ARTIFICIAL INTELLIGENCE APPLICATIONS IN SUPPLY CHAIN RISK ASSESSMENT

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ABSTRACT

Artificial intelligence (AI) is one of the most promising contemporary technological solutions to industry struggles and its applications have somehow revolutionized practically every one of them. This study assesses how AI-related tools have helped the supply chain industry in respect to its constant exposure to risks. Supply chains contribute to every other industry by allowing a steady flow of material, be it raw material, finished goods or commodities. An interruption in these supplies may cause great damage to the image of a company, many times involving financial losses, not to mention potentially more serious consequences in case of medical or pharmaceutical industries, for example. The well-functioning of a supply chain depends upon planning, compliance with time restrictions, and fast information exchange. However, unforeseen situations cause disturbances to daily tasks, causing a chain reaction which affects the overall chain of materials. AI has proven to help prevent such situations, or quickly identify them, which is key to mitigating its consequences, both immediate and downstream throughout the supply chain.

1. INTRODUCTION

Supply chains are responsible for the distribution of finished goods, energy, water, among other supplies to consumers around the world. Many industries depend on a steady flow of materials in order to offer their services to the community. Disruptions to their supply chains could bring serious financial impacts to companies, or even greater impact involving local food and water supply, depending on the severity of the disruption. These high-impact potential outcomes have long motivated research in order to assess and mitigate risks involving the supply chain, including its ability to return to its regular state after a disruption, referred to as resilience. Management Sciences and techniques such as Optimization, Forecasting, and Simulation have been used in supply chain management to reduce its associated risks. Despite the efforts in assessing supply chain risks, disruption rates continue to increase, having global supply chain risk events increased by 36% in 2018 [1]. There is, therefore, a need to improve current mitigation approaches and tools. A promising strategy is to make use of the increasing access to Big Data and real-time surveillance technologies, applying Artificial Intelligence (AI) approaches, including machine learning techniques, in order to improve risk evaluation and management. These approaches have successfully been used in different study areas to broaden knowledge about a certain phenomenon based on large amounts of information related to the event or process. Extrapolation is then used to infer information about future events through the identification of patterns and relationships. In practice, this involves computer vision, natural language processing,

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regression and classification, clustering, and others. In the supply chain context, the main goal would be to anticipate unwanted events, which could be done by identifying patterns involving climate factors that lead to a natural disaster, equipment characteristics that are generally altered before failures or facts that influence demand fluctuations. In case of unexpected events, a secondary goal would be to identify as briefly as possible those that might affect the overall flow of materials throughout the chain. This study aims at investigating current applications of AI methodologies to Supply Chain Risk Assessment (SCRA). An understanding of the current grounds on the use of related technologies in the field will lead to the identification of knowledge gaps, potential improvement initiatives, investigations and applications, and hopefully contribute to reducing disruption rates in industrial supply chains. This study is organized as follows: Section 2 describes similar literature review works and highlights this paper's main contributions, also describing the adopted methodology. Section 3 explores and connects information from the outcoming results, whereas Section 4 seeks to analyse the main findings of this study.

2. DESCRIPTION

2.1. Similar works

Literature reviews are a powerful tool to explore state of the art works in any field of interest. Several studies have investigated escalating trends and management sciences applications in supply chain management. Surprisingly, few of them highlight the role of AI-related technology in the solution of contemporary, or even classic supply chain risk factors such as flow disruptions, stock unavailability, unpredicted demand variations, and natural disasters.

Elleuch and colleagues [2] classify articles on supply chain resilience and vulnerability according to the techniques they apply, such as multicriteria decision analysis, optimization, time series prediction classic models (eg. ARIMA), simulation, etc. However, no AI methodology is mentioned as being applied in the papers reviewed by this literature review. Ribeiro and Barbosa-Povoa [3] also address supply chain resilience and collect papers that propose quantitative methods to support decision-making pertaining to the subject. Only six out of the 56 papers that were analyzed involved data analysis, which was the only category referring to topics in the overall AI category.

Colicchia and Strozzi [4] has focused on the relevance of papers throughout the years, proposing a new literature review methodology which combines the systematic approach with a citation network analysis. Including papers from 1994 to 2010, they analyze the repercussion of different studies and seek to suggest, from the citation network analysis, the strongest trends in Supply Chain Risk Management. Most studies, however, are focused on management sciences, flexibility of supply chain operations, risk-related performance indicators, and supply chain design.

Behdani and colleagues [5] provide an integrated view of the supply chain disruption management, from risk assessment to post-disruption management. Several applications of classical methods such as HAZard and Operability (HAZOP) for risk assessment and Ishikawa Diagrams for risk identification are described as pre-disruption methodologies. Post-disruption approaches involve information sharing and visibility for a quick response to events. Technologies such as IT monitoring systems and RFID can aid in that direction.

Nguyen and colleagues [6] examine the application of Big Data Analytics (BDA) in supply chain management, involving functions such as procurement, manufacturing, inventory, warehousing operations and transportation. Although some of the listed papers are related to risk management, most of the papers applied prescriptive analytics, approaching topics such as Intelligent Transport Systems and warehouse activities efficiency. Due to a more holistic view of BDA applications, risk-related topics were only superficially treated.

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Therefore, there is a current gap in the investigation of specific AI-related technologies applied to supply chain risk assessment initiatives and related topics such as demand prediction, natural disaster anticipation, disruption risk mitigation, among others. This study will contribute towards filling that gap.

2.2. Methodology

The construction of this paper follows an eight-step methodology for a systematic literature review [7]. The first one is defining a clear objective. In this case, the goal is to outline the current state of the art applications of AI tools to SCRA. The focus is mostly on topics such as logistics, inventory management, and transportation of goods. Other factors that can evidently affect the overall functioning of the supply chain, such as equipment failure or risks involving human behavior, are not included in this study for they are considered as specific research subjects. A second objective is to determine prospective fields for future research opportunities. The main questions regarding these matters are: 1. "What are the main AI methods applied to SCRA?" 2. "What are the main issues being addressed by this kind of technology within the field?", 3. "To what future direction do most recent studies point towards, in terms of latest tools of new fields?", "What fields are yet to be explored as an application of AI?".

The second step would be protocoling and training the reviewers in the methodology, in case of a team of multiple reviewers in the data exploration phase, which does not apply in this case.

As a third step, a systematic search in the literature was conducted in the Web of Science database, which includes the most relevant journals in all the main subjects. The keywords used in the web search were a combination of AI-related words and the terms "supply chain" and "risk". Therefore, the following search term was used: ("Supply chain*"AND"risk*" AND("Artificial intelligence"OR"Machine learning"OR"Data science"OR"Big data")). The asterisk ("*") indicates that all words beginning with the indicated letters are considered. The timespan considered was the past 10 years, given that the topic directly involves technology, which evolves quickly, and the fact that the main objective is to understand current tendencies and applications, as opposed to building a historical background on the subject. Therefore, the research was limited from 2010 forward.

In order to process the first group of selected papers, a practical screen, which is the fourth step of the methodology, is performed. This as a necessary step to ensure tractability of the available information. This screening of the most relevant work within the obtained database was attained through a tool called Network Analysis Interface for Literature Studies (NAILS) [8], which is a bibliometric analysis tool that supports systematic literature studies. The provided script, run in R programming language, analyzes the main relations between papers, its topics, journals, the most relevant papers, which are highly cited by others, and other relevant work that is highly referenced though did not seem to have the desired keywords to appear in the original database search. This report helps identify what are the most prominent topics in discussion regarding the exploration of developing technology in the identification, mitigation or management of supply chain risks, using widely accepted relevance measures for scientific work, which are the citation indexes such as in-degree, citation count in Web of Science and PageRank score.

The fifth step requires a quality appraisal of the acquired information. By limiting selected studies to those published in peer-reviewed journals, the quality is already assured by the thorough reviewing process to which these papers are submitted before publication. There is no need for further examination of the technical rigor behind the applied methodologies.

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The following sections contain the outcome of steps six and seven of the methodology, which are the data extraction from the results and a synthesis of the studies. The eighth step is the elaboration of the literature review in itself, formatted as a paper or other type of document, as was done in this work.

3. DISCUSSION

3.1. Overview

The initial database sweeping search returned 228 papers that matched the desired combinations of topics. The most popular keyword in these papers was “big data”, even more than the mandatory topic in the search “supply chain”, which indicates the attention the topic has been receiving from the scientific community (Fig.1). Interesting topics were “supply chain finance”, “supplier selection”, and “resilience”, which were keywords to the same amount of papers as “artificial intelligence”.

Many important technology-related terms did not show up as keywords, or did so only scarcely, because they are incorporated by more general terms like “machine learning”, “industry 4.0”, and “big data [analysis]”. However, this work has reviewed not only general tools like Business Inteligence (BI) or Track and Trace (T&T) softwares, although they will be addressed, but also specific machine learning models and other applications in diverse supply chain issues that lead to vulnerable situations.

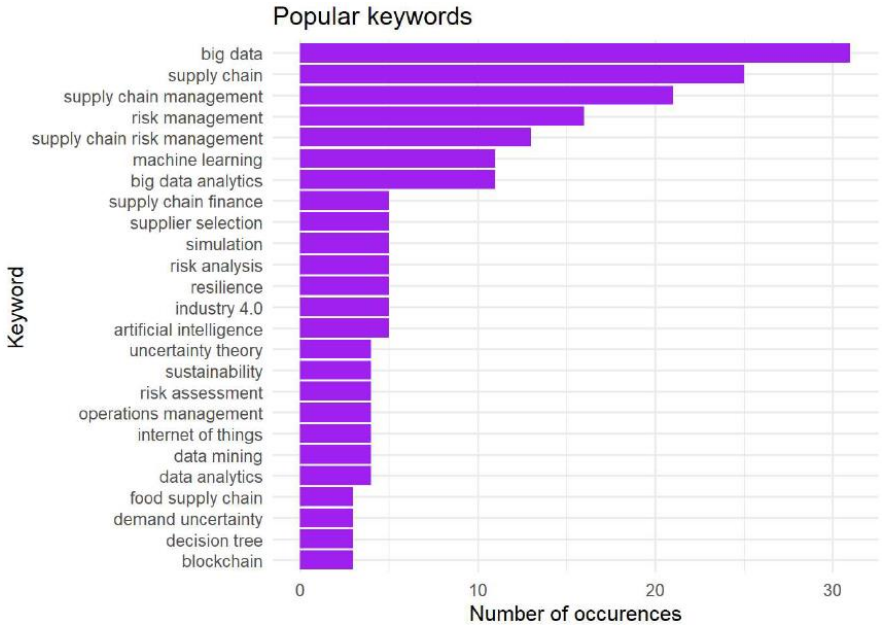

Fig.1 – Most popular keywords in the database

This study shows that research in this domain has steeply increased since 2015 (Fig.2), having tripled in 2019 the amount of papers published per year related to the subject since then, and increased 6-fold if compared to 2014. This suggests a growing interest in the application of AI technology in the supply chain risk management. This is fueled by the fast rate at which new methodologies are allowing deeper understanding of the supply chain behavior, more and quicker information sharing, and automated insights, which used to be available only through expert analysis of limited amount of data, or not at all.

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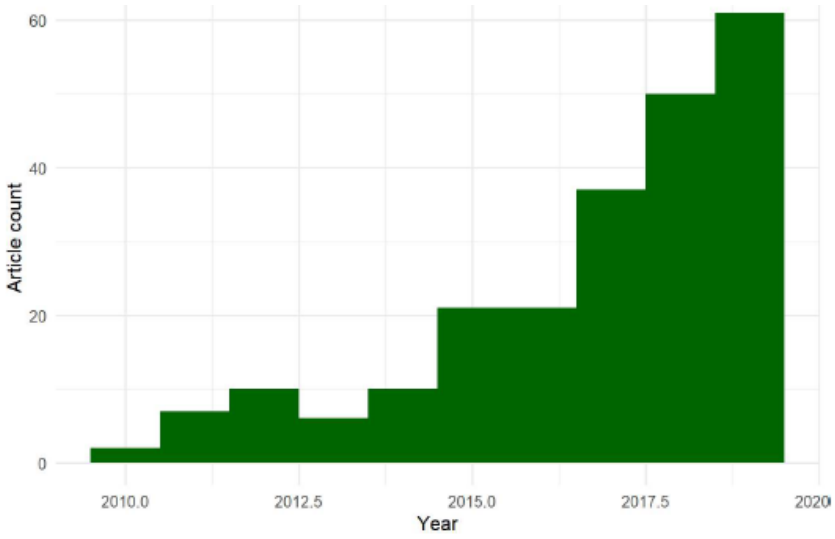

Fig.2 – Steep increase in the number of papers addressing the subject over the years

In the process of understanding state of the art grounds on this topic, it is important to identify important players in this scientific progress. The graphs below show the main journals and authors that can be referred to due to their relevant work in the field. The journals containing the most cited papers in the selected database were ranked (Fig.3) based on the number of citations held by papers of theirs that showed up on our initial Web of Science sweeping. Another interesting information was the relevance of publications amongst those referenced by the papers in our selected database. The journals were then ranked (Fig.4) by the total citations in the papers referenced by the selected works. Finally, strong individual contributors were also identified among the authors of the selected publications based on their citation record (Fig.5).

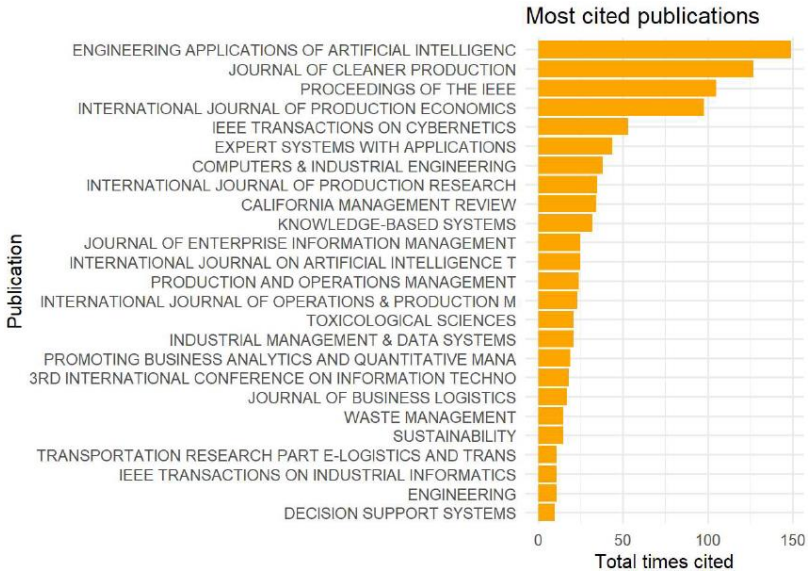

Fig.3 – Journals containing the most cited publications within the selected database

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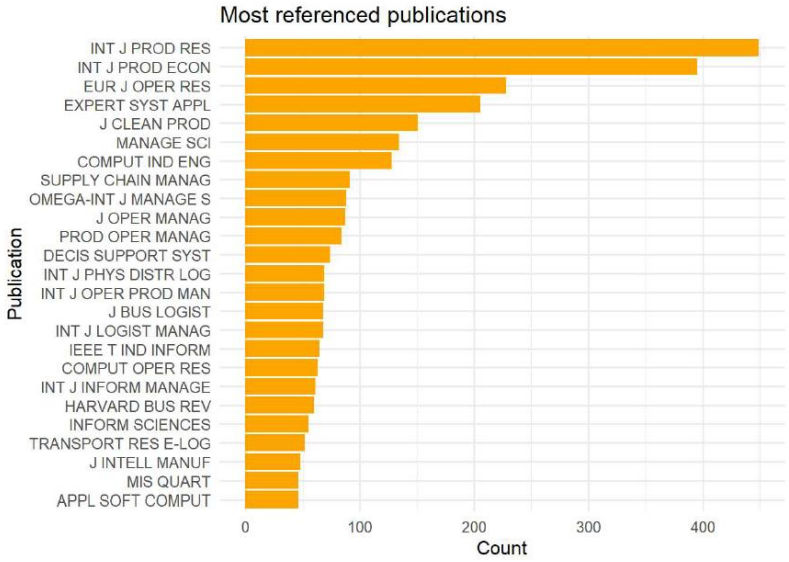

Fig.4 – Journals containing the most referenced publications by papers within the selected database

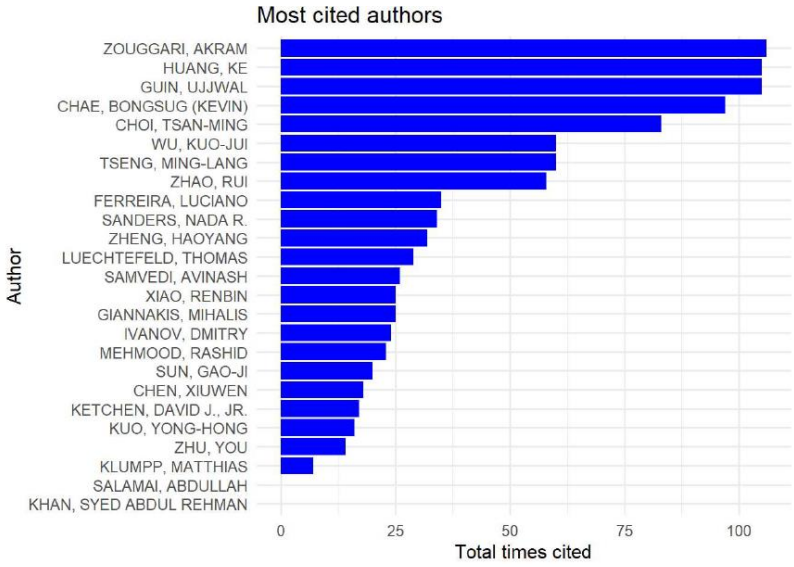

Fig.5 – Authors of the most cited publications within the selected database

3.2. Relevant Work

As suggested by the keyword analysis above, big data is one of the most mentioned topics. Not surprisingly, the most highly citation-indexed paper in the database addresses the recent developments in big data analytics for business operations and risk management [9]. The authors situate the role of Business Intelligence (BI) systems and technologies such as Radio-frequency Identification (RFID) and the Internet of Things (IoT) in the abundance of data available to be explored by data mining techniques. The latter are mostly represented by machine learning models that seek to identify patterns in the available data and provide useful information about the process of interest. According to the study, supply chain operations are the third most popular industry in recent Operational Risk Management (ORM) research, and one of the main goals of big data exploration in this context is minimizing the impact of uncertainties. This can be achieved by available methods to analyze delivery performance and to provide real-time relevant information based on available online

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or cloud-based big data. A gap pointed out in recent studies is the robustness of information and communication technology-based supply chains, that is, the risks of having a digital infrastructure-based operation. This topic has been discussed in recent papers since this study [10].

Common supply chain risk-related applications are demand forecasting and inventory management. Based on different data sources, such as Enterprise Resource Planning (ERP) systems, social media, and reviews on e-commerce websites, natural language processing and sentiment analysis have significantly improved demand forecasting in multiple different scenarios [11-13]. These types of natural language processing models are already being used by large players in the supply chain industry [14].

Chae [15] proposes a framework for analyzing supply chain comments on Twitter. Using the "#supplychain" hashtag, it gathers information from news services, IT companies, logistic providers, manufacturers, etc., to identify potential disruption threats or demand variations. Twitter posts are also used for natural disaster early identification. Through information collected from tweets, online risk-mapping softwares can be used to visualize and monitor real-time information, as in the case study involving earthquakes presented by Ong and colleagues. [16]

Big data analytics has also been applied to supply chain social risks, involving economic, environmental, and social sustainability [17]. A BI that learns to identify unusual work patterns, such as unnecessary stops and speed alterations, and predict workforce health issues, unethical behavior, theft, excessive pollution, and other social risks.

A supply chain is a complex combination of players, and the risk of disruption to one of these players impacts directly on the following ones. This is called the ripple effect, and its consequences are being mitigated by Industry 4.0 technologies by acting in four main activities: plan, source, make and deliver [18]. A delivery information database might be used to indicate situations in which lead time was exceeded, identifying possibly questionable transports or routes. The large amount of data available would require this analysis to be automatic, through an intelligent system that will proactively inform a decision-making individual. In a dynamic analysis, the quick observation of a disturbance can trigger a search for alternative suppliers or shipping routes, as a way of reducing or even preventing the ripple effect. A disseminated use of self-learning robots, such as the one Amazon has recently sought to patent, in warehouses and transportation dashboard systems will also aid in a quicker response to risk factors.

Another important factor in supply chain response agility is communication between different players. Giannakis [19] proposes a multi-agent-based decision support system that processes big data through a smart monitoring module that triggers a standardized information flow when a disruption risk is detected. The system assigns roles to the different players and the risk management module then allows them to conduct real-time e-business through smartphones and notebooks.

In terms of the specific techniques applied to big data exploration, a recent study [20] compares the effectiveness of different available options. Four groups of methods are mainly compared: traditional statistical analysis, pure machine learning models, data mining as a combination of the two previous groups of methods, and optimization models. The main advantages of machine learning models are stated as their versatility and ability to capture complex behaviors. There are, however, limitations regarding model training time, due to the amount of data available to be processed. A few useful strategies, such as splitting the data into more tractable portions, distributed computing systems and incremental learning with new cases, are offered as an alternative to apply these techniques to big data. Interesting applications explored in this work, specifically in transportation management, are climate threats, traffic flow and arrival time predictions, which are directly related to disruption risks in the supply chain, through differentiating frequent and unusual factors using methods such as Bayesian predictors.

Shang [21] also uses Bayesian models to assess transport risks through a nonparametric model that uses air cargo data from 20 airlines and 1336 routes. The study estimates the state-

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dependent density function of transport risk, contributing to better predictions of arrival time. They are also able to differentiate recurrent risks from disruption risks, which is critical in risk management strategic decision-making.

Papakiriakopoulos [22] compares the performance of six different classification models i.e. Naïve Bayes, Bayes Network, Decision Tree model C4.5, Classification and Regression Trees (CART), Multi-Layer Perceptron (MLP) and Radial Basis Function Networks (RBF) in order to predict if a product is out-of-shelf or available at a certain store. The models are based on historic data from the store, such as mean sales of the product, estimation of the inventory level, size of the store, day of the week, etc. The CART decision tree offered the best test dataset prediction results, with an accuracy of 56%. Naïve Bayes offered good results on the training test, with an 87% accuracy, however showed signs of overfitting due to the test dataset result of 33% accuracy. The hardest products to identify were those with lowest average demands.

Supervised machine learning models have been used, in combination with simulation, to support the supplier selection process [23]. Having reliable suppliers reduces the uncertainty in the supply chain and improves delivery reliability to further clients downstream the chain. By comparing k-Nearest Neighbors and Logistic Regression classification models, and combinations of the two, it was found that the hybrid models have better performance in predicting a supplier's proneness to disruption.

There were also many papers that mention the use of technology in supply chain operations, which can impact supply chain risks, but weren't detailed in this study due to its focus on peripheral subjects, such as the selection of best IT systems to be used in the supply chain management [24], even though they include big data handling and risk management functions.

4. CONCLUSION

The application of Artificial Intelligence in supply chain risk management is a recent initiative, with approximately 80% of relevant work in the field having been published in the past 5 years. Despite it being a recent field, great advances have been made, especially as a result of big data exploration in companies and widespread use of BI systems. Advanced AI branches such as machine learning and robotics have been used to address risk by prediction and early identification of disturbances in the process, respectively, which may lead to disruptions. Abundance of relevant and timely information is the key to risk mitigation in supply chains. The integration of information throughout different building blocks of the chain is also aided by technological advances.

Amongst the most widespread AI tools being used to address disruption risks is the use of natural language processing. It can be used to extract information from social media and other online content about customer satisfaction, through sentiment analysis, and therefore possible demand variations. Text mining can also help identify potentially risky situations or allow an early reaction to disturbances that can be quickly detected online. Other machine learning techniques such as Bayesian predictors, Neural networks, and Decision Trees have been used in disruption prevention and detection.

These tools have been applied to many sources of risk such as traffic conditions, road blocks, flight delays, demand variation, among others. Interesting new topics being addressed are financial risks in supply chain and social risks, which include environmental, economic and social sustainability of the chain. This involves human risk, as exemplified by the truck drivers' strike in Brazil in May of 2018, which led to outages in supplies in many industries such as gas stations, supermarkets, and manufacturing plants, due to protests against fuel prices among other truck driver workforce claims.

An interesting observation is that the use of AI is also adding new types of risks into the supply chain through highly connected systems that are subject to failures, power outages, network instability or cyber-attacks. Future works need to address this new type of risk that might not only re-expose the supply chain to the risks mitigated by the use of technology but have further

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consequences due to rising dependency on systemic transactions and communications to the overall functioning of the supply chain, not to mention the use of highly intelligent systems such as autonomous vehicles.

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