors     | Social system of port of call, level of economic development, level of medical treatment, differentiation of customs and social atmosphere, that is, people’s actions, health habits, health facilities and service capacity, domestic relevant safeguard policy factors. |
| Preventive and control measures and effects | The gathering environment, contact probability and personnel density. |
|                   | Current status of disease; level of early disease identification. Ability to cope; cognitive level of social concern; universal health education. |
Susceptible population mainly refers to the situation wherein the cruise transmission, which has a severe impact on the susceptible population. If the size of cruise closed environment mainly determines the speed of virus spread. The ship itself is closed, which readily causes overall crowd infection. The method can be used to identify and assess the risk of infectious diseases on-board a cruise ship. The objects of this study include: biological factors, behavioural factors, environmental factors and social factors, in which, (1) biological factors include source of infection, route of transmission, and susceptible population; (2) behavioural factors include psychology and culture; (3) environmental factors include natural and ecological environment; (4) social factors include laws and regulations, standards, applicability, prevention, control strategies and measures, and level of management (Xiong et al., 2010). Based on the medical research into this novel coronavirus, we select evaluation factors such as transmission route, susceptible population, size of enclosed environment, natural factors, social factors, human factors, prevention and control measures and their effects (Table 1).

Table 2 shows the seven risk factors of infectious diseases in enclosed places on cruise ships, in which the transmission routes are mainly observed through the infection of transmission sources such as droplet transmission, airborne transmission, and dust transmission. China’s novel coronavirus pneumonia outbreak in Wuhan, China, in December 2019, was transmitted through intimate contact, seafood, and droplet transmission. Therefore, the route of transmission of covid-19 is not limited to close contact and seafood (Harbizadeh et al., 2019; Kenar-kooch et al., 2020; Noorimotlagh et al., 2020; Vosoughi et al., 2021). The susceptible population mainly refers to the situation wherein the cruise ship itself is closed, which readily causes overall crowd infection. The size of cruise closed environment mainly determines the speed of virus transmission, which has a severe impact on the susceptible population. If the cruise ship is large enough to accommodate many people, the number of infected people will be large. Cruise ships are small (in relative terms compared to the normal range of human habitat, tourists are densely packed therein, and the virus spreads rapidly; natural factors mainly refer to the departure season and climate, which are the main factors causing the spread of diseases. For example, plague is more likely to break out in spring and summer, and influenza becomes more likely in autumn and winter. If the cruise starts in autumn or winter, if there are susceptible people on the cruise, there may be a large-scale outbreak of influenza thereon. Social factors mainly refer to the sanitary conditions, health facilities, and health service capacity of the cruise ship. Human factors mainly refer to the probability and speed of virus transmission determined by the gathering environment, contact probability, and personnel density in the enclosed places on-board.

2.1. Risk factors and assessment methods of infectious diseases in closed places on cruise ships

According to a study on the outbreak of acute gastroenteritis in the closed sea cruise sites registered by the Centers for Disease Control and Prevention and the National Center for Environmental Health’s Ship Health Program, when considering the regional characteristics, climate characteristics, various human factors, environmental and other factors, the risk assessment method, risk matrix method, and Delphi evaluation method can be used to identify and assess the risk of infectious diseases on-board a cruise ship. The objects of this study include: biological factors, behavioural factors, environmental factors and social factors, in which, (1) biological factors include source of infection, route of transmission, and susceptible population; (2) behavioural factors include psychology and culture; (3) environmental factors include natural and ecological environment; (4) social factors include laws and regulations, standards, applicability, prevention, control strategies and measures, and level of management (Xiong et al., 2010). Based on the medical research into this novel coronavirus, we select evaluation factors such as transmission route, susceptible population, size of enclosed environment, natural factors, social factors, human factors, prevention and control measures and their effects (Table 1).

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| Level | Descriptor | Description |
|-------|------------|-------------|
| 1     | Negligible | Limited or no infectivity; strong control ability; low incidence; low case-fatality rate; slight physical discomfort; small economic losses and small impact. |
| 2     | Smaller    | The concentrated incidence was less than 30; weak infectivity; population susceptibility was weak; low incidence; severe cases were rare; low case-fatality rate; no hospitalisation was required; personal economic losses, a certain social impact, no international impact. |
| 3     | Medium     | 30-100 cases were concentrated in one site; it is highly infectious; susceptible people were found in the crowd; the incidence rate was high, but the severe-case rate was low; mortality was also low; some patients needed to be hospitalised; increased personal economic loss had certain social and international consequences. |
| 4     | Larger     | There were more than 100 cases with concentrated incidence; it was highly infectious; people were generally susceptible; the incidence rate was high; the rate of severe cases was high; mortality was high; most patients needed to be hospitalised; the national economy suffered a certain loss with great social and international effects ensuing; these issues were politically sensitive; they caused certain economic loss, exerting strong social influence. |
| 5     | Catastrophic | Highly contagious; people were generally susceptible; high incidence; high case-severity rate; high fatality rate; multiple deaths; centralised impacts, several people fell ill; the national economic loss was larger, and the social impact and international impact were huge. |

2.1.2. The classification and classification of the incidence of infectious diseases and the impact of epidemic diseases in enclosed places on cruise ships

The probability of infectious diseases can be divided into five grades: almost certain, very likely, possible, unlikely, and almost impossible (Table 2). The harm and influence of infectious diseases can be divided into five levels: negligible, less, medium, large, and disastrous (Table 3).

In the research, according to the risk factors of infectious diseases in enclosed places on cruise ships, the possibility of infectious diseases in enclosed places on cruise ships can be divided into five classes: almost certain, likely, possible, unlikely and almost impossible. At the same time, according to the impact consequences of infectious diseases in enclosed places on cruise ships on the sea, it can be divided into five levels: negligible, less, medium, larger and catastrophic. We make a quantitative analysis of the risk, determine the risk level accordingly, comparing the risk value of a single stage in the whole, and grasp the systematic risk, which is helpful to contain the further evolution of the risk and deal with it effectively.

2.2. COVID-19 risk assessment framework on enclosed marine cruise sites

In order to assess novel coronavirus pneumonia risk in people at sea closed area, a risk assessment model is established based on risk quantitative calculation and risk classification and prevention. The algorithm implementation steps of epidemic spread risk assessment process in closed places of marine cruise ships are as follows:

(1) Model preparation

Step 1. Identification of risk factors of epidemic transmission
Consider five risk factors of epidemic transmission: Route of transmission, Vulnerable population, Natural factors, Social factors, Preventive and control, and identify the risk factors of epidemic transmission.

Step 2. Establish classification standards for infectious diseases
Establish a five level classification of infectious diseases: Negligible, Smaller, Medium, Larger, Catastrophic.
(1) Data processing and analysis

Step 3. Collect epidemic data
Collect COVID-19 data from World Health Organization (WHO), print news media (NM), Government websites (GW), TV news (TN), Public websites (PW), and Health commission press conference, etc.

Step 4. Analysis of epidemic data
The cumulative number of confirmed cases, cumulative number of deaths, cumulative confirmed rate and cumulative mortality were analyzed.

(1) Model establishment

Step 5. Calculate impact consequence (C)
The epidemic spread risk assessment model is established to classify the proportion of the cumulative number of confirmed cases, and the impact consequences are quantified by taking the values of 1, 2, 3, 4 and 5, and each integer corresponds to a corresponding level.

Step 6. Quantitative analysis of VaR (R)
Quantify the risk occurrence possibility P, using the formula \( R = P \times C \) calculate the value of risk R and the proportion of risk in each risk stage.

(1) Model application

Step 7. Risk assessment of each period
The risk of epidemic spread in each period was classified and assessed

Step 8. First calculate the risk value of each stage of epidemic spread, then calculate the overall risk value, and then evaluate and analyze the overall risk of epidemic spread.

The implementation process of epidemic spread risk assessment algorithm in closed places of marine cruise ships is shown in Fig. 1.

Firstly, historical data and existing research results are used to determine the risk factors for infectious diseases in closed sea navigation points, allowing collation and understanding of the pneumonia epidemic situation. Secondly, based on World Health Organization (WHO), Print news media (NM), Government websites (GW), TV news (TN), Public websites (PW), and Health commission press conference, information related to the cruise is collected. Besides, based on medical research results, the population on the cruise ship is divided into four categories: confirmed cases, suspected cases, close contacts, and asymptomatic infected persons. The collected data are screened, and quantitative methods are used to calculate the risk value. Finally, according to the classification grade and classification standard of infectious diseases, the risk grade of COVID-19 pneumonia virus in enclosed places on cruise ships at sea is classified. On this basis, according to the corresponding level, we propose related disposal measures and operational suggestions.

According to data tracked from Guangdong and Sichuan, 1 to 5% of...
people who had close contact with pneumonia patients in COVID-19 were later diagnosed (World Health Organization, 2020). In this study, 1 to 5% of COVID-19 infections in COVID-19 samples were used as the possible range of infection among close contacts. As to the impact of novel Coronavirus epidemic, relevant data provided by the novel coronavirus epidemic will prevail. In this study, data such as the number of confirmed cases in a single day, the number of deaths in a single day, the cumulative number of confirmed cases, and the cumulative number of deaths will be used for classification to ascertain the harm caused by the COVID-19 epidemic in an enclosed cruise ship at sea.

2.3. Risk assessment model for infectious diseases in enclosed places on cruise ships

In this study, data on the spread of COVID-19 on a cruise ship are collected, and the proportion of the total number of confirmed cases is calculated by analysing the number of confirmed cases collected on each day. The formula used the total number of confirmed cases (Q) compared with the sum of passengers and crew on the cruise ship (N), and the ratio of cumulative confirmed cases W can be expressed by Eq. (1):

\[ W = \frac{Q}{N} \]  

Eq. (1) shows that, the higher the proportion of the total number of confirmed cases, the higher the density of infected cases, and the higher the transmission risk of COVID-19; however, the smaller the ratio, the lower the density of infected people, and the lower the risk of transmission.

Different infectious diseases have different routes of transmission and medical characteristics. Based on the novel coronavirus, we aim to assess the risk associated with the progress of infectious diseases. The risk value of the spread of new coronavirus (R) is regarded as the product of the possibility of risk of occurrence (P) and the consequence thereof (C):

\[ R = P \times C \]  

The magnitude of the risk R is determined by the probability of its occurrence (P) and consequences (C). The risk assessment of maritime cruise in a closed area refers to the possibility of infectious diseases while studying the possibility of infectious diseases, and the consequences mainly refer to specific quantifiable factors such as the cumulative number of infected people and deaths from infectious diseases.

In the quantitative analysis of the overall value at risk, we calculated the risk in each period by stages, for example, the risk in the first stage is R1, that in the second stage is R2, and so on to Rn. According to the principle of risk life cycle, the weight of each stage of risk occurrence is assigned to enhance the rationality of the overall risk value. Assume that the weight of the first stage is a1, the weight of the second stage is a2, and the weight of the second stage is an, then the overall risk ̃R is expressed by Eq. (3):

\[ ̃R = \sum_{i=1}^{n} a_i R_i \]  

The overall risk value represents the overall risk level in this period, which is of practical significance for measuring the overall risk level of a certain risk event. Taking scientific and effective measures for different risk levels plays a vital role in mitigating escalation of risk. At the same time, the risk value is different in various stages. Distinguishing high, medium, and low risk stages (and taking effective measures at different stages) can reduce casualties caused by those risks, and even avoid casualties and losses in further amplifying the risks. On this basis, a quantitative analysis of the risk value of each stage has an important guiding function. The risk value of each stage adopts the ratio of the risk value of a certain stage to the overall risk value as given by Eq. (4):

\[ F_j = \frac{\alpha_j R_j}{\sum \alpha_i R_i} \]  

Where if j = 1, 2, ..., n . Fj is the value at risk ratio of the j-th stage, \( \alpha_j R_j \) denotes the risk index of the j-th stage, Rj is the risk value of the j-th stage, Fj value directly reflects the proportion of this stage in the overall risk, and also shows the high or low level of the risk.

In Eq. (4), Rj represents the risk of stage j, \( \alpha_j \) represents the weight of stage j, so \( \alpha_j R_j \) represents the actual risk in stage j. The denominator \( \sum_{j=1}^{n} \alpha_j R_j \) is the total risk of all stages, thus Eq. (4) represents the ratio of stage risk to total risk, so as to measure the risk of stage j. Therefore, Eq. (4) can be used to evaluate the risk of virus transmission at a certain stage. The Eq. (4) is called the risk assessment model of virus transmission in closed environment at sea.

3. Results

3.1. Example: the “Diamond Princess”

Based on the construction of the risk assessment model of new coronavirus infection in the enclosed area of a cruise ship, we assess a real case. At present, many sea cruise confinement outbreaks of the novel coronavirus, including that onboard the “Diamond Princess” as the first outbreak of COVID-19 in such an environment, allow us to study the risk assessment method for the transmission of COVID-19 therein.

3.1.1. A case review and data collection

According to the report of Nanshan Laoyao (2020) and Baidu Encyclopedia (2020) on “Diamond Princes”: On 20 January 2020, the “Diamond Princess” cruise ship sailed from Yokohama, Japan; on 23 January, an 80-year-old man with pneumonia-related symptoms left the ship and returned to Hong Kong on 25 January. On 30 January, he was diagnosed with COVID-19 pneumonia. On 1 February, after the “Diamond Princess” cruise ship arrived in Okinawa, Japan, most passengers disembarked for sightseeing in Okinawa County, and 13 passengers and nine crew members left Okinawa by plane; on 3 February, the cruise ship docked in Yokohama, Japan, but was not allowed to land; on 5 February, the “Diamond Princess” was quarantined at sea, and 10 of the 31 people were transported to medical institutions in Kanagawa Prefecture after being diagnosed. Since then, the number of confirmed cases increased: by 12 February, a total of 174 cases had been confirmed, including one quarantine officer. The quarantine officer was responsible for collecting questionnaires, measuring body temperature, entering the passenger compartment, wearing masks and gloves, but was not wearing protective clothing and goggles. On 13 February, Japanese authorities announced isolation measures to allow crew members to disembark for isolation; as of 14 February, 218 people had been confirmed as COVID-19-infected, including a fireman who helped transport the patients. On 15 February, the Japanese authorities announced that a total of 285 confirmed cases. On 16 February, some 355 people were diagnosed, including a 50-year-old male staff member of the Ministry of Health, Labor, and Welfare. He collected information within five days after boarding the ship and facilitated social distancing when patients disembarked, exceeding 2 m separation at all times. When the patients wore masks and gloves, he could be disinfected and protected as required and made no contact with the crew and passengers; on 17 February, 454 cases were confirmed, and 388 American citizens were evacuated by charter flight. Among them, 14 passengers were found to be virus-positive. On 18 February, 542 confirmed patients were evacuated from South Korea by chartered plane. On 19 February, a total of 621 patients were diagnosed, of which 322 were asymptomatic, accounting for 52% of the total number. As of 20 February, 634 patients had been diagnosed in total, with an incidence rate of 17% [27]. An employee of the Japanese Ministry of Health, Labor, and Welfare, and an
were infected with the virus, while two hospitalised passengers who had disembarked had died. The “Diamond Princess” cruise ship carried 3711 people, including 1045 staff and 2666 passengers, 69% of whom were over 50 years of age; as of 17 April, there were 712 confirmed cases and 13 deaths.

3.1.2. Case analysis

In this study, 725 items of data were collected from Diamond Princess from 5 February 2020 to 17 April 2020: correlation analysis is conducted from the dimensions of a single number, the total number of confirmed cases (Fig. 2), and cumulative number of deaths. The possibility and effect of coronavirus infection among the passengers are quantitatively studied and classified.

The number of people diagnosed each day includes the number of people cured, including one case cured on 13 February, four on 25 February, and 10 cured on 6 March. Among them, there were 99 confirmed cases on 17 February, the highest detected in a single day. The number of confirmed outbreaks was concentrated between 11 and 24 February.

As of 17 April 2020, the total number of “Diamond Princess” cases was confirmed as 712 people (Fig. 3). In 7-day intervals, we counted the number of confirmed cases to be processed, including 5 to 11 February, 12 to 18 February, and 19 to 25 February. The total number of confirmed cases in each unit is maximised, and the cumulative number of confirmed cases is 135, 452, and 695, respectively. These three periods are divided into the budding, growing, and developing stages. From 25 February to April 17, the cumulative number of confirmed cases hardly increased. The disembarkation of the ship’s crew took place on 1 March, and the period from 25 February to 1 March was designated as a stable period. Cumulative growth in the number of cases occurred mainly from 5 to 24 February.

It can be seen from Fig. 3, from 12 to 26 February, that the number of infections rose sharply from 64 to 695; however, from then to 15 April, the number of infections increased slowly to 712, therefore, transmission was slowly controlled therefrom, and its spread was ended.

3.2. Model application

3.2.1. Calculation of the proportion of confirmed cases

In this study, the cumulative number of deaths in the total number of cruise ships was used to classify the consequences and impacts of COVID-19 pneumonia on closed cruise ships. There were 3711 people on the Diamond Princess, including 2666 tourists and 1045 staff members. The total number of people confirmed on the cruise ship is 712. According to formula (1), the proportion of the total number of people diagnosed with virus-positive is listed in Table 4.

On 5 February, the number of confirmed COVID-19 infections increased from 0.27% to 1.89%, showing a relatively slow growth rate; on 11 February, the cumulative number of confirmed COVID-19 cases increased from 3.64% to 17.08%. The cumulative rate of confirmed

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Table 4: Cumulative proportion of confirmed cases on the “Diamond Princess”.

| Date      | Feb. 5th | Feb. 6th | Feb. 7th | Feb. 8th | Feb. 9th | Feb. 10th | Feb. 11th |
|-----------|----------|----------|----------|----------|----------|----------|----------|
| Percentage| 0.27%    | 0.54%    | 1.64%    | 1.72%    | 1.72%    | 1.89%    | 3.64%    |
| Date      | Feb. 12th| Feb. 13th| Feb. 14th| Feb. 15th| Feb. 16th| Feb. 17th| Feb. 18th|
| Percentage| 4.72%    | 4.69%    | 5.87%    | 7.68%    | 9.57%    | 12.23%   | 12.23%   |
| Date      | Feb. 19th| Feb. 20th| Feb. 21th| Feb. 22th| Feb. 23th| Feb. 24th| Feb. 25th|
| Percentage| 14.61%   | 16.73%   | 17.08%   | 17.08%   | 17.08%   | 18.73%   | 18.62%   |
| Date      | Feb. 26th| Feb. 27th| Feb. 28th| Feb. 29th| Mar. 1st  |
| Percentage| 18.62%   | 19%      | 19%      | 19%      | 19%      |
COVID-19 cases in 21 days increased by nearly 10 times compared with that in 10 days. With the measures taken by relevant departments, the diagnosis rate of novel coronavirus infection on the cruise ship was controlled at 19%. The risk of transmission of COVID-19 aboard the “Diamond Princess” was effectively controlled.

According to the classification and grading standards of the hazard and impact of infectious diseases in enclosed places on cruise ships, the range of hazards is 1-5, among which 1 is negligible and 5 is disastrous. The proportion of the cumulative number of confirmed cases in the total number of cruise passengers is divided into categories from 0 to 3%, 3% to 6%, 6% to 12%, 12% to 15%, and above 15%, respectively corresponding to 1 to 5 in the range of degrees of harm (Table 4).

As seen from Fig. 4, from 5 to 10 February, the proportion of the cumulative number of confirmed cases on the “Diamond Princess” increased from 0.27% to 1.89%; however, from 10 to 20 February, the proportion increased from 1.89% to 16.73%, and from 20 February to 1 March, the proportion increased from 16.73% to 19%, and the curve flattened. From this, we can see that the spread was the fastest between 10 and 20 February (c.f. Fig. 3).

It can also be seen from Fig. 4 that during the investigated time period, i.e. from February 5 to March 1, the ratio curve of the cumulative number of confirmed cases of the “Diamond Princess” has risen all the way. This shows that with the passage of time, the proportion of the cumulative number of confirmed cases of the “Diamond Princess” is becoming larger and larger, showing a monotonous upward curve. From Eq. (4), \( \alpha_j \) represents the risk of stage j, \( \alpha_j \) represents the weight of stage j, so \( \alpha_j R_j \) represents the actual risk in stage j. The denominator of Eq. (4) is the total risk of all stages. According to the curve trend in Fig. 4, the proportion of stage j risk \( \alpha_j R_j \) in the total risk is becoming larger and larger. Therefore, Fig. 4 shows that as time goes on, when the risk of the new stage comes, its proportion in the total risk is always greater than that of the previous stage. This indicates that the cumulative number of confirmed cases of COVID-19 will account for an increasing proportion in the future. Therefore, the risk of virus transmission of COVID-19 may still exist and the threat may be greater and greater in the future. Therefore, the epidemic will not end immediately and may coexist with mankind for a long time.

### 3.2.2. Risk assessment: COVID-19 aboard the “Diamond Princess”

In this study, the infection rate of COVID-19 virus of 1-5% is used as the possible spread range of COVID-19 pneumonia virus in an enclosed cruise ship. The probability range of infection is divided into four segments, and the median value of each segment is taken as the probability of novel coronavirus infection in each period. Due to the close nature of the cruise ship itself, passengers on board share air conditioners and restaurants, which is regarded as intimate contact. It can be concluded that the infection rate of close contacts in the germination stage, the growth stage, the development stage, and the stable stage is 1.5%.

As an infectious disease, the COVID-19 pneumonia virus is a typical public health event, so it has a period of occurrence, development, evolution, decline, and termination. Pang et al. (2021) divided the transmission risk of the new coronavirus into four stages: the brewing stage, initial stage, outbreak stage, and stable stage. According to this, we can divide the transmission risk of the epidemic on the “Diamond Princess” into five stages: germination stage, growth stage, development stage, stable stage, and recession stage. The meaning of each stage is explained as follows:

1. **Germination period** means that the earliest one or several passengers carrying the new coronavirus board the vessel. At that time, the risk of virus transmission on the cruise ship is in a potential preparatory process;
2. **The growing period** means that transmission from person to person begins;
3. **The development period** refers to the rapid development of the spread of the new coronavirus, with a sharp increase in the number of new confirmed cases every day, and some deaths;
4. **The stable period** means that the transmission of the new coronavirus is under control, and the daily number of newly-diagnosed cases remains similar, with little fluctuation;
5. **The recession period** means that the transmission of the new coronavirus on the “Diamond Princess” has been completely controlled, the number of the new confirmed cases has been greatly reduced, gradually tending to disappear completely.

As can be seen from Fig. 4, the time sequence and gradual relationship of the five risk stages of the “Diamond Princess” cruise ship in 2020 are as follows: the epidemic germination period is before February 5, the epidemic growth period is from February 5 to February 10, the epidemic development period is from February 11 to February 20, the epidemic stability period is from February 21 to March 1, and the epidemic recession period is after March 1. As shown in Fig. 5.

Due to the particularity of the object of this study, when the members of the ship’s crew disembarked on 2 March, they would not study the later events, therefore, the events described here focus on 5 February to 1 March 1. The risk level is different in different stages. In this paper, referring to the weight distribution of related infectious disease risk life cycle, different corresponding weights are given, which has important practical significance for quantitative assessment, overall analysis, and identification of high-risk stages. Among them, the weight of popular germination options is 12%. The weight on the growing period is 18%. The weight on the epidemic development period is 30%. The option to stabilize the epidemic is weighted at 25%. The weight on the epidemic decline period is 15%.

The case analysis indicates that the close contacts of the “Diamond Princess” cruise ship cases may be infected with COVID-19 pneumonia virus in time. 5 to 11 February represented the budding period of the cruise ship infections, and the probability of close contact infection is 1.5%. From 12 to 18 February, they entered the growth period, and the
From February 17 to 19, the impact of the new epidemic in the closed places of cruise ships is “2”. From February 15 to 10 is “1”. From February 11 to 14, the impact of the new epidemic spread declined. As shown in Table 5. This paper mainly studies the previous four stages, namely the germination stage, growth stage, development stage and stable stage of the epidemic. Corresponding to this is the value of impact consequences in this period of time, the value of the influence and consequence of COVID-19 on the dense population in the closed environment at sea.

According to the quantitative analysis of the COVID-19 risk value, Table 6 summarises the risks by time-period and stage. In which, the proportion from 20-25 February, accounting for 21.608% of the overall risk, is the maximum proportion of the overall risk, highlighting that the risk in this stage is severe and the risk of COVID-19 transmission is high. Besides, on 19 February, the overall risk rate was 21.254%, ranking second among all stages. The lowest risk ratio is from 5 to 10 February, with a ratio of 1.276%. The risk ratio in the highest stage is about 18 times that of the lowest stage. At the same time, the sum of the risk ratios from 17 February to 1 March accounts for more than 70% of the total, indicating that the risk in this period was relatively high. Special attention should be paid to the changes in the value at risk during this period, and dynamic prevention and control measures should be taken to minimise its effects.

In this study, the risk values from 5 February to 1 March are quantitatively analysed, and the corresponding influence consequence (C) under different infection probabilities P is obtained. Thus, the risk values of each stage are calculated. According to the calculation formula of the overall risk value, it can be concluded that the overall risk value on February 5, February 1 and March 1 is 0.14115; in addition, through the weight distribution in different stages, we quantitatively analyse the risk situation of new epidemic spread in different periods, identify the size of the risk value in each stage, compare the risk value in different stages, and take effective prevention and control measures for specific periods, thus providing a level of prevention for solving the risk assessment method for assessing COVID-19 epidemic spread on cruise ships.

Based on the data in Table 6, the risk assessment chart in Fig. 6 shows that the overall risk increased during this period, with a difference of about 18 times between the highest risk level and the lowest risk level. In this paper, the risk level in this stage is defined based on the risk level quantification method, which reflects the spread process of COVID-19 pneumonia infection on cruise ships to some extent. Simultaneously, the overall risk of cruise ships is quantitatively analysed and evaluated, which lays the foundation for the follow-up preventive measures and provides new ideas and methods for the risk assessment of the spread of pneumonia in COVID-19.

As shown in Fig. 6, the risk assessment value from 5 to 10 February is 0.0018, so this stage is the epidemic growth period; the risk assessment value rose to 0.0036 on 11 February and increased thereafter. By 20 February, the risk assessment value rose to 0.03, so 11 to 19 February represented the epidemic development period; from 20 to 25 February, the risk assessment value only rose to 0.0305, thus representing the stable period of the epidemic; from 26 February to 1 March, the risk assessment value dropped to 0.01875 during this period, hence representing the epidemic recession period (Fig. 7).

Compared with Figs. 5 and 7, when the risk assessment value is used to divide the five risk stages, the results differ from those obtained by using the proportion of the cumulative number of confirmed cases. The main reason is that the time division of the stable period and the recession period is different, so the results are different. This is because the cumulative number of confirmed cases is an increasing sequence, which only increases but does not decrease. Therefore, it is impossible to divide the declining period within the time range under investigation. Therefore, the more accurately to assess the risk of virus transmission, it is necessary to calculate the risk assessment values at different times.

4. Conclusions

In this study, the data pertaining to the “Diamond Princess” from 5 February to 1 March are selected: infections among those on the “Diamond Princess” increased cumulatively, and the number of infected people peaked between 11 and 20 February. The risk value should rise from 0.0036 to 0.0305 on 11 February, and from 20 to 25 February.

According to the analysis results of this paper, with the arrival of a new stage of risk, the cumulative number of confirmed cases of COVID-19 in the closed environment of cruise ships at sea will account for an increasing proportion. This fully shows that it is easy for people to contact closely in the closed environment of cruise ships at sea. Passengers can easily gather together during meal time or various recreational activities held on the cruise ship. Therefore, COVID-19 has obvious physical transmission characteristics from person to person in the dense population in the closed environment at sea.

In this paper, the risk assessment of COVID-19 in the closed environment of cruise ships at sea is carried out for the first time, and the risk assessment model of COVID-19 in the closed environment of cruise ships at sea is established to assess the risk of Japan’s “Diamond Princess”. The results of this study reveal the scientific explanation for the possible existence of “the risk of COVID-19 virus transmission may still exist in the future, and the threat may be greater and greater. Therefore, this epidemic will not end immediately and may coexist with mankind for a long time”. It is also revealed that COVID-19 has obvious physical
The future work is to further study the risk measurement and risk assessment methods of COVID-19 spread in marine berths, put forward the risk measurement model of COVID-19 epidemic spread, study the risk threat of epidemic spread by studying the infection rate and death rate of COVID-19 epidemic spread, so as to further evaluate the risk of COVID-19 spread.

The future work is to further study the risk measurement model of COVID-19 spread in closed environment at sea, establish an epidemic spread risk measurement model, define the infection ratio and death ratio, so as to study the risk threat degree and evaluate the risk degree of COVID-19 spread in closed environment at sea.

In short, this article studies the risk assessment method of COVID-19 spread in the closed environment at sea, makes an empirical study on the spread risk of COVID-19 in Japanese "Diamond Princess", and gives the risk assessment results. This is of great significance to the safe navigation of cruise ships at sea during the spread of the epidemic. The passengers on the cruise ship are from different countries and different cities around the world. If the risk management of the spread of COVID-19 on the cruise ship is weak, the passengers who enter various countries after disembarking will spread the COVID-19 virus: on the contrary, if the risk is well managed, passengers may disembark safely. Therefore, it is important to evaluate the risk of COVID-19 virus transmission in the closed environment at sea and to do a good job in the corresponding risk management for the safety of cities in various countries. This work is of sustainable significance to the urban safety and economic development of all countries in the world.}

### Declaration of Competing Interest

The authors declare no conflict of interest.

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