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 SURVEY

Prioritizing Risks in Last Mile Delivery: A Bayesian Belief Network Approach

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ABSTRACT The remarkable explosion of e-commerce has marked the latest years of different industries and put forward a higher requirement for the last mile delivery. The last mile delivery is one of the most complex, costly, and inefficient processes along the entire logistics fulfillment chain in an e-commerce context. Its corresponding risks are major contributors to delivery failure. This work proposes a comprehensive framework on risk identification and analysis in the last mile delivery to support delivery planning. Risks were deduced from available literature, and others were induced through semi-structured interviews with experts in the field. Risks are categorized and the relative probability and severity of individual risks are determined. This study adopts a Bayesian Belief Network (BBN) model to identify the interdependency among risks and rank them, as the conventional ranking methods fail to take interdependency into account. The results indicate that privacy concerns, IT, and natural disasters are the most critical risks. This study will aid logistics service providers to ultimately deciding the solutions of last mile delivery that need to be utilized by prioritizing last mile delivery possible risks to increase their competitiveness and market share and minimize delivery costs.

INDEX TERMS Bayesian belief network, e-commerce, last mile delivery, risk, risk assessment, risk management, COVID-19.

I. INTRODUCTION

Final delivery, with a “last mile” metaphor, relates to the final movement of products from the last upstream distribution center, consolidation point, or local warehouse to the final location (e.g., recipients’ doorsteps or a designated pick-up address). Last mile delivery has been regarded as one of the supply chain’s most complex and inefficient processes [30]. It is rooted in the e-commerce logistics particularity [46], for example, the frequent and larger number of small parcels or packages, the large dispersion of recipients, the time limit for delivery, and the high potential for failure of delivery. Home delivery inefficiency leads to high last-mile delivery costs.

In response, e-retailers and logistics service suppliers’ actors continually seek new delivery service solutions, often driven by technology advancements. Industrial reports show that organizations worldwide are testing new trends, such as

drones, parcel lockers, crowdsourced deliveries, autonomous vehicle deliveries, and fulfillment models [36]. Since many e-retail giants believe that last-mile delivery capabilities are their core assets to gain competitive advantages, last-mile fulfillment is what the ongoing e-commerce battles are fighting [69]. To compete and lead these battles, the service provider must clearly know the risks that last mile delivery faces. Every business faces different types of risk, according to the enterprise’s corresponding sector. Regarding that, each enterprise should focus on risk assessment for identifying the specific risks it faces and take action according to a proper risk response strategy [18]. Reference [61] describes risk management in terms of two interdependent stages: risk identification and risk analysis. In risk identification, all potential risks should be determined within the organization’s boundaries, whereas in risk analysis, probable impact, cause, and control over those risks should be determined.

The commerce and technology relationship has existed for a long time and still continues. In recent decades, various

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advancements and innovations in Information and Communication Technology (ICT) have led to numerous developments in many areas, including global commerce. Consequently, processes in many areas, such as commerce, economy, banking, and customs, have evolved and changed [55]. Traditional commerce will no longer be able to meet modern demands as time goes by [9]. Companies' main challenge is bringing this service to the customer. E-commerce comes with a range of advantages from the customer's point of view, such as a greater choice of service, the ability to obtain products not sold locally, and better price control and convenience. Consumers ordering products online means delivering the items required to them at home. However, the delivery solution is very demanding from the business point of view and requires complex planning. Due to the complex planning and challenging nature of last-mile delivery, businesses usually outsource the delivery aspect to third-party logistics (3PL) companies. Related costs and revenues are the main reason why e-commerce firms outsource [67]. Logistics activities require heavy investment in the support and hardware of information technology that 3PL companies can provide. Therefore, e-commerce companies may avoid heavy investment and operating costs in IT and hardware by outsourcing. Lacity and Hirscheim [41] conclude that it is possible to achieve a 10-20% reduction in cost by outsourcing.

The term last mile is used in the supply chain context to describe the movement of goods from fulfillment centers or transport hubs to their final destinations. In other words, the last mile is the last leg of the product's trip before it reaches the consumers' doorstep, and it is considered as the moment that matters [45]. This last leg is often the supply chain's least effective link, accounting for up to 75% of the total cost of delivery [30]. The last mile is described as the final stage in the online retail distribution process and is one of the most challenging aspects of the supply chain [26]. That is, last mile delivery is the only stage that has direct contact with the customers. The party delivering the goods is the representative of the organization for which they work and all the organizations that have contributed along the supply chain, which involves a professional and customer service-oriented delivery strategy. Reference [15] found that the customer's main drivers for e-commerce are: time savings, economic benefits, and various choices. These include obtaining goods that are not sold locally, better comparison of prices, and convenience. The last-mile delivery poses a paradox between speed and cost; customers expect fast delivery on the same day or on demand but remain highly sensitive to price and prefer the cheapest delivery options. Above all, many other situations raise last mile delivery problems like incorrect customer addresses, crowded customer locations, driver shortages, and some adverse economic conditions like rising fuel prices. The main factors that can adversely affect the efficiency of the last mile delivery are absence of parcel recipient, delivery windows, customers density, and environmental challenges [8], [16], [19], [33], [44], [59].

Finally, Risk Management (RM) can be generally defined as a systematic process that a company follows to reduce the likelihood of unexpected events occurring to maximize profit. The most popular definition of RM is published by Association for Project Management (APM): "A process whereby decisions are made to accept known or assessed risks and/or the implementation of actions to reduce the consequences or probability of occurrence" [56]. Reference [62] describes RM in terms of identifying, evaluating and controlling exposure to each risk that hinders project success. He formulated four basic principles of RM: (1) minimization of negative impacts of risk in a business; (2) recognition, evaluation and economic control of risks that hinder business success and profit; (3) determination of the most relevant way to tackle major and minor risks to a company's profit; and (4) a procedure for adapting to the impacts of progress. According to [12], risk is a fundamental aspect of RM, the main aim of which is to minimize or maintain risk at a level that is acceptable for an enterprise. RM may be compared to drawing a map of hazards and the probable harm they may cause; the map can then be used to solve the challenges caused by risks, according to their sources [12]. It is believed that the risk assessment process, particularly risk identification, is the most important one in the whole risk management process. It must be noted that the risks that are not recognized and described in the first stages of risk management are not subsequently addressed and therefore go unnoticed and uncontrolled. Because of that, this study aims to construct a framework for risk assessment in last mile delivery. Therefore, in the first stage of this study, last mile delivery risks need to be identified and categorized.

This work's contribution extends to academia and logistics companies by investigating and analyzing all risks that impact the last mile delivery efficiency. A last mile delivery risk assessment framework will be developed. This study will help logistics service providers to ultimately decide the solutions of last mile delivery that need to be utilized by considering last mile delivery risks to increase their competitiveness, increase their market share, and minimize delivery costs. The study will achieve the following main objectives (1) Facilitate the ultimate investigation of solutions and challenges of last mile delivery, (2) Extract and identify all possible risks in the different last mile delivery solutions, (3) Categorize the risks of the proposed framework and determine the relative probability and severity of each risk, and (4) Identify risks interdependency and prioritize risks.

The remainder of the paper is organized as follows: A brief overview of the relevant literature is presented in Section 2. The proposed methodology is described in Section 3. The results and analysis are presented in Section 4. We discuss the implications of our study in and present conclusions and directions for future research in Section 5.

II. LITERATURE REVIEW

This section investigates last mile delivery corresponding risks. An in-depth review of the literature concerning last

mile delivery solutions and challenges is presented in order to deduce the delivery risks. Then, risk management and supply chain risk assessment-related work is discussed.

A. LAST MILE DELIVERY SOLUTIONS

Logistics companies have designed different last mile delivery solutions to address the problem of failed deliveries and the rising costs associated with it. The unattended delivery solutions at the customer's home include the reception box, delivery box, and controlled access system, while away from the customer's home include collection points and locker banks [2]. However, all suggested solutions have risks that need to be considered. For example, a reception box, which is fixed to a wall outside the customer's home [2], can be vulnerable to theft or other damages such as rain or storm. In addition, if the customer requires to return goods/parcels, he/she has to drop the parcel at nearby collection points. In technologically advanced and developed countries, they are gradually being replaced with alternative, technologically more advanced solutions, such as; electric vehicles, air drones, cargo pipelines and tubes, 3D printers, and crowdsourcing [40]. However, in other less developed regions, most of these promising solutions still have strict operating rules and a way to go before regulators open the sky for commercial use by drones, or build an infrastructure from scratch to meet the cargo pipelines and tubes needs, as well as the high expenses of these technologies like 3D printers and requiring a license to print specific products [31]. The new form of delivery, the crowdsourcing approach, at this point in time, city logistics are primarily conducted with trucks and vans. Crowdsourcing is the most applicable and feasible advanced solution, it can be applied at this time and this level of advancement in the region.

B. RISK MANAGEMENT IN LAST MILE DELIVERY

Reference [32] states that risk is mainly related to negative events that occur during a project or a process, whereas the Association for Project Management (APM) [4] and the Project Management Institute (PMI) [56] describe risk as either having a positive or a negative impact. "Risk can be defined as an uncertain event or condition that, if it occurs, has a positive or a negative effect on at least one objective, such as time, cost, scope, or quality" [56]. "Risk is an uncertain event or set of circumstances which, should it occur, will have an effect on the achievement of one or more objectives" [4]. From these two definitions, last mile delivery risks can be defined as an uncertain events that can influence the final leg effectiveness. Thus, risk management is essential to ensure that last mile delivery risk induces minimal negative impact. However, the available literature does not cover the possible risks in last mile delivery in specific but it covers risks in the supply chain in general; thus this research builds on previous studies in risk management in supply chain and logistics, in order to investigate the discussed risks and the methodologies followed in assessing these risks. It is advised to follow certain guidelines when considering risk management

in organizations and in the supply chains; they form to ensure that the process is thorough and effective [5]. In all types of organizations, the ISO 31000 family of international standards provide a framework for risk management.

RM is now widely used in almost all projects and is becoming a must-have tool nowadays. To handle the complex and increased uncertainty of projects, several steps must be followed in the context of RM. Project Management Institute (PMI) [56] divided RM steps into RM planning, risk identification, qualitative analysis, quantitative analysis, risk response development and risk monitoring and control. Various methods and tools are used throughout these steps, including brainstorming, Delphi technique, interviewing, root cause analysis, SWOT analysis, probability and impact matrix, risk breakdown structure (RBS), Multi-Criteria Decision Making (MCDM), probability distributions, sensitivity analysis, expected monetary value analysis, modeling and simulation techniques. One weakness of the most common methods for analysis is that they assume independence of risks and ignore any interdependency among the risks. Therefore, this study utilizes the Bayesian Belief Network to capture and analyze the interdependency among risks and the risk network effect.

C. SUPPLY CHAIN AND LOGISTICS RISKS

In recent years, several incidences have shown that global supply chains are exposed to unexpected events and attendant consequences. To derive mitigation strategies, managers require information about the risk their company is subject to. To assess risks, they must be recognized in the first place. Therefore, the first step in the assessment framework is risk identification. Risk identification is a fundamental step in the risk assessment framework. In this step, decision-makers should identify each possible risk event to be able to assess it in the next step. Researchers have categorized risks in Supply Chain in several ways [1], [3], [13], [14], [27], [38], [43], [51], [63], [64], [70]. After identifying risks, risks can be analyzed, evaluated, and managed. Researchers have followed different methods in assessing risks in the supply chain, such as; the Failure Mode Effect Analysis (FMEA) guidelines, the OM-AHP, and N-AHP.

So far, the traditional tools and different models used and developed in risk assessment in supply chain management ignore the complex interdependencies between risks and use point estimates for probability and impact values [52], [53]. A study by [52] was conducted on construction projects, in which they proposed a novel methodology that is grounded in the theoretical framework of BBNs to prioritize risks. Their methodology accounts for interdependent interactions of risks unlike the conventional risk matrix-based tools. They demonstrated their methodology through a real application. They successfully proved the importance of utilizing an interdependency-based risk management process, as the results of two ranking schemes, assuming independence and interdependence of risks were correlated negatively. Therefore, for the purpose of this

study, this research methodology will be based on the study conducted by [52].

D. COVID-19 PANDEMIC AND SUPPLY CHAIN

While supply chains worldwide have already suffered from epidemics and pandemics, an unprecedented, far-reaching disruptive epidemic, namely COVID-19, has recently seriously hit supply chains [6]; COVID-19 is considered a new type of extremely contagious coronavirus with destructive impacts [35]. The new pandemic of COVID-19, first spotted in Wuhan, China, has triggered the most extreme recession in nearly a century. According to the latest Organization for Economic Co-operation and Development (OECD) Economic Outlook [49], it has caused enormous harm to people's health, employment, and well-being. COVID-19 has influenced almost every nation in the world and has virtually put the whole world on hold. The number of confirmed global cases up to date are more than 270 million; the number of deaths crossed 5 million [34], [68]. Due to this pandemic and the resulting global healthcare crisis, the supply chains have faced major upstream disruptions, while hoarding and panic buying have caused similarly significant downstream disruptions. The balance of supply and demand was further impacted by the travel restrictions and lockdowns implemented by several countries worldwide. The COVID-19 pandemic is already affecting large-scale supply chain management (OSCM) operations [54]. The extreme ripple effects of this challenge involve numerous strategies and steps, including comprehensive supply chain resilience strategies [35]. In addition, the response of the OSCM to such outbreaks should be to make global supply chains more interconnected and digitally ready [11]. In such circumstances, the digitalization of the supply chains may enhance the efficiency of the response to outbreak-related disturbances by increasing the flexibility of the OSCM [35]. The pre-disaster and post-disaster outcomes focused on flexibility and durability have been conceptualized as a supply chain model [22], [24] presented a digital supply chain twin system for managing risks in pre, during, and post-disruption stages. Similarly, [50] suggested a dynamic model to evaluate the supply chain service level in separate situations by considering partial and total disruptions. A modular production system analytical model has been developed to analyze the loading or unloading operations sequence using autonomous mobile robots to increase system productivity and flexibility. The study suggested strategic planning for serious, medium, and mild scenarios of logistics problems and revenue losses [22], [28] have developed a smart contract framework for a logistics service provider in the light of emerging technologies. Using an event-driven dynamic approach, the model studies the tradeoff between supply chain lead time and contract costs. All of these proposed solutions that aim to support the supply chain through this pandemic have possible risks, such as IT risks, which need to be considered in managing risks in the supply chain. Other risks resulting from the pandemic should

be considered, such as capacity fluctuations and economic conditions.

III. METHODOLOGY

This study aims to identify and quantify the last mile delivery risks to explore the interdependency between the risks and prioritize last mile delivery risks. The last mile delivery risks were first explored by studying literature to understand these risks and if there is interdependency between them. Then, new factors were induced by interviewing experts. Face-to-face interviews were conducted with two experts to validate the risks of the study, while the online survey was constructed to collect and analyze individual responses through questions.

Methodological triangulation was used for the data collection and validation stages. This method combines quantitative and qualitative methods. The quantitative method examines the occurrence level based on calculations and numbers. It also investigates the relationship between variables statistically. This method is based on structured data collection tools [39]. On the other hand, the qualitative method (non-numerical information) explores the ideas or concepts under study to gain perceptions and a comprehensive understanding of the topic and its variables.

First in this study, the qualitative method was used in mapping risks of last mile delivery from previous literature reviews; subsequently, face-to-face interviews with semi-structured questions were conducted with experts from the logistics and supply chain field. Using the inductive method, the face-to-face interview with semi-structured questions is suitable for an exploratory qualitative survey technique. A face-to-face interview captures the interviewees' reactions and emotions toward the question. On the other hand, semi-structured questions will allow asking new questions to find new risks [39]. This interview method will verify the literature review findings on last mile delivery risks and identify new risks that are not mentioned in the literature. Then, a survey that targets project managers, E-commerce, logistics and supply chain professionals was developed by asking questions on a Likert scale from 1 to 5. Quantitative methods were used to quantify the responses and ranking risks based on their impact and likelihood. Lastly, the Bayesian network method was used to check the interdependencies between the risks.

A. SURVEY

A good questionnaire is the main key to conduct a good survey as stated by [10]. To achieve this study goal, data of risks impact and the likelihood of occurrence were collected based on a structured online survey targeting project managers, E-commerce, logistics and supply chain professionals. To confirm the survey ability to provide sound results regarding the risks of last mile delivery, this study considered both its validity and reliability as a data collection instrument. Specifically, this study analyzed its content, criterion,

and construct validity by interviewing an expert from the field, and its reliability using Cronbach's alpha coefficient. In survey validity, [20] defined the validity of an instrument as the determination of the extent to which the instrument reflects the abstract construct being examined and the degree in which a test or other measuring tool is truly assessing what it proposes to measure. Instrument validity can be assessed using different methods [20].

B. STATISTICAL ANALYSIS

Changing focus from the instrument to the survey responses, additional statistical analysis methods were used to evaluate the collected responses quantitatively. In addition to determining general descriptive statistics to characterize the survey responses, Bayesian Belief Network (BBN), was constructed. Bayesian Networks (BNs), also known as Bayesian Belief Networks (BBNs) and Belief Networks, are probabilistic graphical models that represent a set of random variables and their conditional interdependencies via a directed acyclic graph (DAG) [29]. They can be used to explore and display causal relationships between key factors and the final outcomes of a system in a straightforward and understandable manner. A Bayesian network represents the causal probabilistic relationship among a set of random variables and their conditional dependencies and provides a compact representation of a joint probability distribution [48]. It consists of two major parts: a directed acyclic graph and a set of conditional probability distributions. The directed acyclic graph is a set of random variables represented by nodes.

For risk measurement, a node may be a risk domain, and the states of the node would be the possible responses to that domain. Suppose a causal probabilistic dependence exists between two random variables in the graph. In that case, the corresponding two nodes are connected by a directed edge [48]. The directed edge from node A to node B indicates that the random variable A causes the random variable B. Since the directed edges represent a static causal probabilistic dependence, cycles are not allowed in the graph. A conditional probability distribution is defined for each node in the graph. In other words, the conditional probability distribution of a node (random variable) is determined for every possible outcome of the preceding causal node(s). Since a directed acyclic graph represents a hierarchical arrangement, it is unequivocal to use terms such as parent, child, ancestor, or descendant for certain nodes [60].

Bayesian networks apply Bayes' Theorem (also known as Bayes' rule or Bayes' law). In Bayes' theorem, a prior (unconditional) probability represents the likelihood that an input parameter will be in a particular state; the conditional probability calculates the likelihood of the state of a parameter given the states of input parameters affecting it; and the posterior probability is the likelihood that parameter will be in a particular state, given the input parameters, the conditional probabilities, and the rules governing how the probabilities combine. The network is solved when nodes have been

updated using Bayes' Rule:

$$P(A|B) = \frac{P(B|A)P(A)}{P(B)} \quad (1)$$

where $P(A)$ is the prior distribution of parameter A; $P(A|B)$ is the posterior distribution, the probability of A given new data B; and $P(B|A)$ the likelihood function, the probability of B given existing data A. Bayes' theorem was derived by the Reverend Thomas Bayes, and was first published posthumously in the essay *Towards Solving a Problem in the Doctrine of Chances* [17]. BNs use Bayes' Theorem to update or revise the beliefs of the probabilities of system states taking certain values, in light of new evidence (referred to as a posteriori). Unlike many other modeling techniques used for different risk assessment, Bayesian networks use probabilistic, rather than deterministic, expressions to describe the relationships among variables [7]. Lack of knowledge is accounted for in the network through the application of Bayesian probability theory. This allows subjective assessments of the probability that a particular outcome will occur to be combined with more objective data quantifying the frequency of occurrence in determining conditional probabilistic relationships. Because uncertainty is accounted for in the model itself, Bayesian networks are a particularly appropriate method for dealing with systems where uncertainty is inherent, which tends to be a key issue in ecological systems. Communication of uncertainties is also essential when developing models for management.

The adopted methodology utilized a data-driven approach to capture the range of risk exposure specific to each risk rather than a point estimate. After collecting the data related to the likelihood of occurrence and level of impact of each risk from 3PL providers, the risk exposure of each risk was calculated using equation (2) [71]:

$$r_{ij} = \alpha_{ij}\beta_{ij} \quad (2)$$

where

r_{ij} is the risk exposure assessed by respondent j for risk i ;

i is the ordinal number of risk, $i \in (1, \dots, 23)$;

j is the ordinal number of valid feedback to risk i , $j \in (1, \dots, 25)$;

α_{ij} is the ordinal number representing the likelihood occurrence of risk i , assessed by respondent j , $\alpha_{ij} \in (1, \dots, 5)$;

β_{ij} is the ordinal number representing the level of impact of risk i assessed by respondent j , $\beta_{ij} \in (1, \dots, 5)$.

Secondly, risks exposure were mapped to a risk matrix that was partitioned by the author into three zones; high, medium and low. This partitioning method represents the risk tolerance of a decision-maker in a project [25]. Therefore with regard to discretizing a risk matrix into risk exposure zones, decision makers will have a clear preference.

Thirdly, a data-driven Bayesian approach is used for developing models after discretizing the data inducing the model's network structure and estimating the model's

TABLE 1. Last mile delivery framework.

Criteria	Risk	Reference	Economical	Environmental	Social	Internal	External	Financial	Quality	Operational
Financial Risk	Customers unavailability	[15], [16], [17], [24]	X				X	X		
	Package damage/loss	[21], [23], [25], [65], [66]	X				X	X		
	Customers Density	[18], [25], [26]	X				X	X		
	Cash on delivery		X			X		X		
	Shipment return		X				X	X		
	Competition		X				X	X		
	Economic conditions		X				X	X		
Operational & Technical Risk	Traffic congestion	[19], [67], [68], [25]		X			X			X
	Size and weight limitation	[69]	X			X				X
	Capacity fluctuations		X			X				X
	IT risks		X			X				X
	Delivery location identification		X				X			X
Environmental Risk	Noise pollution	[19, 25]		X			X		X	
	Harmful emission	[19], [25], [67], [68]		X			X		X	
	Natural disaster			X			X	X		
	Operations waste			X		X				X
Quality Risk	Delivery inconvenience	[23], [70]	X			X			X	
	Delivery window	[18], [71]	X			X			X	
	Customer Service quality	[72], [25], [27]	X			X			X	
	Delivery time	[3], [27], [29]	X			X			X	
	Privacy concerns				X	X			X	
Legal related risk	Workforce Protection	[22]			X		X		X	
	Laws and regulations				X		X		X	

parameters [37]. Bayes server software package was utilized and a PC algorithm was used for the modeling of the network. Based on an overall score reflecting the ability to predict the combination of values specific to various scenarios, these algorithms often select a particular network.

Knowing that each risk has the ability to propagate its impact across the entire network, risks can be prioritized. This is done by shifting each risk to both extremes (high, low) and recording the overall risk exposure impact on the network. This concept is operationalized by means of a new risk metric, namely network propagation impact (NPI) [52]; equation (3) shows how to calculate the NPI:

$$NPI_{Ri} = RE|(Ri = high) - RE|(Ri = low) \quad (3)$$

Ranking is done depending on the NPI values. The higher the NPI reflects a higher effect of the risk on the network.

IV. RESULTS AND DISCUSSION

A. LAST MILE DELIVERY RISK FRAMEWORK

The last mile delivery risks were first explored by studying the literature to understand these risks from 3PL context. The framework identified and listed 19 risks associated with the last mile delivery, 12 risks were compiled from 34 studies and 7 risks were added as a result of interviews. The proposed framework categorized risks under five main criteria, which are: (1) financial risk; (2) operation and technical risk; (3) environmental risk; (4) quality risk; (5) legal related risk.

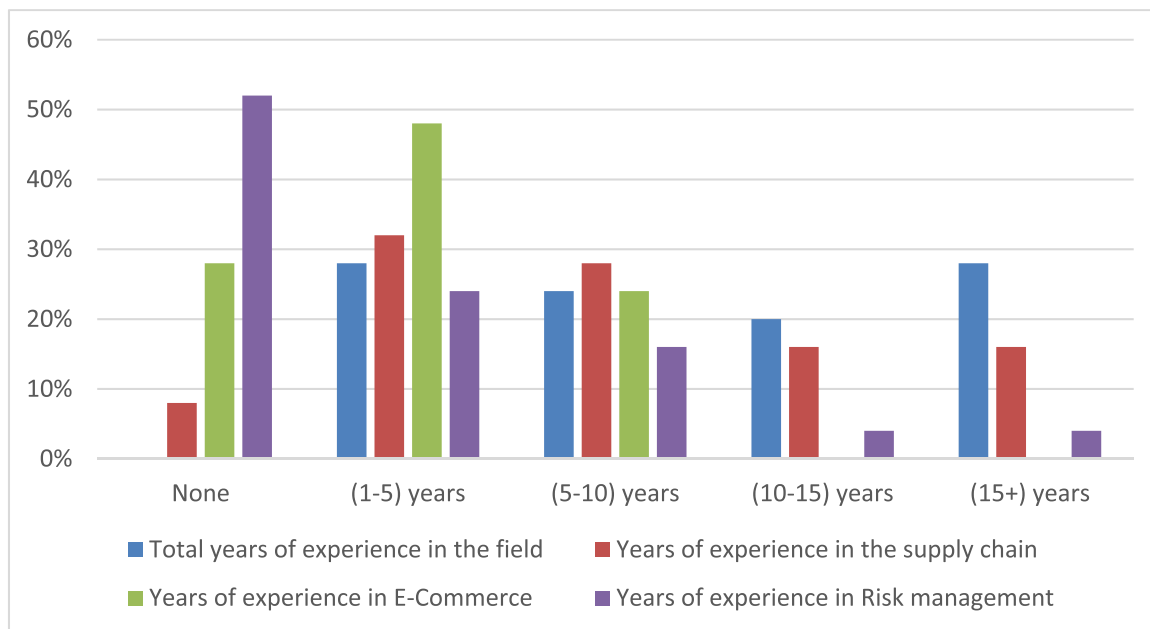


FIGURE 1. Respondents experience profile.

Likelihood		Impact					
		1	2	3	4	5	
		Negligible	Minor	Moderate	Significant	Severe	
1	Almost uncertain	1	2	3	4	5	<div style="display: flex; flex-direction: column; align-items: center;"> <div style="display: flex; align-items: center; margin-bottom: 5px;"> High</div> <div style="display: flex; align-items: center; margin-bottom: 5px;"> Medium</div> <div style="display: flex; align-items: center;"> Low</div> </div>
2	Unlikely	2	4	6	8	10	
3	Fifty-fifty	3	6	9	12	15	
4	Likely	4	8	12	16	20	
5	Almost certain	5	10	15	20	25	

FIGURE 2. Risk matrix representing the risk zones.

Additionally, risks were mapped onto three different schemes as show in Table 1. The first scheme used is based on the triple bottom line (TBL) parts; social, environmental, and financial. Minimum performance is to be achieved in the environmental, economic and social aspects, according to the TBL approach (Schaltegger et al., 2014). The second scheme is based on whether the risk is internal or external to the organization. The last scheme divided the risks based on their impact into financial, quality, and operational risks.

The content validity of the framework was determined by semi-structured face-to-face interviews with logistics and supply chain experts who have more than 15 years of experience. Experts agreed that the 19 identified risks have an impact on the last mile delivery process. Moreover, four risks were added by the experts—namely, shipment return, competition, natural disasters, and operations waste.

B. SURVEY DESIGN AND RESULTS

A survey was conducted targeting project managers, E-commerce, logistics, and supply chain professionals. It was based on the presented theoretical framework developed based on the literature review and semi-structured face-to-face interview with two experts. The survey was divided into two parts; Part one: Respondent’s background. Part two: Relative importance index of last mile delivery risks in terms of occurrence and impact. The survey targeted individuals who work in key logistic international and local organizations in the United Arab Emirates. Most of the survey respondents work in large organizations in different industries related to last mile delivery, including logistics, transportation, freight forwarding, hospitality, and academia. The experience profiles for the respondents are shown in Figure 1. The second part of the survey was designed to avoid having a bias which

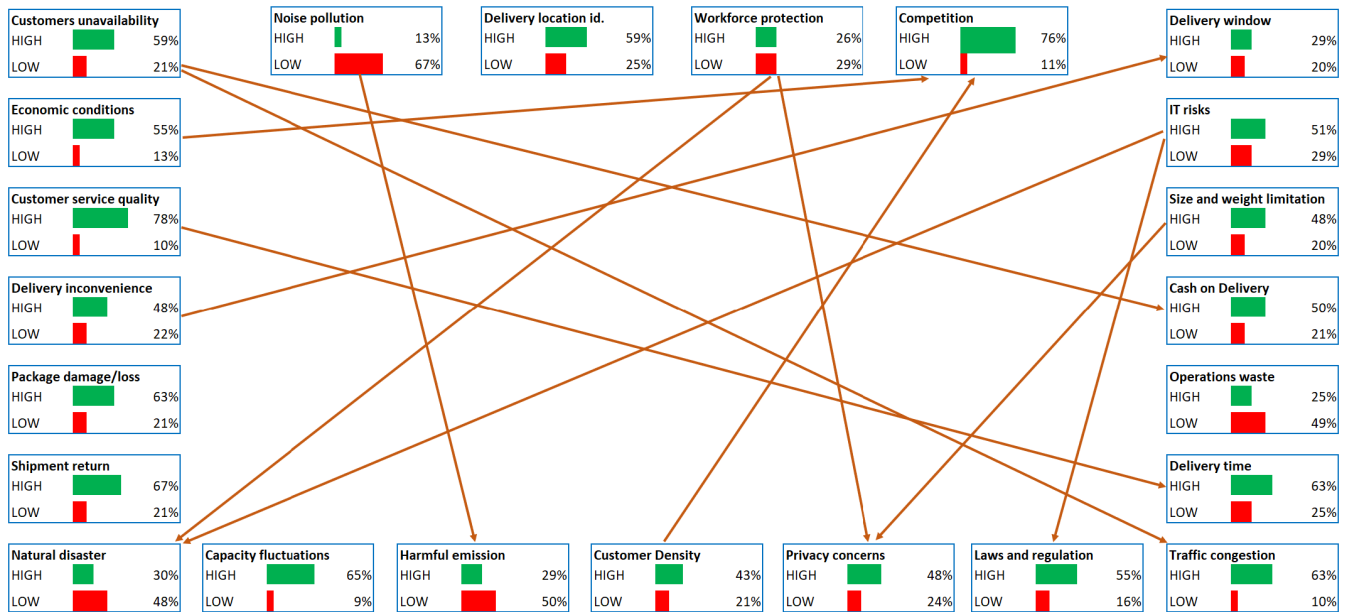


FIGURE 3. Bayesian belief network of last mile delivery risks.

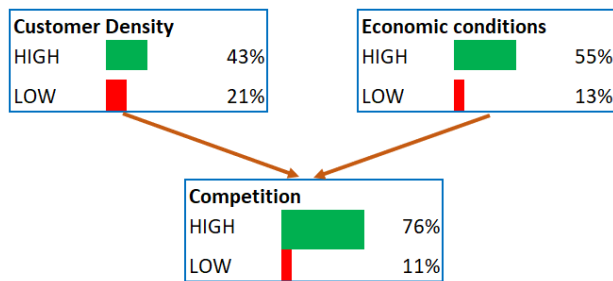


FIGURE 4. Risks interdependency.

was accomplished by developing the initial questions through surveying the literature of important risk factors, second, get feedback and input from two industry leaders, lastly, finalize the survey and ensuring it is inclusive of all aspects and it captures the current status and future trends realistically in last mile delivery.

The second part of the survey is divided into two sections, based on the risk exposure of each risk which is calculated by multiplying the likelihood of occurrence of a risk times the level of impact of that risk [71]. First section asks about the likelihood of the occurrence of each risk of the 23 risks, a five-point Likert scale was used in the survey by the respondents to show their opinion about the level of likelihood of the occurrence of each risk, where (1) indicates almost uncertain, while (5) indicates almost certain. This scale allows the qualitative data obtained from the survey to be transformed into quantitative data [57]. The second section asks about the level of the associated impact of each risk from 1 to 5 on a Likert scale: where 1 indicates negligible impact, while 5 indicates severe impact.

An online website tool was employed in the development and distribution of the survey, as well as in the collection of the responses. The survey link was sent out by emails to project managers, E-commerce, logistics, and supply chain professionals. Only the complete responses were used for further analysis, resulting in 25 completed surveys. The risk exposure of each risk was calculated using equation (2) in Section 3.2. The resulting exposure varies from 1 to 25. Risks exposure was mapped to the risk matrix shown in Figure 2. Risks with a value greater than or equal to 10 are considered critical (high exposure risk), while risks with a value less than or equal to 4 are categorized as low exposure risk. Risks with exposures from 5 to 9 are classified as medium exposure risks.

C. BAYESIAN BELIEF NETWORK (BBN)

The resulting significance index assumes the independence of each risk. The significance score represents the probability of high risk exposure resulting from that risk. The “Customer Service Quality” risk is ranked first with the highest score of 0.7821; followed by the risk of competition and the risk of shipment returns, ranked second and third, respectively. The least ranked risks based on the independence approach were Noise pollution, Harmful emissions, Natural disasters, and Operations waste. Taking a look at the first scheme categorization, the independence based ranking lists the economic risks on the top of the list. In contrast, environmental risks are being rated as the least important.

However, as mentioned earlier, these ranks do not account for interdependencies between the risks; thus, this ranking can be misleading for the decision-makers in the last mile delivery process. In order to consider the interdependencies

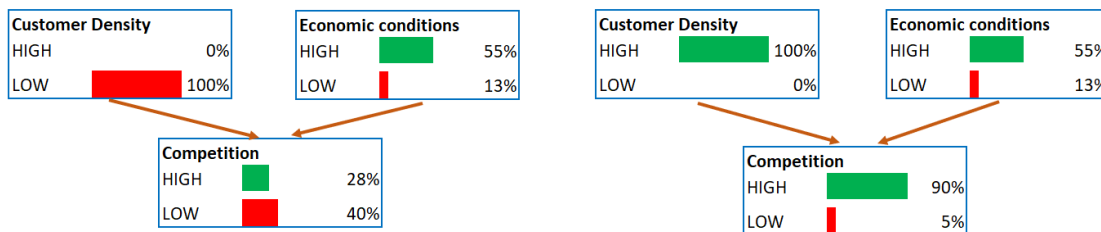


FIGURE 5. Mitigation and realization of customer density risk.

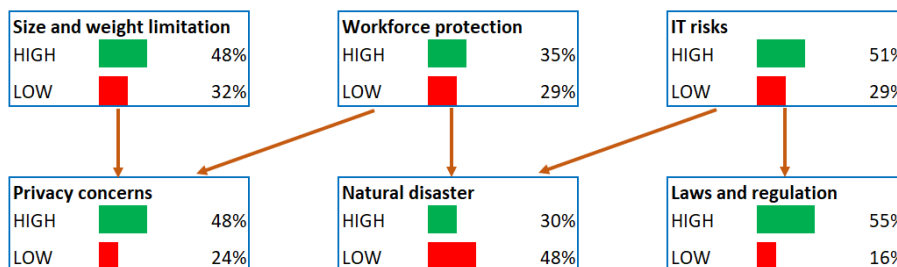


FIGURE 6. Interdependencies between highest ranked risks.

TABLE 2. Comparison between the study's ranking schemes.

Srl	Risk	Interdependence based ranking		Independence based ranking	
		NPI	Rank	Score	Rank
1	Customers unavailability	0.0939	5	0.5897	6
2	Package damage/loss	0.0435	19	0.6282	5
3	Customers Density	0.0706	15	0.4359	12
4	Cash on delivery	0.0764	8	0.5848	7
5	Shipment return	0.0435	19	0.6667	3
6	Competition	0.0615	17	0.7582	2
7	Economic conditions	0.0751	10	0.5513	8
8	Traffic congestion	0.0745	12	0.6282	5
9	Size and weight limitation	0.0738	13	0.4744	11
10	Capacity fluctuations	0.0435	19	0.6533	4
11	IT risks	0.1009	2	0.5128	9
12	Delivery location identification	0.0435	19	0.5897	6
13	Noise pollution	0.0654	16	0.1282	18
14	Harmful emission	0.0554	18	0.287	16
15	Natural disasters	0.1002	3	0.2922	15
16	Operations waste	0.0435	19	0.2533	17
17	Delivery inconvenience	0.0749	11	0.4744	11
18	Delivery window	0.0812	6	0.3974	13
19	Customer Service quality	0.0759	9	0.7821	1
20	Delivery time	0.0787	7	0.6282	5
21	Privacy concerns	0.1055	1	0.4769	10
22	Workforce Protection	0.0726	14	0.359	14
23	Laws and regulations	0.0957	4	0.5513	8

between the risks, a Bayesian Belief Network model for the last mile delivery process performance was developed

by utilizing PC algorithm of the Bayes server [23]. After discretizing the data. Figure 3 illustrates the constructed

network. The network shows that there are interdependencies between some of the risks within the network, whereas other risks are independent and therefore are not affected by other risks.

Three interdependent nodes risks are shown in Figure 4 as an example to illustrate the interdependency between risks and the network impact on the overall risk exposure. The arcs between the nodes indicate the relation between the corresponding risks. In this example, the competition depends on both customer density and economic conditions. This implies that the increase in customer density will affect the risk exposure and lead to an increase in the competition risk. Figure 5 represents the network impact with respect to the mitigation and realization of the customer density risk, respectively.

In order to investigate the relations within the network and to capture the impact of each risk across the network, the network propagation impact was calculated for each risk using equation (3). After accounting for the network effect and the interdependencies; Privacy concerns, IT risks, and Natural disasters were ranked the top three risks with NPI of 0.1055, 0.1009, and 0.1002, respectively, where these three risks are all connected together and connected to three additional risks within the network as shown in Figure 6.

It is noticed that the two approaches result in different ranks as shown in Table 2 as the independence-based ranking scheme does not account for the interdependencies between the risks. For instance, the independence-based ranking listed the economic risks on the top of the list and the environmental risks on the bottom. However, based on the NPI value, the risk network listed a social risk (privacy concerns) as the most important risk. Therefore, decision-makers in last mile delivery should consider the interdependencies and the network effect in order to decide on their risk management strategies.

Privacy concerns, IT risks, natural disasters, laws and regulations, and Customers unavailability are considered high risks relatively, with NPI value around 0.1, have both high probability and high severity. Mitigation strategies are recommended to be developed and implemented for privacy concerns, IT, and customer unavailability risks. However, natural disaster risk and law and regulations are beyond management's control and can be regarded as Force Majeure or an industry crisis. This is where management should be encouraged to transfer these risks by purchasing insurance to hedge against these risks and does not need to take any mitigating action upon themselves for these risks. Organizations should also monitor the rest of the risks to identify the potential trends in their probability or consequences. Some proactive mitigation strategies for these risks also should be made.

V. DISCUSSION AND CONCLUSION

To the best of our knowledge, this is the first study to investigate risk identification and assessment in last mile delivery. This study extracts and identifies all possible risks in different last mile delivery solutions. Risks are categorized and

individual risks' relative probability and severity are determined. Therefore, this study adds to the body of literature a comprehensive framework on risk identification and analysis in last mile delivery from the logistics providers point of view, considering any possible interdependency among the risks.

This study helps logistics service providers to better understand all possible risks and the potential impact of those risks, which were identified in the first step of risk assessment in this study. Therefore, the service providers will be able to identify internal and external risks to be managed. It also quantifies the identified risks in terms of its likelihood and its potential impact, considering any interdependencies between the risks. This, in turn, will help logistics service providers to ultimately decide the solutions of last mile delivery that need to be utilized to treat these risks depending on organizations thresholds, they can determine which risks can be tolerated or which can be confidently avoided or mitigated. This will positively reflect on logistics service providers by increasing their competitiveness, increasing their market share, and minimizing delivery costs.

Last mile delivery is viewed as being the most polluting section of the entire logistics chain and the most expensive. However, it has a remarkable impact on e-commerce and logistics companies, as it is the final leg of the supply chain and reflects the company's image. In last mile delivery, it is important to meet customers' expectations to gain their satisfaction, considering the cost of the process and the environmental impact. This is achieved by efficient last mile delivery planning, where the service provider must clearly know the risks that last mile delivery faces. Therefore, it should focus on risk assessment to identify the specific risks it faces and take action according to a proper risk response strategy.

Although the last mile delivery is one of the most complex, costly, and inefficient processes along the entire logistics fulfillment chain in an e-commerce context, there are no studies to date investigating the assessment of its risks. Therefore, this study proposed a comprehensive framework on risk identification and analysis in last mile delivery, considering any possible interdependency among the risks.

Risks have been deduced from the literature on last mile delivery and others have been induced through semi-structured interviews with experts in the field to better understand risks, find new risks that are not mentioned in the literature, and validate and rank them.

To achieve the study goal, data of risks impact and likelihood of occurrence were collected based on a structured online survey. As the last mile delivery efficiency is affected by the combination of various risk factors, the conventional approach of mapping the risk factors on a risk matrix falls short because it assumes that risks are independent and ignores the complex interdependencies between different risk elements. Therefore this study utilizes Bayesian Belief Network in order to capture and analyze the interdependency among risks as well as the network effect on the overall performance.

After accounting for the network effect and the interdependencies, it was found that privacy concerns risk, IT risks, and natural disasters risk are ranked the top three risks, whereas on the other hand based on the independent ranking scheme, they ranked 10, 9, and 15 respectively.

This study adds to the literature body a comprehensive investigation of last mile delivery risks, help logistics service providers to ultimately decide the solutions of last mile delivery that need to be utilized by prioritizing last mile delivery possible risks to increase their competitiveness, increase their market share, and minimize delivery costs. The limitations of this study affect the accuracy of the developed Bayesian Belief Network, these limitations are represented by the small sample size of the collected data, and the values assigned to the risks exposure are based on expert judgments not a real data from the field. Moreover, risks were assigned to the last mile delivery process in general not for a specific solution. It is recommended for future studies to collect more responses as more data improves model's prediction to help develop more precise and targeted models.

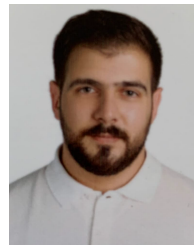
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