

# Research on Emergency Logistics Risk Analysis under Epidemic Based on HAZOP Technology

Jinhu Zhao<sup>1,\*</sup>, Zixiao Zhao<sup>2</sup>

<sup>1</sup>College of Management, Shanghai University, Shanghai, China

<sup>2</sup>Yangtze Three Gorges Oasis Technology Development co., Ltd., Lu'an, China

\*Corresponding Author

## ABSTRACT

This study explores using HAZOP analysis to assess risks in emergency logistics during epidemics. It highlights the importance of various aspects like personnel training and material management in different stages (preparation, rescue, and recovery) of emergency logistics. The study identifies critical risks through HAZOP analysis and proposes countermeasures like improved training and optimized resource allocation to mitigate these risks and improve overall efficiency. This research provides valuable guidance for building more robust emergency logistics systems to better respond to future outbreaks.

## KEYWORDS

HAZOP; Emergency logistics; Epidemics

## 1. INTRODUCTION

In the context of globalization, sudden infectious disease outbreaks have become a global challenge that poses a significant threat to social economic stability and public health. From the SARS outbreak in 2003 to the outbreak of COVID-19 at the end of 2019, each epidemic has had an unprecedented impact on people's daily lives and the global supply chain. Among these, the effectiveness of the urban emergency logistics support system is directly related to the effectiveness of epidemic prevention and control and the maintenance of social order, especially in highly urbanized areas like Shanghai.

The emergency logistics support system undertakes critical tasks such as transporting medical supplies and ensuring the timely supply of daily necessities during an epidemic. Its performance directly affects the efficiency of epidemic prevention and control and the protection of people's livelihood. However, sudden epidemics are often accompanied by uncertainty and complexity, such as shortages of supplies, delays in logistics distribution, and ineffective information transmission. These issues could potentially become risk points in the emergency logistics system, posing significant challenges to epidemic prevention and control.

In light of this, this study employs the HAZOP (Hazard and Operability Study) method to identify and analyze the risks in the urban emergency logistics support system during an epidemic, aiming to understand the potential risk points in the system and provide scientific basis and strategic support for optimizing the emergency logistics system and enhancing epidemic response capabilities. HAZOP, as a risk assessment tool widely used in the chemical and petroleum industries, is an effective method for assessing and managing risks in complex systems due to its systematic and comprehensive nature. By conducting a detailed review of the key links and operational steps in the emergency logistics

system, this paper aims to identify risk factors that may cause the system to deviate from its normal operating state, thereby laying the foundation for developing effective response measures and optimization strategies.

## **2. ORGANIZATION OF THE TEXT**

### **2.1. HAZOP today**

HAZOP analysis is a Process Hazard Analysis (PHA) technique that can be used not only to study the hazards of a system but also to explore operability issues by examining the effects of any deviations from the design conditions. HAZOP originated in the 1970s from the "critical examination" technique developed by the Imperial Chemical Industries (ICI) in the UK. A decade later, HAZOP was formally recognized as a rigorous procedure for hazard analysis method to identify deviations from the intended design. This analysis method is widely used in the chemical industry to identify the presence of hazardous substances in facilities. By applying HAZOP analysis, it is possible to eliminate sources that could lead to major accidents, such as the release of toxic substances, explosions, and fires, thereby enhancing the safety of operating plants under high temperature and pressure conditions as well as under turbulent operational process conditions; It helps in identifying existing safety measures in the current process system, assessing the risk level of various accident scenarios that need attention under these conditions; It involves conducting risk assessments of accident scenarios with reference to risk standards and, if necessary, changing or adding safety measures to reduce the original high-risk level to an acceptable level, thereby achieving sustainable safe operation. In recent years, the application of HAZOP has gradually expanded to other types of scenarios, such as hazard analysis in medical diagnostic systems, road safety measures, and photovoltaic facilities, as well as risk analysis and management in supply chains. This analysis method not only successfully identifies hazards but also identifies problems in operational operations.

Compared with other Process Hazard Analysis (PHA) techniques, HAZOP analysis has advantages in terms of comprehensiveness, systematic approach, meticulousness, and broad applicability. The HAZOP team analyzes each element (and its related characteristics) one by one to identify deviations that could lead to adverse consequences. Predefined "guide words" are used to identify deviations from the design intent through questioning, stimulating the imagination of analysts, focusing their analysis, and eliciting discussion and various ideas. This ensures the thoroughness and meticulousness of the evaluation, making the final assessment results more accurate.

### **2.2. HAZOP in the pharmaceutical industry**

The application of HAZOP analysis in supply chain management provides a systematic method for identifying and assessing potential risks and vulnerabilities. Although HAZOP was originally designed for the chemical and engineering industries, its fundamental principles and techniques are equally applicable to supply chain risk management. By conducting a detailed examination of each link and operational step within the supply chain, HAZOP can reveal deviations that may lead to supply chain disruptions, decreased efficiency, or safety issues.

The supply chain consists of multiple interdependent links, including supplier selection, raw material procurement, production, storage, transportation, and distribution. Each link may harbor specific risks, potentially stemming from internal operational errors, changes in the external environment, or unforeseen events. HAZOP analysis systematically examines each link in the supply chain, using a series of predefined guide words (such as "more," "less," "none," "reverse") to identify potential deviations and assess the consequences of these deviations. This method helps to uncover potential issues that may be overlooked in daily operations.

Originally designed for the chemical and petroleum industries, HAZOP's principles are applicable to any complex system process analysis, including emergency logistics support systems. By systematically examining operational steps to identify deviations, the HAZOP method can be applied to non-industrial environments, such as supply chains for materials, distribution, and management processes. In emergency logistics support, HAZOP can help identify potential risks throughout the entire chain, from material procurement, storage, and transportation to distribution. Using HAZOP's guide words, detailed examination of each link can reveal issues such as material shortages, improper distribution, and ineffective information management.

HAZOP not only helps identify risks but also analyzes the potential consequences of these risks, providing a basis for developing response strategies. Once risks are identified, HAZOP can also be used to develop strategies to mitigate these risks, enhancing the effectiveness and reliability of emergency logistics support. Emergency logistics support systems often operate in uncertain and high-pressure environments. The structured method of HAZOP assists in systematically identifying and addressing risks in such environments.

In summary, the application of the HAZOP method to the study of risks in emergency logistics support is not only theoretically feasible but also provides comprehensive and detailed risk assessments, helping to improve the efficiency and reliability of emergency logistics support systems. The application of this method will contribute to strengthening preparedness for emergency situations, such as infectious disease epidemics.

### **2.3. Method Steps**

The application of the HAZOP method for evaluating the effectiveness and formulating strategies for urban emergency material support during outbreaks of infectious diseases mainly involves the following steps:

#### **2.3.1. Preparation Phase.**

**Scope of Work Confirmation:** Similar to traditional HAZOP analysis, to avoid redundant work, improve efficiency, effectively prevent omissions, and enhance the quality of the analysis, supply chain risk management based on HAZOP analysis also needs to confirm the scope of work before starting. Diagrams can be used to assess the entire system and show the relationships between each system. Detailed and precise diagrams can provide good quality assessments.

**Team Formation:** Form a multidisciplinary team, including emergency management experts, public health specialists, logistics experts, and safety engineers. Ensure team members understand the HAZOP method and its application in this study.

#### **2.3.2. Conducting HAZOP Analysis.**

To analyze logically and effectively, first, divide different process stages into various analysis nodes or operational steps. The entire emergency logistics needs to be divided into multiple sections through the definition of different nodes. In traditional HAZOP analysis, since most production processes tend to be continuous, the HAZOP analysis nodes are process units, i.e., units with defined boundaries such as pipelines between two containers. Additionally, a reasonable scope should be set for each analysis node to avoid increased workload or significant deviations in the final results, or even miss important outcomes.

After selecting the nodes, the leader of the analysis group should confirm the key parameters of the analysis node and invite relevant experts to explain and interpret them, ensuring every member of the group is aware of the existing supply chain's design intent. Subsequently, the analysis team will hypothesize about the normal operation of the supply chain based on the HAZOP analysis method, using "parameter + guideword" to describe deviations in actual parameters from original design values or normal operating values under potential risk scenarios. For example, combining the

parameter "inventory in the information flow" with the guideword "low" can yield "insufficient inventory". All possible process deviations (changes in parameters) and a set of predefined guidewords will be confirmed in advance. These guidewords and parameters can stimulate the evaluators' imagination when identifying hazards and help them focus during the assessment.

### 2.3.3. Risk Assessment.

A common method in risk management involves filtering key events through a combination of occurrence probability and impact level. This process usually involves creating a risk matrix and using it to determine which events should be considered critical.

First, create a risk matrix and define severity criteria, which involves determining the degree of damage or impact that risk events might cause. Analyze the impact of identified deviations on the entire material support system, including effects on personnel safety, material efficiency, and system response. Set grading standards, such as severity being classified as "low," "medium," "high," and occurrence probability as "low," "medium," "high."

Then assess the risks by evaluating the severity of each risk event based on the potential damage or impact it might cause. Estimate the likelihood of each risk event occurring.

This method effectively identifies and prioritizes risk events that are both likely to occur and could have serious consequences. This helps ensure that resources and attention are focused on the most critical risks, thereby improving the overall efficiency and effectiveness of risk management.

### 2.3.4. Recording and Reporting Results

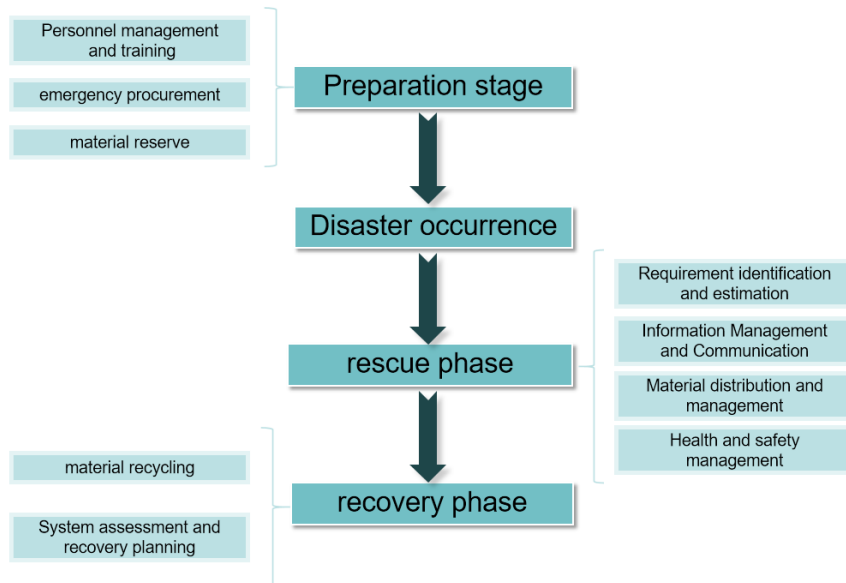
Record identified deviations, related consequences, and potential risks at each step. Keep detailed records of team discussions and the analysis process to ensure transparency and reviewability. Summarize key findings from the HAZOP analysis, including major risk points and potential problem areas. Prepare a report to serve as the basis for subsequent CIA-ISM method analysis.

Through these steps, the HAZOP method can provide a detailed risk assessment foundation for evaluating the effectiveness of urban emergency material support and formulating strategies. These results will provide key inputs for the CIA-ISM method, thus creating a more comprehensive assessment framework.

## 3. CASE STUDY

### 3.1. Node division and parameter setting

In public health crises like sudden epidemics, emergency logistics play a crucial role. The emergency support team is responsible for commanding and coordinating the entire emergency material support process based on overall demands to ensure the efficient and orderly operation of the entire system. This study subdivides the emergency material support process into three stages: preparation, rescue, and recovery, each containing several key links. These stages and their links interconnect to form a complete emergency material support process. In the preparation stage, the focus is on personnel management and training, emergency material procurement, and material reserves. The goal of this stage is to ensure that the emergency response team has the necessary skills and knowledge and that all essential materials are ready to be rapidly deployed when needed. The rescue stage encompasses demand identification and estimation, information management and communication, material distribution and management, and health and safety management. The key to this stage is to respond quickly and accurately to emergencies, ensuring that all activities are conducted efficiently and orderly. The final recovery stage includes material recovery and system evaluation and recovery planning. The objective at this stage is to effectively utilize remaining resources while assessing the effectiveness of the entire emergency response, preparing for similar future events. The specific process is shown in Figure 1.



**Figure 1.** Emergency logistics support process diagram

In conducting emergency logistics support risk studies, HAZOP analysis is widely used as an efficient risk identification tool. HAZOP analysis helps identify potential hazards and operational issues by systematically exploring possible deviations in the process. The HAZOP analysis guidewords selected in this study involve aspects such as "none/insufficient," "excess/too much," "delay," "poor quality," "change in state," and "operational error," aiming to comprehensively evaluate risks that may arise in logistics and supply chain management.

Table 1 HAZOP Analysis Guidewords shows these guidewords and their meanings. These guidewords provide a structured method for assessing and managing potential risks, helping teams identify problems, analyze causes, predict consequences, and develop corresponding risk management and emergency preparedness strategies. In practice, the team will pose a series of questions for each guideword to explore possible deviations and develop action plans to mitigate or eliminate risks based on the results.

**Table 1.** HAZOP analysis guide words

| Guideword                | Meaning   | Guideword         |
|--------------------------|---|-------------------|
| <b>None/Insufficient</b> | Used to explore aspects that are missing or inadequate.     | None/Insufficient |
| <b>Excess/Too Much</b>   | Evaluates situations that are excessive or surplus.         | Excess/Too Much   |
| <b>Delay</b>             | Focuses on delays or lags in time.                          | Delay             |
| <b>Poor Quality</b>      | Considers situations where quality is below expectations.   | Poor Quality      |
| <b>Change in State</b>   | Explores changes due to external or internal factors.       | Change in State   |
| <b>Operational Error</b> | Assesses problems that may arise due to improper operation. | Operational Error |
| <b>Guideword</b>         | Meaning   | Guideword         |

Table 2 HAZOP Parameters categorizes the key parameters in emergency logistics support, including logistics, information flow, financial flow, resources, and tasks. This categorization ensures that every aspect of emergency logistics management receives adequate attention, helping to identify and manage risks and opportunities related to each domain. Furthermore, it also helps optimize the supply chain, enhancing overall efficiency and effectiveness.

**Table 2.** HAZOP parameter types

| Category                | Example   | Category         |
|-------------------------|---|------------------|
| <b>Logistics</b>        | Raw materials, by-products, energy, utilities, etc.                                       | Logistics        |
| <b>Information Flow</b> | Orders, quotations, forecasts, information, inventory, sales volume, action signals, etc. | Information Flow |
| <b>Financial Flow</b>   | Credit, shares, accounts receivable, pledges, contracts, market share, costs, etc.        | Financial Flow   |
| <b>Resources</b>        | Equipment, manpower, intellectual property, etc.  | Resources        |
| <b>Tasks</b>            | Placing orders, monitoring, transportation, reporting, etc.                               | Tasks            |

### 3.2. HAZOP analysis results

After completing the HAZOP analysis, we successfully identified a range of potential risks, covering aspects from operational errors to equipment failures. Next, to effectively manage these risks and focus resources on the most critical issues, we took a series of risk assessment steps. First, we evaluated the significance of each risk based on its probability of occurrence and potential impact. The probability of occurrence was assessed from low to high, considering historical data and expertise, while potential impact was judged based on factors such as possible losses, safety issues, and operational interruptions.

Then, we used a quantitative method to assign an "importance" score to each risk, which was obtained by multiplying the probability of occurrence by the degree of impact. This method allowed us to objectively compare the urgency and severity of different risks.

The probability of occurrence was quantified by assigning scores: 1 for low probability, 2 for medium, 3 for high, and 4 for very high. Similarly, the degree of impact was categorized into four levels based on the severity of the consequences should the risk occur: 1 for low impact, 2 for medium, and 3 for high impact.

We set a threshold, considering risks with an importance score of over 6 as critical risks. These critical risks then became the focus of our attention and the basis for developing response strategies. Listed in the table below:

**Table 3.** Key risk sorting

| <b>Critical Risk</b>                               | <b>Possible Causes</b>   | <b>Possible Consequences</b>                                       |
|--|--|--|
| <b>Inadequate personnel training</b>               | Improper resource allocation, poor planning                            | Personnel untrained in time, unprepared                            |
| <b>Substandard material quality</b>                | Lax quality control by suppliers                                       | Materials unusable, need for repurchase                            |
| <b>Insufficient inventory management</b>           | Lack of an effective inventory management system                       | Shortage or excess of materials, affecting response efficiency     |
| <b>Material shortage</b>                           | Inaccurate demand forecasting, market changes                          | Inadequate emergency response, affecting efficiency                |
| <b>Inappropriate storage location</b>              | Improper location selection, safety issues                             | Material safety risks, low distribution efficiency                 |
| <b>Improper material storage conditions</b>        | Poor management, insufficient environmental control                    | Material damage, expiration  |
| <b>Incomplete data collection</b>                  | Limited information sources, technical issues                          | Incorrect demand estimation, improper resource allocation          |
| <b>Inaccurate demand forecasting</b>               | Insufficient understanding of market dynamics, lack of historical data | Inadequate emergency response, resource wastage                    |
| <b>Insufficient supply of protective equipment</b> | Supply chain disruptions, incorrect demand forecasting                 | Staff exposed to health risks                                      |
| <b>Inappropriate facilities</b>                    | Poor planning, lack of funding   | Increased sanitary risks, higher contagion risks                   |
| <b>Insufficient supervision</b>                    | Poor management, lack of human resources                               | Safety protocols not followed, accidents occur                     |
| <b>Incorrect prioritization</b>                    | Judgment errors, inaccurate information                                | Urgent needs not prioritized, affecting rescue efficiency          |
| <b>Delayed feedback</b>                            | Lack of effective feedback channels                                    | Demand estimates not timely updated, inaccurate emergency response |
| <b>Incomplete information</b>                      | Limited data sources, communication disruptions                        | Insufficient decision-making basis, limited emergency response     |
| <b>Delayed information transmission</b>            | Communication system failure, personnel issues                         | Response delays, unmet needs                                       |
| <b>Lack of appropriate transportation</b>          | Resource limitations or incorrect assessment                           | Low transportation efficiency, unable to deliver on time           |
| <b>Poor quality of material handling</b>           | Insufficient technical skills, managerial negligence                   | Reduced material value, environmental impact                       |

### 3.3. Countermeasures

By sorting out the identified key risks, this article divides them into two categories: routine risks and emergency risks.

**Routine Risks.** These risks are relatively common in daily operations, can usually be predicted, and controlled through standard operating procedures.

1. Inadequate personnel training: Can be prevented through regular training programs and resource allocation.
2. Substandard material quality: Controlled through continuous quality control and supplier management.
3. Insufficient inventory management: Can be alleviated by establishing an effective inventory management system.
4. Improper material storage conditions: Prevented through regular inspections and environmental control.
5. Insufficient supervision: Strengthened through routine supervision and training programs.
6. Poor quality of material handling: Improved through technical training and management measures.
7. Inappropriate facilities: May be caused by sudden events rendering existing facilities unsuitable.

**Emergency Risks.** These risks are usually difficult to predict, may require an immediate response when they occur, and are often triggered by uncontrollable external events.

1. Material shortage: May be caused by sudden market changes or a surge in demand.
2. Insufficient supply of protective equipment: May be caused by supply chain disruptions or sudden epidemics.
3. Inaccurate demand forecasting: May be caused by sudden events leading to drastic changes in market dynamics.
4. Logistics transportation obstructed: May be due to sudden logistics challenges or disasters.
5. Incorrect prioritization: May be caused by the confusion of information due to sudden events.
6. Incomplete data collection: May be caused by technical failures or information gaps due to sudden events.
7. Delayed feedback, incomplete information, delayed information transmission: These are usually related to sudden failures of communication systems.
8. Safety accidents occur
9. Secondary infections occur

By analyzing these key risks, we understand that effective risk management strategies not only need to comprehensively consider the rational allocation of resources, the resilience of the supply chain, and market dynamics, but also need to focus on personnel training, material storage and quality control, as well as the integrity and feedback mechanism of information systems. The key to addressing these risks lies in:

1. Improve personnel training and supervision: Ensure sufficient training resources and strengthen supervision to promote compliance with safety regulations and implement epidemic prevention education and training.

2. Improve inventory and material management: Implement efficient inventory management systems, such as ERP, and optimize storage conditions and environmental control of materials to ensure compliance with the quantity and quality of emergency supplies.
3. Establish an efficient emergency command system: establish a clear command structure, a fast decision-making process, and an evaluation and feedback mechanism.
4. Improve the collaborative governance system between cities: By establishing diversified supply sources between cities and establishing a list of emergency backup suppliers, potential supply chain disruptions can be addressed.
5. Enhance information and communication systems: Improve the resilience of information systems and the strength of communication infrastructure, ensuring the integrity and timely transmission of information.
6. Optimize resource and facility allocation: Conduct risk assessments to select suitable emergency logistics centers, and plan budgets reasonably to improve facility layout.
7. Accurate demand forecasting: Improve the accuracy of predictions and reduce resource waste through big data and machine learning technologies.

These measures can significantly improve the efficiency of emergency response, reduce the risks caused by poor management, ensure the safety of employees, and protect the environment from the negative impact of improper material handling. Through systematic risk assessment and strategy implementation, a more robust and reliable emergency logistics system can be constructed.

#### **4. SUMMARY**

In this paper, we conducted an in-depth study of emergency logistics support during sudden epidemic outbreaks using the HAZOP analysis method to identify and evaluate potential risks at various stages. Through detailed analysis of the preparation, rescue, and recovery stages, we highlighted the complexity and importance of emergency logistics support, especially in key areas such as personnel management, material procurement, material reserves, demand identification and estimation, information management and communication, material distribution and management, as well as health and safety management.

The paper first outlines the characteristics and challenges of each stage, followed by a detailed risk assessment of the key parameters in each link through HAZOP analysis. We identified a range of potential risks, including but not limited to inadequate personnel training, substandard material quality, insufficient inventory management, incomplete information collection, and inefficient material distribution.

For each identified risk, we further conducted a quantitative assessment to determine their probability of occurrence and potential impact. These assessments helped us identify critical risks, providing us with a clear direction to focus resources and develop effective response strategies.

Finally, we proposed a series of solutions and management strategies aimed at mitigating the impact of these risks. These strategies include improving personnel training and supervision, enhancing inventory and material management, optimizing resource and facility allocation, accurate demand forecasting, and strengthening the resilience of information and communication systems. These measures can not only improve the efficiency and effectiveness of emergency logistics support but also enhance the system's adaptability to future uncertainties.

The research in this paper provides theoretical support and practical guidance for building a more robust and sustainable emergency logistics system, which is of significant importance for improving the response capability to sudden infectious disease outbreaks. Through systematic risk assessment

and strategy implementation, a more robust and reliable emergency logistics system can be constructed, offering valuable preparation and experience for potential similar crises in the future.

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