A Study on Risk Management of German Covid-19 Vaccine Supply Chain Based on Interval-Valued Intuitionistic Fuzzy Set Theory

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Abstract. In this paper, by studying the impact of the new coronavirus pneumonia on each link of the vaccine supply chain, a risk assessment index system for the vaccine supply chain under the new coronavirus pneumonia is constructed, and the risk assessment method based on interval intuition fuzzy set theory is used to evaluate the index system. The intuitionistic fuzzy number is converted into interval BPA; then the combination rule based on interval number is used for fusion; finally, the fusion interval BPA is converted into classic BPA for decision-making, and according to the evaluation results, risk management and control measures and suggestions for the vaccine supply chain under the epidemic are put forward.

Keywords: interval-valued intuitionistic fuzzy set theory · BPA · Covid-19 vaccine · supply chain · risk management

1 Introduction

The current traditional supply chain model of vaccine will not adapt to the requirements of rapid and efficient vaccine distribution of Covid-19 vaccine, and the vaccine will gradually pass through the manufacturer, the federal CDC, and each federal state logistics company [2]. The vaccine is stored in the storage centers of the logistics companies, and then the primary vaccination units report their monthly demand plans, and the federal state CDCs give orders to the logistics companies to deliver the vaccine to the primary vaccination units. This model has a low timeliness, and the extremely high lethality and rapid spread of the new coronary pneumonia virus urgently require the vaccine to reach the grassroots vaccination units quickly and efficiently [4]; and secondly, the traditional vaccine supply chain focuses on supply chain fundamentals such as logistics, information flow and capital flow, and lacks the application of new technologies and new management ideas.

In recent years, the state has put forward several management specifications for the storage and transportation of vaccines to promote the standardization of the vaccine circulation process, but the lack of supervision and insufficient implementation have caused

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many measures not to be implemented in concrete terms. Manufacturers, CDCs, logistics companies and grassroots vaccination units lack a complete traceability system, and the information systems adopted by each differ greatly, making it difficult to truly implement full traceability and lacking complete records of vaccines with respect to environmental parameters and handover and transportation, making it difficult to truly guarantee vaccine quality. The fundamental reason is the lack of a system of full traceability, the whole chain of supervision beforehand, during and afterwards has not been formed, and the long-term mechanism of vaccine safety management has not been established [1]. According to a white paper jointly published by international logistics giant DHL and McKinsey & Company, some Covid-19 vaccines currently being developed around the world are likely to have strict temperature control requirements as low as minus 80 °C), the storage temperature of mRNA-1273, a coronavirus vaccine candidate from Modernad, is minus 20, and the storage temperature of BN1162b2, a product candidate from BioNTech, is minus 70 °C. In addition, the potential population size of the Covid-19 vaccine is huge, and the cold-chain market increment is more than 7.2 times higher after successful vaccine development. Stricter temperature control requirements and large-scale transportation make the existing vaccine cold chain face serious challenges. The cold chain logistics industry is still facing serious problems of "broken chain" and lack of effective full control means. These problems require advance planning and preparation by all parties involved in the cold chain of vaccines, including higher requirements for cold chain equipment and temperature control devices, as well as the purchase of more storage devices and transportation vehicles, and stricter supervision means [3].

Vaccine cold chain usually involves various risks, especially at the end of distribution. After the vaccine is successfully developed, a large number of vaccines will inevitably be delivered to grassroots vaccination units, and pharmaceutical logistics enterprises lack experience in large-scale and wide-scale end distribution, which may not be delivered to remote areas, and the delivery timeframe may be reduced. Socialized logistics enterprises have great advantages in distribution network, end distribution and process visualization, and urgently need There is an urgent need for socialized logistics enterprises with strength and technology to enter the vaccine cold chain market [6].

2 Covid-19 Vaccine Supply Chain Risk Identification

Risks will be identified in four areas, namely demand risk, supply risk, logistics risk and financial risk, which will be further subdivided under each risk broad category.

GSK, a well-known vaccine manufacturer, defines vaccine supply chain distribution as the relevant supply chain management measures that ensure that the particular product is always kept at a constant temperature from the producer to the consumer. In the context of the international vaccine distribution market, many scholars have summarized different definitions of the vaccine supply chain according to the characteristics of the industry. They believe that vaccines are different from the supply chain of bulk commodities, and the vaccine supply chain pays particular attention to the impact of major epidemic contexts, which are also affected by factors such as the bidding process, shelf life and cold chain logistics, so the supply chain should be designed in terms of economic, technical and performance value-added, while environmental sustainability.

The development of the vaccine supply chain cannot be achieved without the participation of public health sectors such as WTO, and requires mutual cooperation of various groups and organizations. In such a severe epidemic context, in order to share resources and reduce waste, the supply chain integration between German vaccine manufacturers and other industries has thus become a strategic plan to improve the efficiency of the supply chain and bring efficient benefits.Its characteristics are as follows:

(1) Strict storage and transportation conditions for Covid-19 vaccine
The vaccine requires special refrigerated facilities and equipment during transportation and storage, so the initial investment in facilities and equipment is large, and more technological means are required for the whole transportation process. In addition, there are many circulation links, which require a lot of human and material resources and high operating costs. Therefore, the cost of vaccine cold chain is higher than that of ordinary logistics.
(2) High temperature and equipment requirements for Covid-19 vaccine
The vaccine must be transported in the cold chain at a constant temperature range; exceeding or falling below the limited temperature range of the vaccine will denature the proteins in the vaccine and degrade the polysaccharide antigens, making the vaccine lose its proper immunogenicity. Vaccines have a direct effect on the human body, and if the cold chain is broken or the temperature is higher than required during transportation, the vaccine will be less effective or even ineffective, i.e. the human body will not be able to produce antibodies. Therefore, the temperature requirements are extremely high, and vaccines generally need to be kept at 2 to 8° during transportation and storage, with some requiring even lower temperatures.
(3) Time-sensitive and difficult to plan
The Covid-19 vaccine has a long production cycle and an expiration date. To ensure timely supply and no backlog, the supply must be carefully planned and scientifically arranged. A production cycle of vaccine generally includes cell culture, harvesting of viral fluid, inactivation, purification, and a series of steps such as product distribution, testing, and packaging, which takes a considerable amount of time before the final product is made. For example, it takes about 40 days for an influenza vaccine to go from production to packaging and marketing. All vaccines have a specified expiration date and can only be supplied and used within the expiration date. Once the vaccine exceeds the expiration date, it can no longer be used for vaccination to avoid adverse physiological reactions to the human body. Therefore, in the logistics management of vaccines, it is necessary to pay attention to the expiration date of vaccines at all times to ensure that they are sold and used within the expiration date to avoid wasting resources and protect the health of vaccinated people.
(4) Difficult quality control
The circulation of vaccines in the whole supply chain needs to go through many links and departments, and it is difficult for personnel to strictly implement the relevant technical requirements in the whole circulation process, and at the same time, storage and transportation have to be carried out, and some force majeure factors, such as broken chains in the supply chain caused by natural disasters, are

prone to occur in this process, which also causes greater management difficulties for the quality control of vaccines.

2.1 Demand Risk

There is a global need for multiple different types of vaccine candidates to maximize the chances of finding a successful solution. When a new vaccine is successfully developed, demand will outstrip supply. Excessive demand and competition for supply have led to vaccine nationalism and the risk of price fraud, which can only be addressed by global solidarity, public sector investment and engagement.

2.2 Supply Risk

Vaccine supply should be adjusted according to changes in market demand. If demand continues to grow in the context of a major epidemic, vaccine manufacturers should promptly assess the adequacy of suppliers' capacity, and if a vaccine inventory shortage occurs, they need to promptly develop a list of supplemental vaccine supplies. If demand decreases, demand planning departments should adjust forecast data as soon as possible and promptly communicate with material planning departments to reduce procurement and prevent excessive inventory backlogs, so to reduce risks in supply.We need to work closely with the demand department, communicate in a timely manner, and make appropriate adjustments to prevent these extreme situations of inventory shortages or excesses. In addition, if the supplier is located in a federal state with a serious epidemic, which may close the country as a result, or if transportation is restricted, the procurement volume should be transferred to other suppliers in advance to ensure the normal operation of the supply chain. It can be seen that purchasing from only a single supplier or a supplier in a single region will have a relatively large risk of stock outage.

2.3 Logistics Risk

Under the epidemic, there are fewer flights in German air transport and frequent strikes in road transport, resulting in low attendance of truck drivers, leading to a reduction in transport capacity or transport capability. In the case of capacity constraints, vaccine shipments should be prioritized according to emergencies as much as possible to ensure that the vaccine supply chain end is matched with resources on a priority basis. At the same time, vaccine companies should strengthen cooperation with third-party logistics service providers, as a good partnership can play a positive role when facing risks and ensure stable service levels and lower transportation prices. It is also due to the limited capacity, oversupply and significant increase in transportation prices that companies should increase the cost budget for transportation activities to prevent the actual final cost from exceeding the budget too much and affecting the performance evaluation. In addition to this, transit time and punctuality of transportation cannot be 100% guaranteed. When it comes to international transportation, vaccine materials need to be prioritized during customs clearance, and real-time tracking systems should be fully utilized to keep track of the location of the cargo and the expected time of arrival at the destination, so as to ensure the consistency of production operations.

2.4 Financial Risks

If the market demand abroad remains low, German vaccine companies will see their own revenues decrease, but their costs remain the same or even higher. Some companies choose to reduce costs by requiring employees to take time off from work.

3 An Interval Intuitionistic Fuzzy Set Decision Model Based on Evidence Theory

The model proposed in this paper converts interval intuitionistic fuzzy set decisions into interval BPA decisions based on evidence theory. In the following, the method of converting interval intuitionistic fuzzy sets into interval BPA, the method of fusion of interval BPA and how to use the fused interval BPA decisions are presented respectively [5].

3.1 Interval BPA Generation

Let the identification framework be $H = \{H_1, H_2,\ldots, H_n\}$, The corresponding n subsets are $F_1, F_2,\ldots, F_n$, When the interval BPA $[a_i, b_i]$, the BPA is valid when the following conditions are met.

(1) $a_i \leqslant S(F_i) \leqslant b_i$, among them $0 \leqslant a_i \leqslant b_i \leqslant 1$ $(i = 1, 2,\ldots, n)$.

(2) $\sum_{i=1}^{n} ai \leq 1$, $\sum_{i=1}^{n} bi \geq 1$;

(3) $S(A) = 0, \forall A \notin \{F_1, F_2 \ldots, F_n\}$.

When $\sum_{i=1}^{n} ai > 1$ or $\sum_{i=1}^{n} bi < 1$, then the interval BPA is not a valid BPA.

The second of these points ensures that in each interval $[a_i, b_i](i = 1,2,3\ldots n)$ there is at least one of m(Fi), which let

$$\sum\nolimits_{i=1}^{n} S(F_i) = 1 \tag{1}$$

The model converts the decision problem based on interval intuitionistic fuzzy sets into an evidence-theoretic information fusion problem to be solved. Let the discriminative framework in the evidence theory corresponding to interval intuitionistic fuzzy sets be {G (Yes), V(No),(G, V(Yes, No))} The interval intuitionistic fuzzy set can be converted into the corresponding interval BPA, if ($[a, b]$, $[c, d]$) for 1 IVIFN, of which: $[a, b] \subseteq [0, 1]$, $[c, d] \subseteq [0, 1]$, $b + d \leq 1$. The hesitation of the IVIFN [e, f] = [1-b-d, 1-a-c], Then the interval transformed into BPA is S(G) = $[a, b]$, S(V) = [c, d], S(G,V) = [e, f]. so S(G), S(V) and S(G, V) meet the conditions. Therefore, the interval BPA generated by this method must be valid, and there is a one-to-one correspondence between the transformed interval BPA and IVIFN.

3.2 Interval BPA Fusion

Assuming $S_1, S_2,\ldots, S_n$ is a multiple interval number basic probability assignment that $S_i\ (A_i) \leq S_i\ (A_i) \leq S_i + (A_i)$, and i = 1,2,3…,n. Interval Evidence $S_1, S_2,\ldots, S_n$ the combination of the results with $S_1 \oplus S_2 \oplus S_3 \ldots 2 \oplus S_n$, Then the upper and lower limits of BPA after the combination can be determined by the following equation:

$\max/\min\ [S_1 \oplus S_2 \oplus S_3 \ldots \oplus S_n](C) = \sum S_1(A^1{}_{j1}) \ldots S_n(A^n{}_{jn})$.

$A^1{}_{j1} \cap A^2{}_{j2} \cap \ldots \cap A^n{}_{jn} = C$

$$S_1\left(A^1_{j1}\right) \ldots S_n\left(A^n_{jn}\right) \tag{2}$$

$C \neq \emptyset\ A^1{}_{j1} \cap A^2{}_{j2} \cap \ldots \cap A^n{}_{jn} = C$

s.t. $\sum_j = 1^{ni} S_i(A^i{}_j) = 1$

$S_i\ (A^i{}_j) \leq S_i\ (A^i{}_j) \leq S_i + (A^i{}_j)$

$i = 1,2,3,\ldots n,\ j = 1,2,3,\ldots n_i$

3.3 Interval BPA Decision

Expressing the attribute values by interval numbers in the evaluation phase can better reflect the real-world ambiguity, but using interval directly in the final phase.

BPA is not convenient for decision making. Thus, the model in this paper converts the uncertain interval BPA into the deterministic classical BPA. The conversion method is as follows.

If $Sx_1\ (G) = [a, b] \subseteq [0, 1]$, $Sx_1\ (V) = [c, d] \subseteq [0, 1]$, $Sx_1\ (G, V) = [e, f] \subseteq [0, 1]$ is the fused set of interval BPA, then the transformed classical BPA is:

$$Sx_1(G) = (a + b)\ /\ 2 \tag{3}$$

$$Sx_1(V) = (c + d)\ /\ 2 \tag{4}$$

$$Sx_1(G, V) = (e + f)\ /\ 2 \tag{5}$$

The sorting principle is as follows the bigger $SX_1\ (G)$ is, the better result will achieve; the smaller $SX_1\ (V)$ is, the better result will achieve.

3.4 Case Study

3.4.1 Covid-19 Risk Assessment Index System of Vaccine Supply Chain

In the study on the quality and safety of vaccine transportation, through the risk identification of different links of the vaccine supply chain, the regulatory focus of the quality and safety of vaccine transportation was revealed from different perspectives, a theoretical framework for monitoring the safety risks of vaccines was constructed, and finally a risk evaluation index system of the vaccine supply chain under the epidemic was built covering four primary indicators, including demand risk, supply risk, logistics risk and financial risk, and 12 secondary indicators. As shown in Table 1.

Table 1. Vaccine supply chain risk evaluation index system

Tier 1 Indicator	Tier 2 Indicator	Indicator Description
T1 Demand Risk	T11 demand information mismatch	lagging information on vaccine demand data
	T12 demand IT	unstable demand information system
	T13 demand Information transfer	demand delivery distortion
T2 Supply Risk	T21 natural environment	public health emergencies
	T22 economic environment	the impact of the global economy on the vaccine supply chain
	T23 policies and laws	customs inspection and other measures
T3 Logistics Risk	T31 demand interruption	weakening customer demand
	T32 supply interruption	suppliers affected by the outbreak
	T33 logistics disruption	poor operation
T4 Financial Risk	T41 operation	internal control deficiencies
	T42 management	poor decision making
	T43 partnership	unstable partnership

3.4.2 Risk Analysis of Covid-19 Vaccine Supply Chain Based on Interval Intuitionistic Fuzzy Sets

In order to effectively identify the vaccine supply chain risks brought about by the epidemic, so as to effectively avoid the risks and reduce the losses caused by the risks, five experts in related fields were invited to evaluate this paper. The four experts were members of the federal and state governments and university experts (hereinafter referred to as B_1, B_2, B_3, and B_4). The evaluation language used interval intuitionistic fuzzy sets. In the context of the epidemic, each expert was invited to give evaluation results for each indicator based on the established evaluation index system. The evaluation results are given in the form of interval intuitionistic fuzzy sets, as shown in Table 2.

Firstly, the fuzzy entropy of the evaluation of five experts is calculated separately based on the intuitive fuzzy matrix of the evaluation interval of the experts. Then each expert's weight is calculated by the entropy weight calculation formula. According to the set of secondary indicators in the intuitionistic fuzzy evaluation matrix of the experts, the secondary indicator group evaluation matrix is formed, as shown in Table 3.

According to the weight of each indicator of the secondary indicators and the comprehensive evaluation value were assembled to obtain the evaluation value of the primary indicators, the interval intuitionistic fuzzy numbers in Table 1, 2, 3 are converted into interval BPAs, and a basic probability assignment function based on the number of intervals is generated for all candidates under each evaluation index. In the following, we take candidate T11 as an example to illustrate the interval BPA generation and combination process in this paper. Let the identification framework $S \in \{(G),(V),(G,V)\}$, the evaluation result of Indicator T11 under evaluation index B_1 is ([0.4,0.55], [0.3,0.4],

Table 2. Decision Matrix

Tier2 Indicator	B1	B2	B3	B4
T11	([0.4,0.55],[0.3,0.4])	([0.45,0.55],[0.3,0.4])	([0.45,0.5],[0.35,0.45])	([0.45,0.55],[0.35,0.45])
T12	([0.6,0.7],[0.2,0.3])	([0.65,0.75],[0.15,0.25])	([0.65,0.7],[0.15,0.25])	([0.65,0.75],[0.15,0.25])
T13	([0.45,0.55],[0.3,0.35])	([0.4,0.5],[0.35,0.45])	([0.45,0.55],[0.35,0.45])	([0.4,0.5],[0.35,0.45])
T21	([0.45,0.55],[0.35,0.45])	([0.5,0.55],[0.35,0.45])	([0.45,0.5],[0.35,0.45])	([0.45,0.55],[0.35,0.45])
T22	([0.65,0.75],[0.2,0.25])	([0.7,0.8],[0.1,0.2])	([0.7,0.75],[0.2,0.25])	([0.75,0.85],[0.1,0.15])
T23	([0.45,0.5],[0.3,0.4])	([0.5,0.55],[0.25,0.35])	([0.45,0.55],[0.35,0.45])	([0.5,0.55],[0.3,0.35])
T31	([0.45,0.55],[0.3,0.4])	([0.4,0.55],[0.3,0.4])	([0.45,0.5],[0.35,0.45])	([0.45,0.55],[0.35,0.45])
T32	([0.65,0.75],[0.15,0.25])	([0.7,0.8],[0.1,0.15])	([0.65,0.7],[0.2,0.25])	([0.65,0.75],[0.15,0.25])
T33	([0.5,0.55],[0.35,0.45])	([0.45,0.55],[0.25,0.35])	([0.45,0.55],[0.35,0.45])	([0.45,0.5],[0.35,0.45])
T41	([0.65,0.75],[0.2,0.25])	([0.65,0.75],[0.15,0.2])	([0.7,0.75],[0.15,0.25])	([0.75,0.85],[0.35,0.45])
T42	([0.75,0.85],[0.1,0.15])	([0.75,0.85],[0.1,0.15])	([0.75,0.85],[0.1,0.15])	([0.75,0.8],[0.1,0.2])
T43	([0.6,0.7],[0.2,0.25])	([0.65,0.75],[0.15,0.25])	([0.65,0.75],[0.15,0.25])	([0.65,0.7],[0.15,0.25])

Table 3. Results of evidence fusion

Tier 2 Indicator	S(G)	S(V)
T11	[0.4235,0.5209]	[0.3154,0.4137]
T12	[0.5432,0.6159]	[0.3125,0.3406]
T13	[0.5306,0.5847]	[0.2704,0.3612]
T21	[0.3206,0.4033]	[0.2588,0.3527]
T22	[0.6434,0.7036]	[0.1450,0.2362]
T23	[0.4302,0.5223]	[0.4302,0.4128]
T31	[0.4337,0.5245]	[0.3680,0.4720]
T32	[0.7034,0.7919]	[0.1329,0.1908]
T33	[0.4591,0.5453]	[0.3125,0.4157]
T41	[0.6837,0.7503]	[0.1428,0.2187]
T42	[0.7034,0.8300]	[0.1250,0.1781]
T43	[0.6955,0.7829]	[0.1857,0.2704]

[0.4,0.3] The affiliation degree of the evaluation result is the degree to which the candidate is supported under evaluation indicator B_1, for which a base probability assignment is generated, i.e. S(G) = [0.4, 0.55]; the unaffiliated degree is the degree to which the candidate is not supported by evaluation indicator B1, i.e. S(V) = [0.3,0.4]; the degree of hesitation is the unknown part, i.e. S(G,V) = [0.4,0.3]. Therefore, the basic probability

Table 4. Classical evidence structure representation of fusion results

Tier1 Indicator	S'(G)	S'(V)	S'(G,V)
T1	[0.4837,0.5688]	[0.2601,0.3709]	[0.0000,0.0000]
T2	[0.5304,0.6301]	[0.2308,0.3422]	[0.0000,0.0000]
T3	[0.6235,0.7245]	[0.1945,0.2801]	[0.0000,0.0000]
T4	[0.7206,0.8244]	[0.1203,0.1909]	[0.0000,0.0000]

distribution function of T_{11} under B_1, using Matlab to solve the above nonlinear optimization problem with constraints, yields the following conclusion, as shown in Table 4.

The improved score function was used to rank their first-level risk evaluation indicators. The higher the score function value, the lower the corresponding risk. Therefore, among the risk indicators of commodity supply chain, the highest risk is supply risk, followed by demand risk, logistics risk, and financial risk.

4 Countermeasures to Solve the Problem of Covid-19 Vaccine Supply Chain Risk Assessment Index

4.1 Optimize the Vaccine Supply Chain System

If the transportation of vaccines is carried out according to the traditional vaccine supply chain centered on the Federal Agency for Disease Control and Prevention and Control, there is a lack of timely information communication, and this process is not only less efficient but also takes longer to adapt to the characteristics of the tight and fast demand of the Covid-19 vaccine cold chain. In addition, because of the numerous links, multiple handling, storage and transportation are required, which makes it more difficult to control the quality of vaccines. Therefore, vaccine companies should use a third-party logistics company as the core of the supply chain risk management model, in which the material procurement departments of grassroots vaccination units share vaccine terminal demand information with the logistics company for real-time feedback, and the logistics company adopts a quantity-based replenishment strategy based on the real-time demand of grassroots units, and when the vaccine stock reaches a replenishment point, the logistics company will distribute and replenish the stock. The logistics company reaches an agreement with the vaccine manufacturer, who sends the produced vaccines to the logistics company for storage in advance. The Federal State CDC oversees the process and does not perform storage or transportation of vaccines. Secondly, the vaccine cold chain focuses more on the application of new technologies such as the Internet of Things and blockchain to visualize and trace the information of the vaccine cold chain throughout the whole process and to guarantee the safe and efficient operation of the vaccine cold chain.

4.2 Sound Electronic Traceability System of Vaccine Supply Chain

The two-dimensional code technology, RFID technology (radio frequency identification) and blockchain technology can be applied to the supply chain of each vaccine manufacturer. When the vaccine is produced, the labeling operation can be carried out to establish a traceability two-dimensional code for each vaccine, which is the so-called electronic ID card, so that various temperature and humidity information can be easily recorded, and blockchain technology can be used to read the information of the electronic label and carry out collection and intelligent recognition, etc., and store all information such as the process of vaccine circulation into the system, so that system members can check the required data at any time, ensuring traceability of vaccine circulation, and supervisory departments can also participate in the shared device end to strengthen supervision.

4.3 Enhancement of Vaccine Cold Chain Technology

In response to the increasingly severe epidemic, the market needs a larger scale vaccine production system, so the vaccine supply chain system is very important, especially the cold chain technology at the distribution end. First, the German government has introduced policies to encourage companies producing vaccine storage and packaging equipment to continue to expand production and increase production capacity to meet the upcoming explosive vaccine cold chain demand. All units upstream and downstream of the vaccine cold chain should make equipment purchases in advance and plan the amount of equipment to be purchased. Secondly, the vaccination units in each federal state should make advance plans and conduct training on equipment and vaccination techniques to ensure that vaccination is carried out in an orderly and stable manner.

4.4 Introduction of Third-Party Logistics

For the vaccine supply chain focusing on cold chain technology to become the top of the pyramid in the transportation industry, the personnel training and technical requirements are higher than those of the traditional supply chain industry, and the terminal distribution equipment should meet the requirements of the World Health Organization. The German state government makes use of the advantages of socialized logistics enterprises in transportation network, full traceability system and terminal distribution to supplement the demand for vaccine cold chain that cannot be met by traditional pharmaceutical logistics. To introduce socialized logistics enterprises must improve the market access mechanism and introduce logistics enterprises with advanced facilities, complete technologies and specialized talents. Establish a market access mechanism and support a number of socialized logistics enterprises. At present, the third-party logistics organizations led by DHL are strongly supported by government departments and have entered the vaccine cold chain market after being certified by relevant national health departments to carry out the distribution business of Covid-19 vaccines.

5 Conclusions

In the context of a pandemic epidemic, Germany should control Covid-19 vaccine supply chain risks at a strategic level. In terms of financial risk, companies should take advantage of the scale effect of third-party logistics to increase the probability of centralized vaccine transportation through the integration of product flows as a way to reduce supply chain costs, and by establishing third-party logistics centers to standardize the vaccine distribution market, supply chain risk managers can reduce and control risks through centralized and standardized management. In terms of supply risk, vaccine companies should establish logistics centers according to customer demand to ensure timely and safe supply, and the synergistic effect among logistics centers can ensure customer demand to the greatest extent. In the face of natural disaster risks, decentralized placement of stocks in multiple logistics centers shares the risk of irresistible results of vaccines due to safety storage problems, and the logistics centers that are not affected can respond quickly to provide temporary supply to customers in the affected areas until the affected logistics centers return to normal. In terms of logistics risks, the regional service capacity of logistics centers is well utilized, and suppliers have strong local transportation and storage capacity, and are also more familiar with local laws and regulations, so they can better serve customers. After combining the identification of vaccine supply chain risks and corresponding measures, the supply chain risk level is summarized in general as the delivery risk level, which refers to the risk value that the logistics center cannot meet the demand of the covered customers. A higher risk value means that more customers will not receive vaccines. Companies should set the corresponding delivery risk level according to their own supply chain strategies and establish an optimal Covid-19 vaccine supply chain network under a certain risk level.

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