

This is an Open Access document downloaded from ORCA, Cardiff University's institutional repository: <https://orca.cardiff.ac.uk/id/eprint/169114/>

This is the author's version of a work that was submitted to / accepted for publication.

Citation for final published version:

Mogale, Dnyaneshwar , Xian, Dongxiao and Sanchez Rodrigues, Vasco 2024. Managing logistics risks in pharmaceutical supply chain: A 4PL perspective. *Production Planning and Control* 36 (10) , pp. 1414-1429. 10.1080/09537287.2024.2363938

Publishers page: <https://doi.org/10.1080/09537287.2024.2363938>

Please note:

Changes made as a result of publishing processes such as copy-editing, formatting and page numbers may not be reflected in this version. For the definitive version of this publication, please refer to the published source. You are advised to consult the publisher's version if you wish to cite this paper.

This version is being made available in accordance with publisher policies. See <http://orca.cf.ac.uk/policies.html> for usage policies. Copyright and moral rights for publications made available in ORCA are retained by the copyright holders.



# **Managing Logistics Risks in Pharmaceutical Supply Chain: A 4PL Perspective**

D. G. Mogale\*, Dongxiao Xian, Vasco Sanchez Rodrigues

*Logistics and Operations Management Section, Cardiff Business School, Cardiff University,  
Colum Dr, CF10 3EU Cardiff, UK*

**\*Corresponding author: Dr D. G. Mogale**

***Email list:***

**D. G. Mogale:** MogaleD@cardiff.ac.uk

**Dongxiao Xian:** dorisxian0@gmail.com

**Vasco Sanchez Rodrigues:** sanchezrodriguesva1@cardiff.ac.uk

Article in **Production Planning and Control, 2024**

**Abstract:** Supply chain risks and vulnerabilities are growing recently due to the global, interconnected, and complex networks. The Pharmaceutical Supply Chain (PSC), as a critical national asset, requires increased attention to mitigate severe consequences of global events. With various risks impacting both the firm's performance and the lives of patients, effective risk management is paramount for the PSC. This empirical study focuses on the UK based Fourth-Party Logistics (4PL) provider, which manages pharmaceutical manufacturers' logistics operations. The 4PL provider's past experiences with unexpected risky events have influenced its performance. This study aims to explore inherent logistics risks, evaluate them, and recommend mitigation strategies. An integrated approach considering probability, impact and manageability parameters is proposed for risk assessment. In identifying 11 risks from the 4PL perspective, structured interviews are used to gather risk information. The probability of risk occurrence, severity of impact, and manageability are quantified. The delivery delay should be given priority in the follow-up risk management process, while counterfeiting has the least priority. Finally, three resilience strategies named improving flexibility, redundancy, and creating a risk culture are proposed for the 4PL case company. The study offers multiple theoretical and managerial implications based on its findings.

**Keywords:** Pharmaceutical Supply Chain, Risk Management, Resilience, The 4PL Provider, Vulnerability, Healthcare Industry

## 1. Introduction

The healthcare system is a critical part of every national infrastructure and Covid-19 has highlighted the importance of this system in saving human lives (Spieske et al., 2022). Over the past two decades, there has been noteworthy expansion within this industry, resulting in the worldwide revenue reaching \$1.48 trillion in 2022. (Statista 2023). Despite this significant growth, the pharmaceutical industry faces various challenges like raw material and drug shortages, global network complexities, diverse and varying regulatory requirements across different regions, lack of cold chain logistics, capacity constraint, geopolitical uncertainties, market competition, pandemics, product quality maintenance, safety and fluctuating demand (El Mokrini and Aouam 2022). The Pharmaceutical Supply Chain (PSC) plays a vital role in the healthcare system by distributing the high-quality medicines to patients on time under highly regulated conditions (Mehralian et al., 2012), ensuring drug safety, reliability, and quality, as well as safeguarding the health of patients (Aldrighetti et al., 2019). The PSC suffered a severe defeat due to Covid-19, highlighting the critical need for effective risk management within it (Senna et al., 2023a).

Due to the complex, globalised and interconnected nature of the SCN, most pharmaceutical companies outsource the logistics activities so that they can focus on their core competencies (Huq et al., 2016). A 3PL provider offers transportation, warehousing and distribution services but with limited integration between different logistics functions, limited visibility and lack of flexibility to manage fluctuating demand and other risks (Feng et al., 2023). A 4PL integrates multiple 3PL providers to optimise SC costs, use advanced technology, enhance visibility and improve overall performance. Therefore, many global pharmaceutical manufacturing firms have moved towards the 4PL providers in recent years to manage their logistics activities (El Mokrini et al., 2016a).

The Pharmaceutical Supply Chain has unique characteristics when compared to other supply chains such as automotive, manufacturing, aerospace, retail and fashion. Unlike these sectors, the PSC prioritises saving human lives over making profit (Senna et al., 2023a). This focus on human health requires strict adherence to diverse regulations and quality standards imposed by various regulatory bodies. The consequences of errors within the PSC extend beyond financial terms, directly affecting the health of populations and nations (Merkuryeva et al., 2019). Public confidence is paramount in the PSC making it more susceptible to risks compared with other sectors (Eyindia, 2009). The specific storage and transportation infrastructure is needed to ensure the safety of temperature-sensitive and perishable medicines (Kumar 2019).

Counterfeiting and theft are significant challenges due to the high value of pharma products which underscores importance of supply chain security. Timely delivery of products at right destination plays a vital role for patient health and regulatory compliance (El Mokrini et al., 2016). Therefore, the PSC should be highly agile and responsive to meet market demand and regulatory requirements. Border restrictions and driver shortages contribute to delivery delays. Additionally, illegal immigration is a unique risk that can compromise the integrity of temperature-sensitive pharma products if individuals tamper with vehicles to conceal themselves. Limited coordination among PSC members exacerbates the operational inefficiencies and creates the bullwhip and ripple effect in the SCs (Nasrollah 2017). The global, complex and limited supply and delivery channels further hinder operational performance of the PSC compared to other sectors (Nguyen et al., 2022, Singh et al., 2016). The wide varieties of medical devices, growing population and aging demographics challenges emphasise the imperative need for effective management of the PSC.

This study was conducted with the UK-based 4PL company experiencing various logistics risks. Logistics risks have adverse impacts and severe consequences on the overall SC (de Vries et al., 2021). This company offers comprehensive logistics services across automotive, aerospace, retail, food, technology and healthcare industries, including international transportation, warehousing, distribution, and professional logistics solutions. This 4PL provider has a strategic partnership with the pharmaceutical company to manage their logistics activities. This firm was under significant pressure due to recent unexpected events and wanted to mitigate these risks. The main goal of this study was to help the 4PL company in gaining a comprehensive understanding of the causes and effects of supply disruptions within the PSC, focusing on the logistics process perspective. To achieve this aim, following three research questions are set.

RQ1. What are the main logistics risks in the PSC from a 4PL perspective?

RQ2. How to implement an integrated approach of risk assessment considering probability, impact, and manageability?

RQ3. What Supply Chain Resilience (SCR) strategies can guide the 4PL company in responding to logistics disruptions?

This research study makes meaningful contributions to existing literature in several ways. Firstly, it explores an under-researched topic by investigating logistics risk management in the PSC from the unique perspective of 4PL providers. Secondly, the manageability parameter of risk that is inadequately addressed in many existing studies is considered in risk

assessment. Thirdly, risks such as driver shortages, border restrictions and illegal immigrations which have received less attention in the extant literature are studied in this paper. Finally, a novel conceptual framework integrating risks, causes, consequences, mitigation, and resilience strategies based on the primary data collected is proposed to advance knowledge around this topic.

The rest of the paper is organised as follows. Section 2 explores previous literature on relevant topics, including risk management in the healthcare sector and risk modelling approaches. Section 3 presents the detailed research methodology followed during this study. Section 4 demonstrates the results and findings. Section 5 combines the interview findings with existing research to discuss the implications and offers suggestions on resilience strategy from the 4PL perspective. Finally, Section 6 summarises the study and discusses the limitations, recommending future studies on this topic.

## **2 Literature review**

### ***2.1 Supply Chain Risk Management (SCRM)***

Supply chain risk management (SCRM) refers to the collaboration and coordination among supply chain partners to identify and manage risks, thereby reducing vulnerability and its impact, while ensuring profitability and maintaining supply chain continuity (Tang 2006). It developed from efforts to reduce SC vulnerability against risks (Rangel et al., 2015). SCRM helps organisations improve supply chain efficiency and resilience by monitoring anticipated risks and controlling potential risks (Jüttner et al., 2007). Various scholars conducted comprehensive and systematic literature reviews on SCRM (Olson and Dash 2010; Tang and Musa 2011; Sodhi et al., 2012; Heckmann et al., 2015; Ho et al., 2015; Fan and Stevenson 2018; Agrawal and Jain 2021; Gurtu and Johny 2021; Katsaliaki et al., 2021; Emrouznejad et al., 2023; Sudan et al., 2023). Risk identification, assessment and mitigation are the standard simplified processes most discussed by various scholars (Sodhi et al., 2012; Nakandala et al., 2017). Additionally, risk monitoring is widely accepted as the fourth step (Ghadge et al., 2012). Other risk parameters, such as urgency, controllability, vulnerability, detectability and manageability are also related to risk management. Some authors have attempted to enhance probability-impact risk modelling by incorporating these additional risk parameters. Mizgier et al., (2015) analysed the impact of disruptions on a focal firm through Monte Carlo simulation. They found that the network structure and correlations of hazard events can cause unexpected diversification effects. The potential losses of hurricane disruption risk on oil

supply chain infrastructure were quantified using numerical simulation by considering secondary data (Wanger et al., 2014). A novel methodology for risk aggregation of multiple products based on summation and variance -covariance was proposed by Mizgier (2017a). Furthermore, Mizgier and Wimmer (2018) quantified the effect of persistent losses induced by operational disruptions on multi-period risk measures. The results revealed that operational risk was underestimated when multiple losses occurred due to the event being ignored in long-term capital planning.

## ***2.2 Pharmaceutical Supply Chain Risk Management (PSCRM)***

The PSC is essential for delivering efficient, effective, and timely healthcare services to patients. The global PSC faces challenging risks from regulatory pressures, policy changes, and fierce competition (Mehralian et al., 2012). Thus, there is a dire need to explore risk management approaches in the PSC field. Among all stakeholders, upstream members (pharmaceutical manufacturers) and downstream members (hospitals or pharmacies) are the two main research objects. Scholars mainly focused on different risk factors emerged from downstream, such as low efficiency of the medicine distribution process (Papalexi et al., 2020), drug expiration risk (Pinna et al., 2015) and distribution network-related risks (El Mokrini et al., 2018) in the past. Furthermore, demand fluctuations and forecasting inaccuracy represent other major demand-side risks. The pharmaceutical firms and their suppliers are the focal players in the PSC from the supply end. Therefore, abundant risks are bound with them. Regulatory, quality, inventory, delivery, technical, reputational, environmental, information, operation, counterfeiting, financial and theft-related risks are common categorises that pharmaceutical firms consider on the supply side of the PSC (Breen 2008; Jlassi et al., 2021). Moreover, suppliers' risks that disrupt the drug supply were prioritised in the risk ranking (Jaberidoost et al., 2013; Jlassi et al., 2021). Risks associated with single sourcing are considered as the primary cause of supply failures and drug stockouts. IT risk pose a threat to the cyber-based supply chain of global pharmaceutical firms (Boyson 2014), while concerns also emerged regarding risks related with international relations, trade tariffs and ever-expanding outsourcing landscape within the PSC (Zhang et al., 2013).

There is little literature that focuses on the logistics aspect between the supply and demand sides, and even less discussion regarding its risks. Some researchers studied logistics outsourcing related risks (operational, financial, technology, information, relational and internal) that emerge during business operation and cooperation with logistics service providers

(LSPs) (El Mokrini et al., 2016a; El Mokrini and Aouam 2022). They also investigated quality control risk in cold chain logistics, transportation losses, quality damage, drug expiry and waste risks due to low loading efficiency and high inventory levels in the PSC (Aldrighetti et al., 2019). The risks during long-haul transportation due to unexpected situations were explored by Breen (2008). Moreover, resilience is another popular research angle in the PSC. Resilience must be strengthened in the PSC to address the challenges posed by drug shortages, supply disruption, growing drug demand, and the rising frequency of catastrophic events (Lawrence et al., 2020; Yaroson et al., 2021). No single mitigation or resilience strategy can be universally applied to all risk threats across different scenarios because risks vary from one business to another, and PSC is inherently unique. Therefore, some performance indicators should be focused on identifying the most relevant factors of the specific PSC, measuring its resilience level before and after actions, then helping to find effective and targeted suggestions to improve resilience performance (Karmaker and Ahmed 2020).

### **2.3 Research gaps**

Among the reviewed literature on PSCRM, it is evident that the research in the risk management field is limited from a logistics perspective and even less in the aspect of 4PL providers (König and Spinler 2016). The research on this topic is fragmented and scarce (Wang 2018). Specific risks are mostly explored and integrated risk management (risk identification, assessment, and mitigation) has been appeared in limited studies. Previous authors mainly looked at the risks in internal hospital chains and overlooked the upstream SC risks from suppliers and manufacturers. Limited empirical studies are available on this topic (Senna et al., 2023b). The current study aims to bridge these gaps in a realistic view. The relevant literature on manageability implied that manageability was rarely discussed in the risk analysis phase from the PSC perspective (Charkhakan and Heravi 2023). Therefore, this paper incorporates the manageability indicator into the risk management process to develop an integrated risk ranking in the 4PL.

### **3. Research methodology**

Supply chain risks are typically assessed using qualitative and quantitative methods. Qualitative approaches commonly employed include interviews, case studies, questionnaire survey, focus groups, systematic literature reviews, and development of conceptual frameworks and models (Bak, 2017). On the quantitative side, various methods exist which are typically

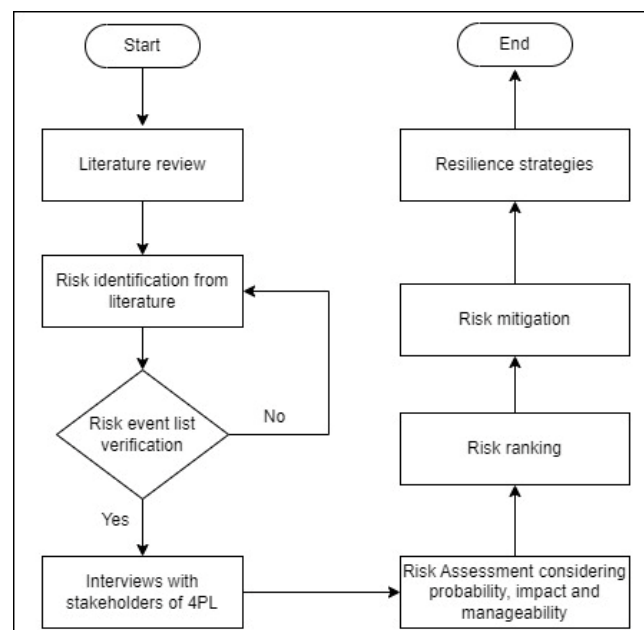
based on the probability of occurrence and potential impacts. These methods comprise of mathematical programming models (Mizgier et al., 2017b), simulation models (such as agent-based, system dynamics and discrete event simulation) (Aldrighetti et al., 2019, Mizgier et al., 2015), complexity and graph theories and Bayesian networks (Lawrence et al., 2020). Furthermore, scholars utilise multi-criteria decision-Making methods like AHP, DEMATEL and TOPSIS to prioritise risks based on their importance (El Mokrini et al., 2016b). Some researchers analysed risks through the implementation of empirical methods including Structural equation modelling (SEM) (Sreedharan et al., 2019), Partial least squares SEM (Falasca et al., 2021, Getele et al., 2019) and covariance-based SEM (Senna et al., 2023a). Mixed methods (such as simulation and analytical modelling, SEM and regressions, qualitative and quantitative) are also applied by some authors for managing risks in supply chains.

Manageability is a concept used in project-based industries' risk analysis. It denotes the ease of project execution for teams or risk owners, containing the potential of stakeholders and mitigation strategies to reduce the probability of occurrence and the severity of impact for risks (Charkhakan and Heravi 2023). Previous authors like Fan (2010) defined risk manageability as the ability to decrease probability and consequences of the negative events. The manageability level of the risk owner shows the extent to which uncertainties and consequences can be reduced. Consequently, certain risks have higher potential for reduction, making them more manageable for risk holders, thereby exhibiting high manageability (Aven et al., 2007). However, several factors influence the assessment of risk manageability. Risk manageability increases along with the experience of the risk owners (Sirazetdinova and Valitov 2014). Additionally, risk tolerability introduces a threshold, marking an organisation's preliminary judgment of manageability (Obonia and Obonia 2013).

Manageability serves as an independent qualitative analysis indicator, accompanying traditional risk indicators like probability and impact. It improves the determination of risk significance and creates a comprehensive risk analysis. Given the limited criteria of probability and impact dimensions for risk assessment, it is necessary to extend the criteria. Subjective interpretation compensates for these deficiencies but can significantly influence the rating result of the risk matrix due to the various evaluation criteria of risk managers (Anthony Cox Jr 2008). Assessing a high manageability risk with available tools to mitigate or transfer, can lower its final risk level. Integrating the manageability matrix with Probability-Impact matrix can help in visualising a robust risk assessment process and identifying areas for risk improvement (Charkhakan and Heravi 2023). Furthermore, Sirazetdinova and Valitov (2014) considered both positive and negative aspects of probability and consequence along with risk

manageability as index to evaluate risks. They introduced weight of importance to these indicators separately based on risk managers' decisions. Acceptance of the project depends on the outcome of the final integrated index considering all indicators. This study is inspired from this work.

In this paper, a mixed qualitative and quantitative method was implemented. Initially, a series of relevant risk events from existing studies were identified through literature review. Subsequently, qualitative data was gathered through structured interviews and a portion of the responses was quantified to further analyse the data. To evaluate PSC supply and logistics risks, a total of 11 interviews were conducted with managers and operations professionals from the 4PL case company, client enterprise and downstream subcontracting enterprise. During interviews, the questions were asked about the causes, consequences and responses to listed risky events, as well as their ratings for probability, severity of impact, and difficulty level of managing the risks. Additionally, several open-ended questions were included in the interviews to facilitate qualitative analysis. The interview questions comprised a series of risks events identified from existing studies, which may potentially occur in the logistics phase and supply side of PSC. The research methodology is illustrated in Figure 1.



**Figure 1.** Research methodology

A coding system is used to systematically assign a number to a category of content or typical answer, ensuring consistency with the pre-coded definition of the answer (Srnrka and Koeszegi 2007). After quantifying risk probability, impact severity, and manageability, we

calculate the risk probability and impact (P-I) ranking. Using the weighting method in conjunction with manageability and P-I scores, a final risk prioritisation is determined.

## 4. Results and findings

### 4.1 Risk identification

Considering the case company being the 4PL provider in this research, the risk classification is based on the focal firm. Three types of risks are considered: Internal (operational) and supply chain risks (external to the firm) and external (environmental). The initial risk events identified from historical resources are listed in Table 1.

**Table 1** Identified risks

| Sr No | Category           | Risk events                           | Description                                                                            | References                                                                                   |
|-------|--------------------|---------------------------------------|----------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------|
| 1     | Internal risks     | Poor handling within the organisation | Picking errors for medication and packaging issues                                     | Breen (2008), EI Mokrini and Aouam (2022), El Mokrini et al., (2016b)                        |
| 2     | Supply chain risks | Delivery delay                        | Unavailability of fuel, congestion, weather, illness, etc.,                            | EI Mokrini and Aouam (2022), Breen (2008), El Mokrini et al., (2016b)                        |
| 3     |                    | Poor performance of LSP               | Low flexibility and responsiveness of LSP; Poor communication and information sharing  | EI Mokrini and Aouam (2022), Breen (2008), El Mokrini et al., (2016b)                        |
| 4     |                    | Quality risk                          | Quality issue during transportation or transportation loss                             | Aldrighetti et al., (2019), EI Mokrini and Aouam (2022), Govindan and Chaudhuri (2016)       |
| 5     |                    | Counterfeiting                        | Counterfeiting is a risk that usually occurs in the logistics phase                    | Breen (2008), Enyinda et al., (2010), Jaberidoost et al., (2013), Boyson 2014)               |
| 6     | External risks     | Political risk                        | Conflicts between countries or different regions, different legislations, and policies | Rathore et al., (2021), Prakash et al., (2017)                                               |
| 7     |                    | Natural disaster                      | Such as some extreme weather like floods, typhoons and even Covid-19                   | Nakandala et al., (2017), Prakash et al., (2017), Govindan and Chaudhuri (2016)              |
| 8     |                    | Labour strike                         | Workers strike from any node of the supply chain                                       | Prakash et al., (2017), Rathore et al., (2021), Nakandala et al., (2017), Ma and Wong (2018) |

The risk factors mentioned under the external category provide a macro perspective relevant to the logistics industry. They are extracted from prevalent and widely discussed issues in the global supply chain. The initial version of the list of risk events was verified by academic experts. Border risk and illegal immigration were two new risks that the company was specifically highlighted and recommended for discussion during the interview and subsequent

research. Border risk refers to the potential closure of national borders due to unexcepted events such as Covid-19. Illegal immigration risk involves international transportation safety and serious legal concerns. The 4PL companies prioritise the quality and safety of products throughout the logistics process. Thus, counterfeiting risk was suggested to be exclusively discussed with participants from the pharmaceutical company. This risk has been identified as the most severe risk and requires consideration by decision-makers within the pharmaceutical industry.

After identifying the potential risk events in the PSC, the subsequent risk evaluation step requires three essential indicators: the probability of risk occurrence, the severity of impact and the manageability levels (low, medium and high). In addition, the rating scales in Table 2 reflect the pre-coded expected answers for the structured interview.

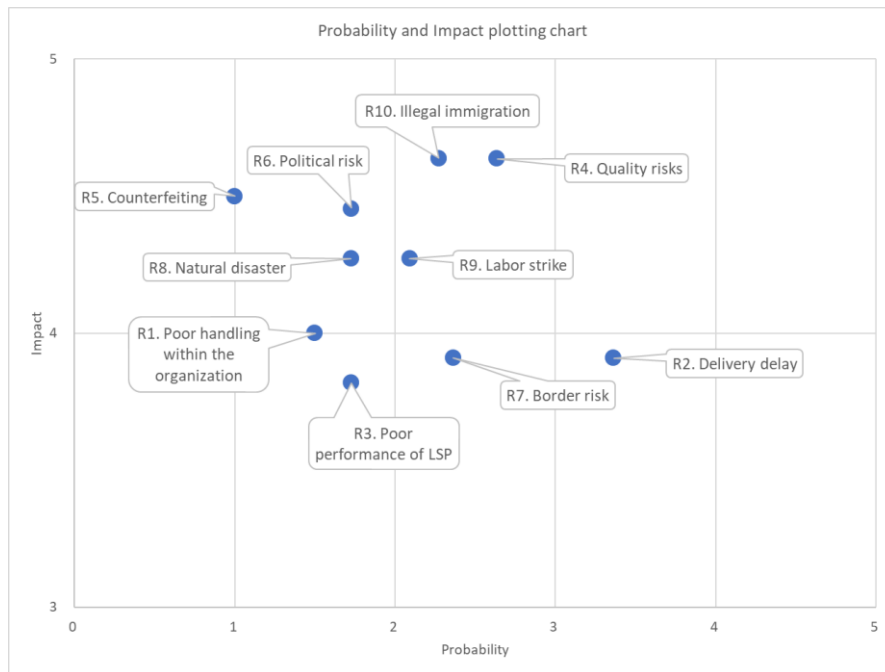
**Table 2** Pre-coded answers for interview

| Scales | Probability of occurrence          | Severity of impact                                                                                                                                  | Manageability scale                                                          |
|--------|------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------|
| Low    | Rare to happen                     | Cause minor disruptions and delays to various parts of the supply chain, but overall operations run smoothly with minimal impact on most functions. | Hard to manage or totally uncontrollable                                     |
| Medium | Occur sporadically in regular work | Cause disruptions to certain parts of the supply chain, while the main functions continue to meet requirements.                                     | Can be managed sometimes and need to input major effort (time or cost, etc.) |
| High   | Happen frequently                  | Cause disruptions to essential parts of the supply chain, resulting in significant delays, costs and efforts required for recovery.                 | Easily manageable with common organisational management tools.               |

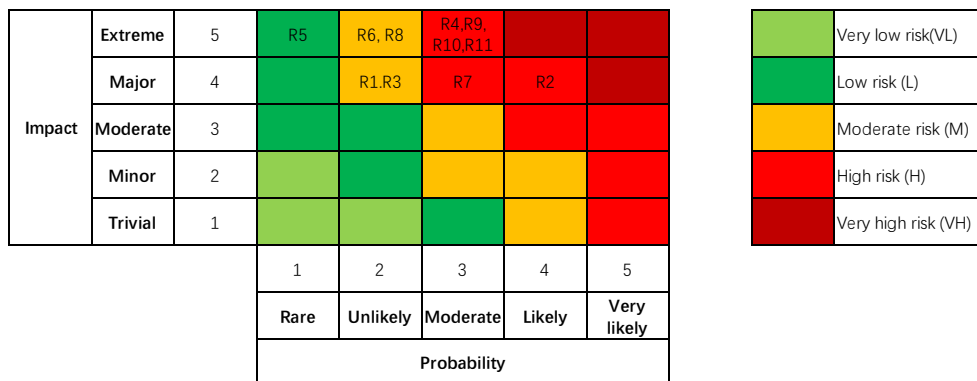
## 4.2 Risk analysis

A probability-impact (P-I) matrix is used to analyse risk factors and determine the risk level. In addition to P-I indicators, manageability is also considered a crucial factor in determining the final integrated risk level. However, since the rating scales are limited to low, medium and high, a coding system (Low: 1, Medium: 3 and High: 5) is used to convert these data into numerical values.

Introducing the coding system into the quantifying process enabled the formation of the score matrix. The average score was taken as the final score of each risk. The overall descriptions for P-I and manageability of risk events indicate that the average scores for probability are 3 and below, while the severity of impact average scores are 4 and above. Furthermore, less than one-third of the average risk manageability scores reach 3 and above. The visualisation of the P-I indicator of each risk involves plotting scores of two dimensions, as shown in Figures 2 and 3.



**Figure 2** The Probability and impact chart



**Figure 3** Risks allocation in P-I matrix

Due to the P-I matrix, the score obtained by multiplying probability and impact numbers represents a final risk level index. The risk ranking illustrates the priorities of these risks, with higher risk levels receiving higher ranks (See Table 3). The overall scores and rankings for P-I and manageability are presented in Table 4.

**Table 3** Risk ranking based on P-I scores

| Sr No | Category       | Risk events                               | Probability of occurrence | Severity of impact | P-I Scores | Ranking |
|-------|----------------|-------------------------------------------|---------------------------|--------------------|------------|---------|
| 1     | Internal risks | R1. Poor handling within the organisation | 1.50                      | 4.00               | 6.00       | 10      |

|    |                    |                             |      |      |       |    |
|----|--------------------|-----------------------------|------|------|-------|----|
| 2  | Supply chain risks | R2. Delivery delay          | 3.36 | 3.91 | 13.15 | 1  |
| 3  |                    | R3. Poor performance of LSP | 1.73 | 3.82 | 6.60  | 9  |
| 4  |                    | R4. Quality risks           | 2.64 | 4.64 | 12.22 | 3  |
| 5  |                    | R5. Counterfeiting          | 1.00 | 4.50 | 4.50  | 11 |
| 6  | External risks     | R6. Political risk          | 1.73 | 4.45 | 7.69  | 7  |
| 7  |                    | R7. Border risk             | 2.36 | 3.91 | 9.24  | 5  |
| 8  |                    | R8. Natural disaster        | 1.73 | 4.27 | 7.38  | 8  |
| 9  |                    | R9. Labor strike            | 2.09 | 4.27 | 8.93  | 6  |
| 10 |                    | R10. Illegal immigration    | 2.27 | 4.64 | 10.54 | 4  |
| 11 |                    | R11. Driver Shortage        | 3.00 | 4.33 | 13.00 | 2  |

**Table 4** Overall risk scores and ranking

| Sr No | Category           | Risk events                               | Probability of occurrence | Severity of impact | P-I Score | Ranking | Manageability | Ranking |
|-------|--------------------|-------------------------------------------|---------------------------|--------------------|-----------|---------|---------------|---------|
| 1     | Internal risks     | R1. Poor handling within the organisation | 1.50                      | 4.00               | 6.00      | 10      | 3.75          | 1       |
| 2     | Supply chain risks | R2. Delivery delay                        | 3.36                      | 3.91               | 13.15     | 1       | 3.00          | 3       |
| 3     |                    | R3. Poor performance of LSP               | 1.73                      | 3.82               | 6.60      | 9       | 3.55          | 2       |
| 4     |                    | R4. Quality risks                         | 2.64                      | 4.64               | 12.22     | 3       | 2.64          | 4       |
| 5     |                    | R5. Counterfeiting                        | 1.00                      | 4.50               | 4.50      | 11      | 1.50          | 10      |
| 6     | External risks     | R6. Political risk                        | 1.73                      | 4.45               | 7.69      | 7       | 2.09          | 8       |
| 7     |                    | R7. Border risk                           | 2.36                      | 3.91               | 9.24      | 5       | 2.09          | 8       |
| 8     |                    | R8. Natural disaster                      | 1.73                      | 4.27               | 7.38      | 8       | 1.36          | 11      |
| 9     |                    | R9. Labor strike                          | 2.09                      | 4.27               | 8.93      | 6       | 2.36          | 6       |
| 10    |                    | R10. Illegal immigration                  | 2.27                      | 4.64               | 10.54     | 4       | 2.64          | 4       |
| 11    |                    | R11. Driver Shortage                      | 3.00                      | 4.33               | 13.00     | 2       | 2.33          | 7       |

It is evident that the rankings of each risk in the two aspects differ. The prioritisation of risks considering P-I and manageability largely depends on the organisation's attitude and

strategy towards risk management. Some believe that risks with high manageability and risk level offer more opportunities for improvement and should be prioritised considering the primary target for the mitigation strategy (Huber and Huber 2003; Breen 2008). However, other argue that higher priority should be assigned to risks with a higher probability of occurrence, greater impact severity and lower manageability simultaneously (Huber and Huber 2003), implying that risks that are more challenging to manage should be considered top priority.

In this study, the first opinion is preferred after discussing with academic and industry experts. An integrated risk index should be determined by considering P-I and manageability, and they need a score with the same evaluation criteria. In this context, ranking serves as an explicit criterion for selection. A higher P-I rank, and manageability rank correspond to a higher score, respectively. The lowest score was set as 1, with subsequent scores increasing by 1 for each place higher in the ranking, capped at 11. However, manageability and P-I index do not always hold the same significance, owing to the differences in objectives, experiences and preferences of the organisation and risk stakeholders. Weighing indicators are introduced to balance the importance of manageability and P-I. The integrated risk level of a risk event can be calculated using the following formula:

$$R = a * PI + b * M$$

$$a + b = 1, a > 0, b > 0$$

*R*: Final integrated risk index number

*b*: The weight of manageability

*a*: The weight of P-I

*M*: The score of manageability's rank

*PI*: The score of P-I 's rank

As the manageability is equally emphasised by managers of the 4PL case company, the weight of each indicator is assigned the same value of 0.5. The weighted scores of the risk events are presented in Table 5, allowing for easy observation of the ranking of the final integrated risk scores in the table.

**Table 5** Final ranking with weighted scores

| Sr No | Category           | Risk events                           | P-I score | Manageability score | P-I weighted score | Manageability weighted score | Sum  | Ranking |
|-------|--------------------|---------------------------------------|-----------|---------------------|--------------------|------------------------------|------|---------|
| 1     | Internal risks     | R1. Poor handling within organisation | 2         | 11                  | 1.0                | 5.5                          | 6.5  | 5       |
| 2     | Supply chain risks | R2. Delivery delay                    | 11        | 9                   | 5.5                | 4.5                          | 10.0 | 1       |
| 3     |                    | R3. Poor performance of LSP           | 3         | 10                  | 1.5                | 5.0                          | 6.5  | 5       |

|    |                |                          |    |   |     |     |     |    |
|----|----------------|--------------------------|----|---|-----|-----|-----|----|
| 4  |                | R4. Quality risks        | 9  | 8 | 4.5 | 4.0 | 8.5 | 2  |
| 5  |                | R5. Counterfeiting       | 1  | 2 | 0.5 | 1.0 | 1.5 | 11 |
| 6  | External risks | R6. Political risk       | 5  | 4 | 2.5 | 2.0 | 4.5 | 9  |
| 7  |                | R7. Border risk          | 7  | 4 | 3.5 | 2.0 | 5.5 | 8  |
| 8  |                | R8. Natural disaster     | 4  | 1 | 2.0 | 0.5 | 2.5 | 10 |
| 9  |                | R9. Labor strike         | 6  | 6 | 3.0 | 3.0 | 6.0 | 7  |
| 10 |                | R10. Illegal immigration | 8  | 8 | 4.0 | 4.0 | 8.0 | 3  |
| 11 |                | R11. Driver Shortage     | 10 | 5 | 5.0 | 2.5 | 7.5 | 4  |

The result shows that delivery delay (R1) holds the top position in the ranking. With the highest P-I level, it suggests that risk management would have a significant impact once a mitigation strategy is implemented. Additionally, its manageability is relatively high, meaning that the efforts required from managers to address it can be relatively low. Quality risk (R4) and illegal immigration risk (R10) claim the second and third positions, respectively for similar reasons. The labour strike risk (R9), political risk (R6) and counterfeiting risk (R5) occupy the 7<sup>th</sup>, 9<sup>th</sup> and 11<sup>th</sup>, respectively, due to their lower P-I and manageability levels than others. The poor handling risk (R1) and LSP performance risk (R3) hold 5<sup>th</sup> rank jointly. Despite their low P-I ranks (10<sup>th</sup> and 9<sup>th</sup>, respectively), their high manageability scores elevate their positions. This indicates that the high final integrated index for these two risk events is significant due to their high manageability. Therefore, although they may not be urgent considerations in risk management, they can be easier to improve and mitigate with management strategies. Conversely, driver shortage risk (R11), border risk (R7), and natural disaster risk (R8) demonstrate comparatively higher P-I levels but lower manageability. These risk events secured 4<sup>th</sup>, 8<sup>th</sup> and 10<sup>th</sup> places, respectively. The challenges in managing these risks pull down their original priorities in organisational risk management decisions, underscoring the significance of considering manageability in the final decision-making process.

#### **4.3 Causes of risk events**

##### *Poor handling within the organisation (R1)*

As sub-contractors of the 4PL company, hauliers declined to assess this risk because their involvement begins only with the product loading process in the warehouse. Any operations

that directly touch the product are beyond their responsibility. Logistic is a labour-intensive industry and human error is leading cause of poor performance in product handling. Interviewees from the pharmaceutical company acknowledged that human error sometimes occurred before the products were handed over to the 4PL case company due to the workers' inadequate training.

#### *Delivery delay (R2)*

The causes of this risk can be various. The primary reason for delivery delays, as mentioned by most interviewees from the 4PL company and hauliers, is congestion at warehouses during truck loading and unloading. Additionally, the complicated international network is difficult to control, while truck capacity limitations and driver shortages across Europe further contribute to reduced delivery efficiency.

#### *The poor performance of LSP (R3)*

As every supplier is selected from several alternative companies with outstanding performance and is constrained by working instructions and requirements from shippers, they have cooperated for years. All interviewees were convinced that there is rarely poor communication between both the 4PL with pharmaceutical manufacturers and hauliers with 4PL. LSPs can consistently provide high flexibility and responsiveness as well. However, some incorrect information will inevitably be shared, which is the only possible reason LSP's poor performance.

#### *Quality risk (R4)*

Some unexpected situations during the transportation phase may result in product quality losses. Initially, poor route arrangement or misrouting can lead to unscheduled long transport times, potentially increasing the likelihood of cold-chain equipment breakdown and creating improper storage environments for medicine in transit. Irregular maintenance is also a possible cause of vehicle and equipment breakdown. Inappropriate operation by drivers and workers during truck loading and product quality checks can also result in product quality damage.

#### *Counterfeiting (R5)*

Only four interviewees from the pharmaceutical manufacturer discussed the counterfeiting issue. They acknowledged that counterfeiting poses a risk to pharmaceutical manufacturing, but they have not encountered it themselves. Therefore, they could not provide any information about why it occurs in the supply chain.

#### *Political risk (R6)*

Completely different laws between two countries are a critical issue to consider during international trade. Differences in legislation may lead to unexpected politics-related issues if

companies do not pay attention to them. Moreover, the probability of military conflict is mentioned as another reason for political risk. Although the interviewees indicate that they have never been involved in any military conflicts in their countries, it remains a concern that cannot be ignored, particularly in certain countries in the context of global trade.

#### *Border risk (R7)*

During Covid-19, proper documentation such as driver's Covid pass, and essential custom documents were necessary when crossing international borders. Inadequate documentation was an obstacle to international transit. Additionally, the interviewees frequently mentioned about port congestion and their closures due to the pandemic spread. Brexit might bring new policies such as trade barriers to border controls, creating uncertainties for the UK and other European countries.

#### *Natural disaster (R8)*

Extreme weather is the most often cited reason for supply-side interruptions and affects the transport efficiency as the climate rapidly changes due to human activities, posing a severe problem worldwide. It leads to extreme weather events becoming a new normal to the world. Organisations should raise awareness of the interruption risks caused by extreme weather.

#### *Labour strike (R9)*

Interviewees frequently mention that labour strikes regularly occur in France. Strikes are considered a lawful right for workers when they are dissatisfied with their working environment, salary, working times, unfair treatment, or any violation of strict labour laws. Therefore, the issue of labour strikes cannot be ignored.

#### *Illegal immigrations (R10)*

Although the interviewees state that they have never met illegal immigration events before, they still insist this is a necessary concern. There are many cases that show the invasion of illegal immigrants has caused significant losses to international transportation companies, primarily due to insecure parking (Lietuvnikė et al., 2018, Urciuoli and Hintsa, 2017)

#### *Driver shortage (R11)*

This is an additional risk identified from the interview results and is the last supply chain risk. Three interviewees mentioned this risk, citing reasons such as long working hours, low welfare and salaries, difficulties for EU drivers brought by Brexit, and the high demand for drivers after Covid-19.

### **4.4 Consequences of risk events**

The consequences of risk events mentioned by interviewees are mainly grouped into seven themes.

#### *Delivery delays*

It is the most direct consequence for almost all interruption events. When risk events occur and cannot be addressed immediately or no contingency plans in place, time-wasting is unavoidable, which probably leads to delivery delays. Recalling products and rearranging deliveries are common strategies employed to mitigate product quality damage and loss (R4, R5, R10) in the logistics process. However, these tasks invariably need additional time to execute, thereby disrupting the original plan. Moreover, transportation process can be disrupted by other events (R2, R6, R7, R8, R9, R11), resulting in logistics delays.

#### *Lost business*

Poor performance of suppliers directly impacts the Key Performance Indicator (KPIs). If a supplier consistently underperforms over the long term (R2, R3, R4), or fails to effectively manage recurring risks and mitigate potential negative impacts with timely solutions (R2, R4, R8), their partnership with the company is likely to be reevaluated. In the worst-case scenario, this could result in the pharmaceutical company losing orders. LSPs will be replaced by other alternatives and removed from the supplier list.

#### *Unmet patients' final demand*

According to interviewees from pharmaceutical manufacturer, the most severe impact of any disruptions is failing to meet patients' urgent requirements. Issues such as medicine quality problems occurring in the logistics phase (R4, R5), drug damage or loss (R10), and delivery delays (R1, R2, R3, R6, R7, R8, R9, R11) can significantly affect patients' experiences. In the healthcare industry, the minor impact of unmet patients' requirements may result in customer complaints, but the most serious consequence could involve patients' lives and health, which is dreaded to imagine.

#### *Product quality issue*

Participants expressed significant concern about product quality due to the stringent regulations of medicine. They said that most events have the potential to compromise quality. Poor operations may occasionally cause product damage (R1). Delivery delays increase the probability of medicine deterioration in transit (R2, R3, R6, R7, R8, R9, R11), exacerbating the situation if there are operational errors or unsatisfactory transportation conditions (R4). Counterfeit products have significant quality hazards if they left unidentified (R5). Products in the transit have a high possibility to be damaged or contaminated by unauthorised invaders (R10).

### *Reputational damage*

The focal organisation faces reputational risk when any supply chain member encounters crisis events (Rajagopal et al., 2022). A company's reputation depends on its perception by stakeholders. A damaged reputation can decrease employee and customer loyalty and jeopardise the company's financial condition and viability. Therefore, the organisation should prioritise any event that could affect its reputation. When the media publicise social issues such as illegal immigration and drug counterfeiting, the public notices the related management loopholes. Thus, their positive perception of certain enterprises may reduce (R5, R9, R10). Additionally, poor business performance reduces customer goodwill to company and negatively impacts its reputation (R1, R2, R3, R4).

### *Extra financial cost*

The interviewees indicated that the negative consequences of uncertainties would be reflected at the financial level. Any damage to products and barriers to the logistics process can bring additional economic losses to the organisation. Additional costs might be spent to deal with the harmful effects of risk events (R1, R4, R5, R8), while excess time and labour costs are spent to reach the intended goals (R3, R6, R7). Financial support for the proper functioning of alternative resources may also be necessary in certain cases (R9, R11). Furthermore, the company may face economic penalties for failing to meet regulatory responsibilities and performance criteria (R10, R2).

## **4.5 Risk mitigation**

The responses to each risk event generally fall into six different categories.

### *Management tools*

The KPI is the most frequently mentioned tool by interviewees to control and correct LSPs' performance in operations, delivery and quality management (R1, R2, R3, R4). Kaizen, a lean management tool, is used to effectively guide employees in following instructions (R1). Additionally, data analysis is beneficial for managers in identifying the root causes of risk issues (R2, R4, R5), while supplier review meetings serve as a vendor relationship management tool. Regular meetings facilitate close monitoring and governance of LSPs, allowing for the review of assessment results and work feedback (R3).

### *Standard operation procedure (SOP) and training*

Clear working instructions for correct operation processes help prevent worker mis-operation. Product handling processes in the warehouse should be established to enable workers to

eliminate errors and reduce time wastage. In addition, regular training sessions should be arranged to assess whether operators have grasped the necessary skills and are following SOPs (R1). During transportation, SOPs remain crucial for drivers to follow. Security parking guidelines for drivers are essential, as security during transportation represents a weak link against quality and illegal immigration risks. Drivers must adhere to guidance and pass through checkpoints to ensure truck security (R4, R10). Furthermore, instructions for truck loading and unloading, as well as temperature management, are also necessary SOPs to follow (R2, R4).

#### *Proactive awareness*

The awareness of paying attention to potential risks is indispensable for an organisation's risk management. The corrective and preventive action (CAPA) system aims to identify and investigate product and quality problems, then take appropriate and effective corrective and preventive measures to prevent the recurrence of such issues (R1). The organisation should always be proactive and vigilant to potential risks. Regular maintenance of vehicles, essential backup components and security equipment should be arranged to prevent potential transportation loss and quality risks during transit (R4, R10). Implementing unique or specific packaging is a method to monitor and control counterfeiting (R5). Moreover, strict monitoring and exhaustive investigation of market intelligence, government regulatory and necessary background information are helpful for minimising the probability of risk occurrence and well-prepared for upcoming risks (R6, R7, R8, R9, R11).

#### *Risk planning*

A contingency plan is an action plan designed to help the organisation effectively respond to significant future risk events. It serves as a “plan B” to continue business operations in case the original process is interrupted by unexpected situations. Nearly all interviewees view a contingency or emergency plan as a fundamental management method for every event, aiming to prevent disruptions or quickly resume normal operations (R2, R3, R4, R6, R7, R8, R9). In addition to a contingency plan, a preventive plan is also advantageous to mitigate risk events from occurring to the greatest extent (R9).

#### *Alternative resources*

To mitigate the consequence of risk, additional resources need to be arranged for the business. It also means “redundancy”, which has been proven to be one of the most efficient ways to enhance the supply chain resilience. Measures such as alternative transportation capacity (R2), alternative qualified LSPs (R3), alternative transportation route plans (R6), alternative human resources (R9) and even local replacements (R7) are prepared for any needed situations.

#### *Digital technology*

To address the chronic issue of frequent human errors in operations, Radio Frequency Identification (RFID) can be employed to automatically identify product information using pre-coded microchips (R1). Moreover, the pharmaceutical company designed interactive systems and interfaces to strictly serialize and verify product information to identify and trace the source of counterfeit drugs (R5).

#### ***4.6 Supply chain resilience strategies***

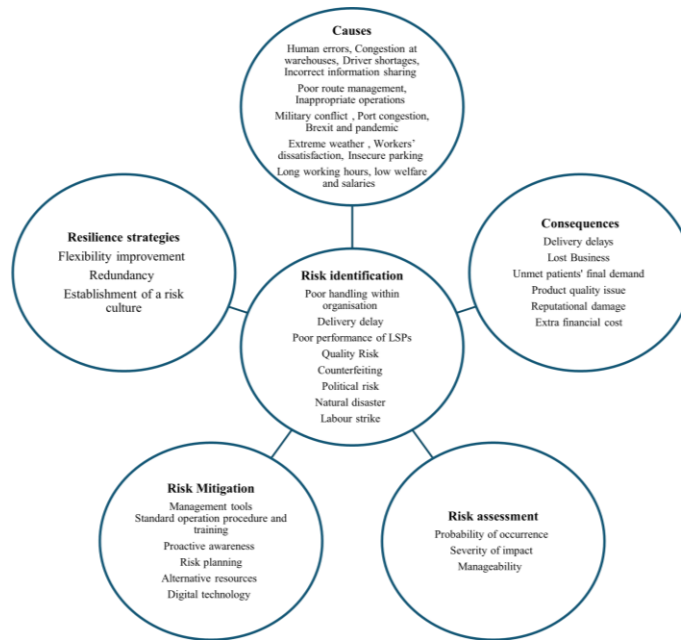
Resilience and vulnerability are interrelated, so enhancing supply chain resilience reduces vulnerability to disruption events, and conversely, reducing vulnerability creates a more resilient supply chain. In this study, the SCs vulnerability to risk events can be roughly assessed through probability of occurrence, severity of impact, and manageability. High manageability indicates that current management tools can reasonably control the risk, thereby reducing the likelihood of SC disruption and corresponding vulnerability. Conversely, low manageability suggests that the SC is more susceptible to risk events. Alongside the probability and impact indicators, a higher risk level demonstrates a potentially severe outcome, while a lower-risk level implies a result that is relatively more acceptable to the enterprise. When a high-risk level meets low manageability, the event has the potential to become the most vulnerable point of the SC. Given the organisation's limited resources, the response strategy should prioritise addressing these vulnerability points. Building SC resilience should be considered first when suggesting a response strategy for these vulnerability points. According to the interview results, driver shortages, natural disasters, and border risks are the primary vulnerability points. Other risk events with low manageability and slightly higher risk levels are the secondary vulnerability points. Prevention strategies should be the main approach for addressing these risks.

The 4PL company should improve flexibility, as it is one of the preventive strategies. Flexibility can help the company resist external shocks and internal management risks when facing different risk events. However, creating a flexible SC requires short-term resource contributions and long-term capital investments. The resources, necessary costs, and desired level of flexibility need to be defined by the company based on the market situation, customer requirements, and other relevant conditions. The importance of each factor for the company needs to be identified. Natural disaster risk is a high-consequence, low-probability, low-manageability risk, which individuals cannot prevent from occurring. If the 4PL has no flexible responses, a supply disruption event will occur. On the contrary, when a flexible system is

established by 4PL, once a natural disaster occurs in specific areas, the risk response mechanisms of other unaffected areas can be mobilised. This may include inventory transfers between warehouses and flexible arrangements of transportation capacity, all of which can help alleviate disruptions and mitigate their impact to a certain extent. However, it remains unclear how much flexibility the organisation needs to reduce risk and enhance resilience.

Redundancy is a strategy that companies should also consider. Its presence has been confirmed in interviews as part of risk handling approaches. In practice, redundancy is manifested through replaceable backup resources, which can assist in addressing resource shortages and supply disruptions caused by risk events. This includes excessive human resources and transportation capacity, which is the most effective strategy to cope with long-term disruptions (Aldrighetti et al., 2019). However, not all redundancy efforts result in a higher resilience level. When a company focuses on creating an efficient SC, funds should be invested in the most essential resources to maximise benefits. Consequently, relatively low-probability and low-impact risk events may be ignored or accepted because the losses directly incurred from bearing their consequences are often less costly than the expenses associated with redundancy resources. Outsourcing can help companies reduce the costs of idle resources and minimise the investment of management resources (Ghadge et al., 2012). However, the risks associated with it cannot be ignored.

Finally, the establishment of a risk culture is a strategic approach to building a resilient SC. It can positively influence the organisation's effectiveness in risk management and SCR (Kurniawan et al., 2017). Employees should have thorough understanding of the organisation's ongoing activities and strategic objectives to enhance effective communication among staff at all levels of the company, serving as the foundation for employee participation in the company's strategy. Additionally, employees should be empowered to make quick decisions within the scope of their responsibilities to foster initiative in resilience strategy and risk management. The framework considering risks, causes, consequences, mitigation, and resilience strategies is depicted in Figure 4.



**Figure 4** Conceptual framework for logistics risk management in the PSC

## 5. Discussion on the findings

Interview results reveal varying perceptions among interviewees about the occurrence, severity and management approach of the same risks. For instance, participants from the 4PL case company and hauliers emphasise the importance of addressing warehouse congestion during truck loading and unloading, as it frequently causes delivery delays, according to the operational department. A study by Sanchez-Rodrigues et al., (2010) also mentioned similar risks identified by focus groups from logistics-related industries. Practitioners are particularly concerned about risks associated with operational practices. Additionally, interviewees' perceptions of risks vary based on their positions. Typically, those in logistics and SC departments or those familiar with logistics and SC operations listed logistics risks as less controllable, despite their extensive experience in dealing with these issues. This contradicts the claims of Sjöberg et al., (2004), who suggested that when individuals believe they can control events, perceived controllability is higher, resulting in lower perceived risk levels. Moreover, unusual risks are considered more frightening, and the perception of their severe consequences will be higher than that of usual events. Since external risks are uncontrollable and unpredictable for individuals and organisations, and are imposed from outside the SC, few interviewees rated them as low or medium. The average ratings for risks under this category are in the middle to upper level among all. Illegal immigration, political, and natural disaster risks even rank 1<sup>st</sup>, 3<sup>rd</sup> and 4<sup>th</sup>, respectively, in severity. Based on the study of Sjöberg et al.,

(2004) and Cori et al., (2020), the interview results are reasonable and support previous research findings.

Delivery delay is undoubtedly a primary risk that the 4PL case company needs to address, consistent with research by Breen (2008), El Mokrini et al., (2016b), Govindan and Chaudhuri (2016), El Mokrini and Aouam (2020) and Ersoy and Tanyeri (2021). Some scholars consider delivery delays as part of distribution risk in the transportation field, but it remains at the top of the risk list in the logistics phase (Govindan and Chaudhuri, 2016). Transportation delays occur frequently across various industries, affecting the SC economically and environmentally (Sanchez-Rodrigues et al., 2010). Failure to deliver goods within the scheduled time window can result in significant financial losses and jeopardize product safety in the PSC cold chain logistics (Hemalatha and Balaji 2020). Additionally, timely delivery plays a vital role in reducing inventory levels and fulfilling orders. Efficient network route planning, timely monitoring, and proactive implementation of contingency plans can significantly minimise the likelihood of delayed deliveries. Quality risk is another issue for the 4PL case company to emphasise in transportation, consistent with the viewpoints of Govindan and Chaudhuri (2016) and Wang et al., (2013). However, Govindan and Chaudhuri (2016) considered transportation quality risk as an inherent internal risk of 4PL and ranked it among the top three risks. Similarly, Wang et al., (2013) assigned it a similar rank in the research of Agri-food supply chain, which also included cold chain transportation. Whether caused by subjective human error or objective environmental conditions, quality risk during transit affects all aspects of the SC and the direct benefits of the organisation and customers. Therefore, ensuring its priority in risk management is essential to enhance logistics service quality and efficiency, and help the PSC effectively control process risks (Ersoy and Tanyeri 2021).

Illegal immigration is rarely included in the previous studies on risk assessment of the SC. However, it is emphasised in international road freight and sea freight as a security risk (Urciuoli and Hintsä 2017). Since the participants are primarily from European countries, predominantly covered by land, road freight becomes a significant entry point for unauthorised intruders. It poses a threat to most cross-border logistics companies resulting in significant financial and physical losses on products, cost and even driver safety (Lietuvnė et al., 2018). This risk is more relevant to the 4PL case company than the shipper (Urciuoli and Hintsä, 2017). Therefore, it is reasonable that illegal immigration risk is first time considered in the assessment and finally rated as the third risk requiring mitigation. To mitigate the impact of illegal immigration, prioritise prevention measures such as training drivers in transport code

compliance, emphasising safety norms, and ensuring proper sealing of trucks after loading. Familiarity with designated parking points along the route is essential for effective prevention measures. The issue of driver shortage was stressed years ago in the logistics field. However, the case company is based in the UK, where the driver shortage is severe, exacerbated by new immigration rules emerging from Brexit which make the transport system's resources scarce (Holmes, 2021). In addition, the high turnover rates of labour caused by the epidemic makes the driver shortage more prominent. Many experts claim that driver shortage will become the main risk of the SC alongside increasing demand in the foreseeable future, negatively impacting the logistics performance of enterprises and causing a series of problems in the SC (Wang 2018). The relatively high importance of driver shortage in the trucking industry is consistent with the study by Dadsena et al., (2019).

Poor handling is a common operational risk in warehouse and transportation (Kharisma and Ardi, 2020). It belongs to shippers and poses pressure on 4PL companies (Govindan and Chaudhuri 2016). According to El Mokrini et al., (2016b), poor handling of goods leads to product damage, waste and shipping errors, resulting in a comparatively high-risk level. However, in this research, poor handling is considered a moderate risk since 4PL's operational teams have minimal responsibility for handling products. Implementing corrective action systems is an effective method to monitor this risk. Poor performance indicates low flexibility and information sharing. It arises from the logistics outsourcing, proven to be a significant risk for shippers (Govindan and Chaudhuri, 2016), and a moderate internal operational risk for the 4PL company (El Mokrini et al., 2016b). Outstanding LSP performance enhances customer satisfaction, maintains relationship between enterprises and improves SC efficiency (Ersoy and Tanyeri, 2021).

The labour strike is a common interruption risk for the SC, indirectly impacting product quality when it occurs at key nodes of the SC (Marinkovic et al., 2020). It was evaluated as a moderate risk event with low probability high impact in Behdani et al., (2012) study, consistent with our findings. The company needs to minimise its impact, as prevention is challenging. This involves closely monitoring trends and preparing alternative plans to mitigate risk. The political environment between countries can increase the risk in the global SC, leading to cost increases, SC collapse and other adverse effects (Jiang et al., 2018). The characteristics of low probability, high impact and low manageability of political risks in this study align with the research findings of Steckel and Kumar (2009), which shows the vulnerability of SC components during political events. Mehralian et al., (2012) recognised it as a moderate external risk in the Iran PSC. Natural disasters have been identified as a critical exogenous

destructive risk in the SC due to the high frequency of climate change and extreme weather events in recent years (Lawrence et al., 2020). It poses significant risks to human social activities and the environment. Although they typically result in serious consequences, the probability of their occurrence is relatively low (Stecke and Kumar 2009). Counterfeiting risk is of least concern to respondents according to the results. This contrasts with ideas in the literature but remains reasonable. Previous studies on the PSC highlighted counterfeiting as a significant risk. For instance, Breen (2008) and Enyinda et al., (2010)) believed counterfeiting risk as the most severe risk for pharmaceutical company managers. However, their perspectives are from the viewpoint of pharmaceutical companies, not 4PL companies as in this research. The consequence of counterfeit drugs is less relevant to 4PL companies unless it is considered as logistics risk, such as when counterfeit drugs are stolen or replaced during transit (Enyinda et al., 2010).

## **6. Conclusion**

The UK-based 4PL provider, which manages the logistics operations of a pharmaceutical manufacturer recently experienced unexpected events. Consequently, the case company sought to further explore supply risks. This study aimed to identify these supply risks in the PSC from the 4PL perspective, analyse them using probability, impact and manageability parameters, and propose resilience strategies. The 11 logistics-related risks faced by the 4PL provider were identified, including one internal operational risk, four SC risks and six external risks. Among the external risks, driver shortage emerged as a new risk through the interviews. Risks were evaluated across multiple dimensions using probability of occurrence, severity of consequences and manageability. Delivery delays, quality risks, illegal immigration and driver shortages were the top four risks. Three strategies for building SCR were proposed to address the vulnerabilities: increasing flexibility within the company, adopting a certain level of redundancy and creating a corporate risk culture. Additionally, the study analysed the current situation of the identified risks in the SC of the target company, including common causes of events, main consequences and practical responses to risk events.

This research has practical significance for the logistics risk management of the target 4PL company. Since the interviewees were all relevant stakeholders of the company, their answers provide a review and evaluation of the target company's logistics risk management status, which is valuable for the company. It offers important insights into risk events in the PSC logistics phase for managers. Additionally, the risk ranking can help enterprises to find

the focal points of risk management, enabling managers to implement follow-up risk mitigation and SC continuous improvement procedures with a clearer logic. Moreover, by considering the integrated risk index, managers can effectively allocate resources to manage various risk events. Furthermore, this study may inspire other 4PL enterprises in PSC due to the industry's similar operational mode and characteristics.

As this study fixed the sample size of interviews, there is a possibility that the data may not comprehensively cover all aspects, such as theft risk, which is frequently mentioned by scholars but not addressed by the participants in the interviews. This implies that the collected data may not be fully saturated with all possible risks (Hinton and Ryan, 2020). Risk assessment in this study relies on the expertise and experience of the participants. Future research endeavours can enhance the universality of these findings and offer inspiration and reference for 4PL companies in the pharmaceutical or food industry. Expanding the range and sample size when selecting interviewees can be considered. Engaging experts from all segments of the PSC in risk evaluation would broaden the perspective of on general risks faced by 4PL companies.

## References

- Agrawal, Nishant, and Rajesh Kumar Jain. 2022. "Insights from Systematic Literature Review of Supply Chain Resilience and Disruption." *Benchmarking* 29 (8): 2495–2526.
- Aldrighetti, Riccardo, Ilenia Zennaro, Serena Finco, and Daria Battini. 2019. "Healthcare Supply Chain Simulation with Disruption Considerations: A Case Study from Northern Italy." *Global Journal of Flexible Systems Management* 20 (s1): 81–102.
- Boyson, Sandor. 2014. "Cyber Supply Chain Risk Management: Revolutionizing the Strategic Control of Critical IT Systems." *Technovation* 34 (7): 342–353.
- Breen, Liz. 2008. "A Preliminary Examination of Risk in the Pharmaceutical Supply Chain (PSC) in the National Health Service (NHS)." *Journal of Service Science and Management* 01 (02): 193–199.
- Dadsena, Krishna Kumar, S. P. Sarmah, V. N.A. Naikan, and Sarat Kumar Jena. 2019. "Optimal Budget Allocation for Risk Mitigation Strategy in Trucking Industry: An Integrated Approach." *Transportation Research Part A: Policy and Practice* 121: 37–55.
- de Vries, Harwin, Marianne Jahre, Kostas Selviaridis, Kim E. van Oorschot, and Luk N. Van Wassenhove. 2021. "Short of Drugs? Call upon Operations and Supply Chain Management." *International Journal of Operations and Production Management* 41 (10): 1569–1578.
- El Mokrini, A., E. Dafaoui, A. Berrado, and A. El Mhamedi. 2016a. "An Approach to Risk Assessment for Outsourcing Logistics: Case of Pharmaceutical Industry." *IFAC-PapersOnLine* 49 (12):1239–1244.
- El Mokrini, A., N. Kafa, E. Dafaoui, A. El Mhamedi, and A. Berrado. 2016b. "Evaluating Outsourcing Risks in the Pharmaceutical Supply Chain: Case of a Multi-Criteria Combined Fuzzy AHP-PROMETHEE Approach." *IFAC-PapersOnLine* 49 (28). 114–119.

- El Mokrini, Asmae, and Tarik Aouam. 2022. "A Decision-Support Tool for Policy Makers in Healthcare Supply Chains to Balance between Perceived Risk in Logistics Outsourcing and Cost-Efficiency." *Expert Systems with Applications* 201 (June 2021).
- El Mokrini, Asmae, Loubna Benabbou, and Abdelaziz Berrado. 2018. "Multi-Criteria Distribution Network Redesign - Case of the Public Sector Pharmaceutical Supply Chain in Morocco." *Supply Chain Forum* 19 (1): 42–54.
- Emrouznejad, Ali, Sina Abbasi, and Çiğdem Sıcakyüz. 2023. "Supply Chain Risk Management: A Content Analysis-Based Review of Existing and Emerging Topics." *Supply Chain Analytics* 3: 100031. doi:10.1016/j.sca.2023.100031.
- Fan, Yiyi, and Mark Stevenson. 2018. "A Review of Supply Chain Risk Management: Definition, Theory, and Research Agenda." *International Journal of Physical Distribution and Logistics Management* 48 (3): 205–230.
- Feng, Lin, Xiaodong Li, Xingxing Zhang, Adolf K.Y. Ng, Peng Jia, and Haibo Kuang. 2023. "Modelling the Roles of Fourth-Party Logistics (4PL) on the Improvements of Supply Chain Stability of Port Logistics Services: The Case of Ningbo-Zhoushan Port in China." *International Journal of Systems Science: Operations and Logistics* 10 (1). doi:10.1080/23302674.2023.2239137.
- Ghadge, Abhijeet, Samir Dani, and Roy Kalawsky. 2012. "Supply Chain Risk Management: Present and Future Scope." *The International Journal of Logistics Management* 23 (3): 313–339.
- Govindan, Kannan, and Atanu Chaudhuri. 2016. "Interrelationships of Risks Faced by Third Party Logistics Service Providers: A DEMATEL Based Approach." *Transportation Research Part E: Logistics and Transportation Review* 90: 177–195.
- Gurtu, Amulya, and Jestin Johny. 2021. "Supply Chain Risk Management: Literature Review." *Risks* 9 (1): 1–16.
- Heckmann, Iris, Tina Comes, and Stefan Nickel. 2015. "A Critical Review on Supply Chain Risk - Definition, Measure and Modeling." *Omega* 52: 119–132.
- Ho, William, Tian Zheng, Hakan Yildiz, and Srinivas Talluri. 2015. "Supply Chain Risk Management: A Literature Review." *International Journal of Production Research* 53 (16): 5031–5069.
- Huq, Fahian, Kulwant S. Pawar, and Helen Rogers. 2016. "Supply chain configuration conundrum: how does the pharmaceutical industry mitigate disturbance factors?" *Production Planning & Control* 27 (14): 1206–1220.
- Jaberidoost, Mona, Shekoufeh Nikfar, Akbar Abdollahiasl, and Rassoul Dinarvand. 2013. "Pharmaceutical Supply Chain Risks: A Systematic Review." *DARU, Journal of Pharmaceutical Sciences* 21 (1): 1–7.
- Jlassi, Jihene, Nesrin Halouani, and Abderrahman El Mhamedi. 2021. *Pharmaceutical Supply Chain Risk Assessment in the Time of COVID 19/Case Study. IFIP Advances in Information and Communication Technology*. 632 IFIP. Springer International Publishing.
- Jüttner, Uta, Martin Christopher, and Susan Baker. 2007. "Demand Chain Management-Integrating Marketing and Supply Chain Management." *Industrial Marketing Management* 36 (3): 377–392.
- Karmaker, Chitra Lekha, and Tazim Ahmed. 2020. "Modeling Performance Indicators of Resilient Pharmaceutical Supply Chain." *Modern Supply Chain Research and Applications* 2 (3): 179–205.
- Katsaliaki, K., P. Galetsi, and S. Kumar. 2022. *Supply Chain Disruptions and Resilience: A Major Review and Future Research Agenda. Annals of Operations Research*. 319.

- Kurniawan, Rofyanto, Suhaiza Hanim Zailani, Mohammad Iranmanesh, and Premkumar Rajagopal. 2017. "The Effects of Vulnerability Mitigation Strategies on Supply Chain Effectiveness: Risk Culture as Moderator." *Supply Chain Management* 22 (1): 1–15.
- Lawrence, Jeanne Marie, Niamat Ullah Ibne Hossain, Raed Jaradat, and Michael Hamilton. 2020. "Leveraging a Bayesian Network Approach to Model and Analyze Supplier Vulnerability to Severe Weather Risk: A Case Study of the U.S. Pharmaceutical Supply Chain Following Hurricane Maria." *International Journal of Disaster Risk Reduction* 49: 101607.
- Mehralian, Gholamhossein, Ali Rajabzadeh Gatari, Mohadese Morakabati, and Hossein Vatanpour. 2012. "Developing a Suitable Model for Supplier Selection Based on Supply Chain Risks: An Empirical Study from Iranian Pharmaceutical Companies." *Iranian Journal of Pharmaceutical Research* 11 (1): 209–219.
- Mizgier, Kamil J. 2017. "Global Sensitivity Analysis and Aggregation of Risk in Multi-Product Supply Chain Networks." *International Journal of Production Research* 55 (1): 130–144.
- Mizgier, Kamil J., Stephan M. Wagner, and Matthias P. Jüttner. 2015. "Disentangling Diversification in Supply Chain Networks." *International Journal of Production Economics* 162: 115–124.
- Mizgier, Kamil J., and Maximilian Wimmer. 2018. "Incorporating Single and Multiple Losses in Operational Risk: A Multi-Period Perspective." *Journal of the Operational Research Society* 69 (3): 358–371.
- Mizgier, Kamil J., Joseph M. Pasia, and Srinivas Talluri. 2017. "Multiobjective Capital Allocation for Supplier Development under Risk." *International Journal of Production Research* 55 (18): 5243–5258.
- Wagner, Stephan M., Kamil J. Mizgier, and Philippe Arnez. 2014. "Disruptions in Tightly Coupled Supply Chain Networks: The Case of the US Offshore Oil Industry." *Production Planning and Control* 25 (6): 494–508.
- Nakandala, Dilupa, Henry Lau, and Li Zhao. 2017. "Development of a Hybrid Fresh Food Supply Chain Risk Assessment Model." *International Journal of Production Research* 55 (14): 4180–4195.
- Olson, David L., and Desheng Dash. 2010. "A Review of Enterprise Risk Management in Supply Chain." *Kybernetes* 39 (5): 694–706.
- Papalex, Marina, David Bamford, and Liz Breen. 2020. "Key Sources of Operational Inefficiency in the Pharmaceutical Supply Chain." *Supply Chain Management* 25 (6): 617–635.
- Pinna, Roberta, Pier Paolo Carrus, and Fabiana Marras. 2015. "The Drug Logistics Process: An Innovative Experience." *TQM Journal* 27 (2): 214–230.
- Prakash, Surya, Gunjan Soni, Ajay Pal Singh Rathore, and Shubhender Singh. 2017. "Risk Analysis and Mitigation for Perishable Food Supply Chain: A Case of Dairy Industry." *Benchmarking* 24 (1): 2–23.
- Rajagopal, Varthini, Prasanna Venkatesan Shanmugam, and Ratnapratik Nandre. 2022. "Quantifying Reputation Risk Using a Fuzzy Cognitive Map: A Case of a Pharmaceutical Supply Chain." *Journal of Advances in Management Research* 19 (1): 78–105.
- Rangel, Djalma Araujo, Taiane Kamel De Oliveira, and Maria Silene Alexandre Leite. 2015. "Supply Chain Risk Classification: Discussion and Proposal." *International Journal of Production Research* 53 (22): 6868–6887.
- Rathore, Rishabh, J. J. Thakkar, and J. K. Jha. 2021. "Evaluation of Risks in Foodgrains Supply Chain Using Failure Mode Effect Analysis and Fuzzy VIKOR." *International Journal of Quality and Reliability Management* 38 (2): 551–580.

- Sanchez-Rodrigues, Vasco, Andrew Potter, and Mohamed M. Naim. 2010. "Evaluating the Causes of Uncertainty in Logistics Operations." *International Journal of Logistics Management* 21 (1): 45–64.
- Senna, Pedro, Augusto Reis, Lino Guimarães Marujo, Julio Cesar Ferro de Guimarães, Eliana Andréa Severo, and Ana Carla de Souza Gomes dos Santos. 2023a. "The Influence of Supply Chain Risk Management in Healthcare Supply Chains Performance." *Production Planning and Control*. Taylor & Francis. doi:10.1080/09537287.2023.2182726.
- Senna, Pedro, Augusto Reis, Ana Dias, Ormeu Coelho, Julio Guimaraes, and Severo Eliana. 2023b. "Healthcare supply chain resilience framework: Antecedents, mediators, consequents." *Production Planning & Control* 34 (3): 295-309.
- Sjöberg, Lennart, Elin Moen, and Torbjorn Rundmo. 2004. *Of the Psychometric Explaining Risk. An Evaluation of the Psychometric Paradigm in Risk Perception Research*. 2.
- Sodhi, Manmohan S., Byung Gak Son, and Christopher S. Tang. 2012. "Researchers' Perspectives on Supply Chain Risk Management." *Production and Operations Management* 21 (1): 1–13.
- Spieske, Alexander, Maximilian Gebhardt, Matthias Kopyto, and Hendrik Birkel. 2022. "Improving Resilience of the Healthcare Supply Chain in a Pandemic: Evidence from Europe during the COVID-19 Crisis." *Journal of Purchasing and Supply Management* 28 (5).
- Stecke, Kathryn E., and Sanjay Kumar. 2009. "Sources of Supply Chain Disruptions, Factors That Breed Vulnerability, and Mitigating Strategies." *Journal of Marketing Channels* 16 (3): 193–226.
- Sudan, Tapas, Rashi Taggar, Pabitra Kumar Jena, and Deepika Sharma. 2023. "Supply Chain Disruption Mitigation Strategies to Advance Future Research Agenda: A Systematic Literature Review." *Journal of Cleaner Production* 425 (April): 138643.
- Tang, Christopher S. 2006. "Robust Strategies for Mitigating Supply Chain Disruptions." *International Journal of Logistics Research and Applications* 9 (1): 33–45.
- Tang, Ou, and S. Nurmaya Musa. 2011. "Identifying Risk Issues and Research Advancements in Supply Chain Risk Management." *International Journal of Production Economics* 133 (1).
- Urciuoli, Luca, and Juha Hintsa. 2017. "Adapting Supply Chain Management Strategies to Security—an Analysis of Existing Gaps and Recommendations for Improvement." *International Journal of Logistics Research and Applications* 20 (3): 276–295.
- Wang, Huihui, Min Huang, W. H. Ip, and Xingwei Wang. 2021. "Network Design for Maximizing Service Satisfaction of Suppliers and Customers under Limited Budget for Industry Innovator Fourth-Party Logistics." *Computers and Industrial Engineering* 158.
- Wang, Michael, and Ferry Jie. 2020. "Managing Supply Chain Uncertainty and Risk in the Pharmaceutical Industry." *Health Services Management Research* 33 (3): 156–164.
- Yaroson, Emilia Vann, Liz Breen, Jiachen Hou, and Julie Sowter. 2021. "Advancing the Understanding of Pharmaceutical Supply Chain Resilience Using Complex Adaptive System (CAS) Theory." *Supply Chain Management* 26 (3): 323–340.
- Zhang, Min, S. Pawar Kulwant, Janat Shah, and Peeyush Mehta. 2013. "Evaluating Outsourcing Partners' Capability: A Case Study from the Pharmaceutical Supply Chain." *Journal of Manufacturing Technology Management* 24 (8): 1080–1101.