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Highlighting the Importance of Considering the Impacts of Both External and Internal Risk Factors on Operational Parameters to Improve Supply Chain Risk Management

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ABSTRACT Operational risk management in supply chain activities is important for the successful achievement of the desired outcomes. Although it is an active area of research with an aim of improving a firm's success in its operations, a drawback of existing approaches is that they analyze it from only the perspective of events local to the supply chain. In this paper, we argue that it is also important for firms in a supply chain to consider external events as they will directly influence the internal ones and use various real-world examples of the risks in different processes of a supply chain as justification to prove our point. We then consider supply chain risk management not only as an operational research process, as do all the relevant survey papers, but a data science problem to gain deeper real-time insights for information risk management. Then, we suggest directions for future research that will assist supply chain risk managers to undertake better supply chain risk management processes.

INDEX TERMS Supply chain risk management, supply chain resilience, supply chain dynamics, big data, decision analysis.

I. INTRODUCTION

Since the performances of supply chains (SCs) are uncertain as a result of unexpected changes in their supply processes, the concept of SC risk management (SCRM) has been developed as a means of mitigating their risks [21], [25], [30] by executing strategies to manage them and reduce a SC's vulnerability to them [42], [85]. Many researchers have proposed definitions of a SC risk; for example, [30] defined it as ''the prospect and influence of surprising macro and/or micro level proceedings or conditions that poorly impact any portion of a SC yielding to irregularities, strategic level failures, or tactical or operational''. SC risks are broadly classified as operational and disruptional [12], [21], [83]. Operational risks involve uncertainties related to providing a supply that satisfies demand and result from insufficient or unsuccessful processes, people and/or systems, such as quality and/or delivery issues. Disruptional risks focus on disruptions that occur because of human-made or natural disasters, for example, earthquakes, floods and terrorist attacks. As, because of its uncertainties, a disruptional risk is unpredictable, it is difficult to control and manage, and requires business continuity management while an operational one is relatively more manageable because it can be predicted from past events [12].

Our focus in this paper is on operational risks related to a SC's operations which can be categorized as, for example, those pertaining to material, supply, product and information flows, which relate to different functions of a SC's operations [21], with their different sub-categories related to a SC's various internal and/or external sources. Operational risks arising from internal sources are due to the different levels of commitment to information flows, finance, product and/or demand between any two partners who do not follow a defined Service Level Agreement (SLA). On the other hand, the operational risks of external sources are

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caused by deviations in these sources which result in them occurring in a different way from that defined in a SLA. In other words, they are a result of the environmental factors at different locations which impact on SC partners and their capabilities to adhere to the terms of the relevant SLA [9]. Although some methods in the literature attempted to deal with such types of external risk as disruptions to operational factors by building resilience into their operations [61] most adopted a reactive approach that handled disruptions after they occurred. While this makes sense for risk events of the type 'unknown', for others, such as emerging risks and 'known', SCRM can be improved by adopting a proactive approach using an information open-loop SC in which local firms consider not only the readily available key information but also the complementary external information related to them and their suppliers for operational risk management. Using such an approach, events which may negatively affect the key operational performance factors are identified beforehand at the earliest possible time in order to be managed before they can detrimentally impact on the goal. Most recent studies that considered operational risk examined only the internal sources of a SC [13], [49], [81], [88].

In this paper, we argue that, to achieve an effective operational risk management process, it is very important to also consider the external sources of risk. To achieve this objective, organizations should have the capability to identify, capture, process and use external information before merging it with internal information to ensure better operational risk management. Despite the importance of this, very few studies have actually proposed models that considered the impact of external factors on operational risk [20], [52], [91]. The few methods which adopted a proactive approach for dealing with disruptive events, changed the SC's structure before a disruption occurred [34], [58]. However, while these methods ensured the continuity of a SC's operations during disruptions, as they did not analyses, anticipate and manage events on a real-time basis, they could have had a detrimental impact on the goal. There is some anecdotal evidence that companies have used such analytics with real-time data in combination with an existing information system to obtain a better-informed SCRM model [92]. Specific to SCRM, DHL emphasized the need for it to have such data feeds of global incidents to achieve better impact assessment and mitigation of its SC's operations [18]. However, no studies with a professional and scientific rigor have specifically examined techniques that could enable logistics companies to obtain a complete picture of uncertainties for better SCRM.

Our aim in this paper is to highlight for risk managers the need to consider external events (where possible) and grant them equal importance to internal ones when undertaking an informed analysis of operational SC risks. While some researchers have discussed the need for an end-to-end view of a SC, to date, no methods for achieving this have been proposed in the literature. The rest of this paper is organized as follows. Section 2 discusses the classification of operational risks and the need to maintain visibility not only across a SC but also outside it to ensure an informed SCRM. Section 3 presents a survey of the literature on risk management approaches for the various SC processes from a visibility perspective. Section 4 highlights the implications for risk managers of ignoring external events when conducting SCRM and Section 5 presents our suggestions for future research in this area. We summaries this paper in Section 6, emphasizing some new directions for SCRM research.

II. CLASSIFICATION OF OPERATIONAL RISKS IN SC MANAGEMENT (SCM) AND NEED TO CONSIDER EXTERNAL RISKS FOR BETTER SCRM

The process of risk management can broadly be classified as risk identification, assessment and mitigation. The first is the process of identifying risks that will be managed by reducing the vulnerabilities faced by the SC [73]. Determining uncertainties can reduce a SC's non-adherence to the terms of its SLA and then be assessed in the risk assessment step by determining the likelihood of a risk event occurring and its impact [27]. Risk management is the process in which the strategies and methods used to reduce or eliminate undesirable risks are developed [30]. Measures can be directed towards decreasing the severity of a risk's consequences, minimizing the likelihood of a risk occurring and reducing an organization's exposure to risk [30] using approaches such as behavior-based management techniques, building strategic associations with suppliers, gaining the early involvement of suppliers and/or adopting business continuity planning as a proper risk [44], [60].

The first key step that needs to be performed well in SCRM is risk identification that is, identifying the factors or events which have the capability to disrupt a SC's operations defined in the SLAs. While SC operational factors can be categorized in many different ways, this paper uses the six broad classifications proposed by [63]. Rangel et al.'s literary review also highlights the lack of consensus among the authors surveyed on the types of operational risks that affect a SC which lead to difficulties in identifying the point in a SC where there is a particular risk. Existing approaches for determining risk events for SCRM could include every step in the sub-categories of risk management shown in Figure 1. Operational risks would be included in the SC processes of plan, source, make, delivery and its internal stages. According to [63], the 'plan' process covers the activities related to planning the demand, supply, capacity and resources to achieve the best outcome, the 'source' one to purchasing the required materials, including selecting suppliers, the 'make' one to transforming the materials into products and/or services, the 'delivery' one to ensuring the proper transmission of orders to relevant organizations upstream that will result in the timely production and subsequent delivery of goods, the 'return' one to the return of products and/or services, and the 'other' one to factors such as the environment and culture, that is, those not directly related to the SC processes of product and service delivery.

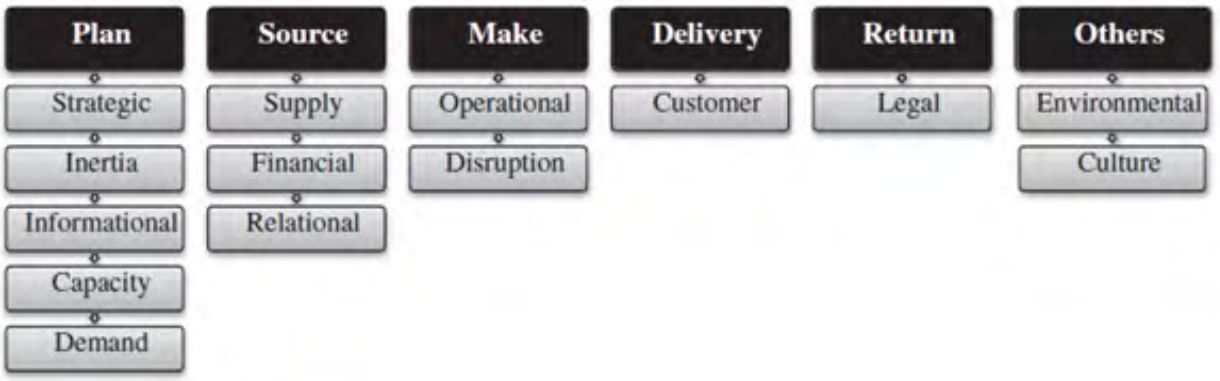

FIGURE 1. Classifications of operational risks in SCs proposed by Rangel et al. (2015).

A. SC VISIBILITY AND NEED TO CONSIDER IT FROM THE PERSPECTIVE OF EXTERNAL EVENTS

An organization in a SC is responsible for achieving the expected outcomes in at least one or a combination of the areas in Figure 1 while also considering the factors that may impede it from doing so. SC visibility is defined as ''the extent to which actors organizations within a SC have access to or share information which they consider as key or useful to their operations and which they consider will be of mutual benefit'' [46]. It has several benefits, including improving responsiveness to changes in supply and demand, obtaining a clear view of the entire SC, decreasing business risk and enhancing a SC's collaboration and performance [39]. It is dependent on the extent and scope of the information being shared and its theoretical background is based on two theories, namely, the Resource Dependence Theory (RDT) and Relational View (RV). From an organization's perspective, the first relates to the collection of information that will affect that organization's behavior, that is, it indicates the dependency of an organization on others for critical resources and concerns it collecting the information important for it to realize its expectations. The RV studies the inter-organizational relationships of a SC as a source from which to obtain a competitive advantage while sharing resources between SC partners assists in coordinating their benefits [41]. It examines how the formation of such relationships assists an organization to acquire resources to reduce its uncertainties and interdependencies [29]. Reference [39] explained that these schemes for SC visibility have led organizations to engage in either collaborative behavior, where companies are willing to share information with their partners to leverage social capital or opportunistic behavior where they maintain some degree of information asymmetry to control the behaviors of their SC partners.

Our objective in this paper is not to differentiate between RDT and RV but to emphasize the need for SC visibility by gaining a broader view of information that includes external events in order to achieve better SCRM. In this respect, the RDT premise is beneficial for organizations as it demonstrates their levels of dependence on their immediate responsible entities, as shown in Figure 2 for two service providers, 1 and 2, which are dependent on hub 2 that, in turn, is dependent on hub 1. From the perspective of the service provider 1, current SCRM methods which analyzed the risk of failure focused on using only information local to the SC and related to the SLAs (from hub 2). As depicted in Figure 3, while this would assist SCRM by considering internal events, it would not make a SC immune to events external to it and would impact on its partners (hub 2) committing to the factors defined in the relevant SLA. In other words, better SCRM could be achieved when, rather than being able to see only events internal to a SC, each organization also considered external ones that would impact equally on an upstream partner's capability to commit to the defined SLAs.

The majority of approaches proposed in the literature managed only SC risks that impacted on the performance of a SC partner [12], [30], [55], [80] and, in most cases, controlled and managed those which arose from factors internal to the SC [6], [16], [65], [67], [72], [86]. In the classifications of operational risks proposed by [63], Table 1 shows what types assist in the management of SC operations, with those that do not depend on the performance of the SC's partner, namely, external events, not considered. However, they are important as they impact directly or indirectly on internal risk classifications and their objectives; for example, as an external event, such as an increase in the price of a particular product due to environmental factors, significantly impacts on an entire internal SC process, it also affects well-managed risk management tasks in the local process, such as planning (plan), sourcing (source) and manufacturing (make). Although it is evident that organizations may adopt some processes to deal with them, how they do so is unknown. In the next section, we use examples to demonstrate the need to consider external events that negatively impact on the operational factors of risk.

III. OVERVIEW OF RISK MANAGEMENT AND CLASSIFICATION OF OPERATIONAL RISKS IN CONTEXT OF SCS

A. RISK MANAGEMENT APPROACHES FOR PLAN PROCESS

The plan process in SC operations is important for planning the demand, supply, capacity and resources required to achieve the best outcome and guiding the other

FIGURE 2. Networked view of SC showing interdependencies among different partners.

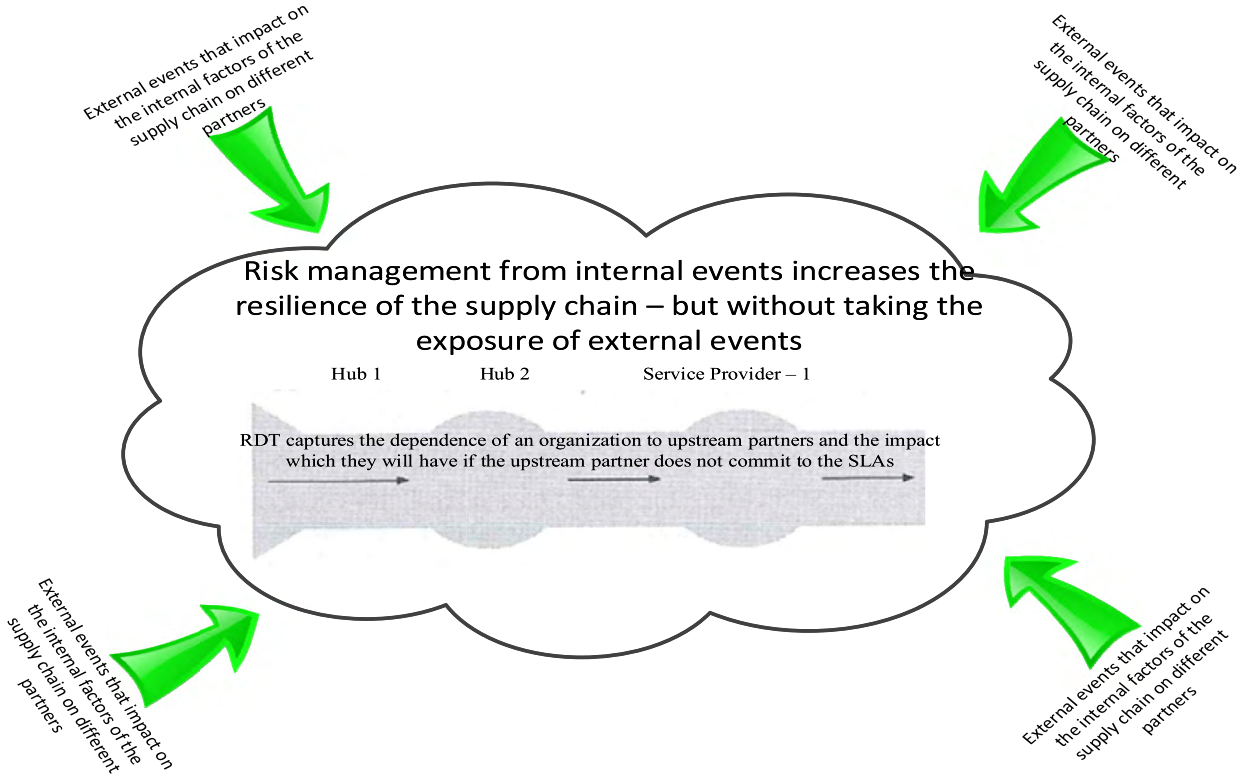

FIGURE 3. Emphasis on need to consider both external and internal events and their impacts to achieve better SCRM.

decision-making processes [63]. According to [38], managing risks in the plan process of a particular project requires controlling them at acceptable levels. Reference [50] identified different risk types that occur in the plan process and discussed how they could be analyzed and managed. According to [63], these risks can be categorized as five types: *strategic; information; capacity; demand;*and*inertia*. Table 2(a) defines each type, including its scope and how it

TABLE 1. Internal and external operational risk types in SC.

Type	Description
	Internal risk types (Rangel et al., 2015)
Plan risks	occur in input information regarding demand and supply, capacity and resources
Source risks	occur while collecting information and materials in the planning process of SCM
Make risks	occur while obtaining resources transformed into products and/or services
Delivery risks	occur while requesting and transporting order/product
Return risks	occur when receiving material flows, services and/or products
	External risk types ('supply chain risks', April 2017)
Environmental risks	emanate from outside SC, are often related to social, economic, governmental and climatic factors and lead to additional supply and demand risks
Business risks	occur as a result of external factors that impact on management stability, suppliers' finances, and/or supplier firms' sales and purchases
Physical plant risks	occur due to events impacting on condition of supplier's physical facility and regulatory compliance

can be addressed. As can be seen, although several studies in the literature defined, assessed, mitigated and predicted these different types, as shown in the last column, they did not consider the external factors that affect them.

To consider such external events, the visibility of an organization's SC needs to be expanded, especially in the techniques used to assess and manage risks. According to [47], increasing visibility leads to various positive impacts, such as increasing the trust between organizations and better management of risks. This is particularly relevant to the plan process as it will assist organizations to analyses events that have an impact on SC risks before they occur and enable them to identify possible weaknesses in their SCs and develop emergency plans, thereby making a better management of such risks a reality. Such an analysis could then be used by organizations to adapt their mitigation efforts and more effectively minimize the impacts of risk events. An analysis of existing approaches for modeling, identifying and resolving plan-based risks showed that they used concepts such as fuzzy theory, distribution function in tandem models and probabilistic functions with known distributions to model supply and demand, as shown in Table 2(b). However, as can be seen in the last column, their common drawback was their limited access to SC visibility which affected their capability to make better, well-informed SCRM decisions.

B. RISK MANAGEMENT APPROACHES FOR SOURCE PROCESS

The *source* process in a SC relates to the purchase of the required materials, including the selection of suppliers. To successfully achieve its objectives, it is important to manage risk at several levels. According to [63], the risks affecting this process can be classified as three types, namely, *supply, financial* and *relationship*, which, as they considerably affect the output of the source process in terms of factors such as cost and quality [22], [36], need to be managed. Table 2(c) defines each type of risk in this process, its scope, events it addresses and the consequences of not considering those related to external factors.

As can be seen in Table 2(c), the current research presented in the literature addressed different aspects of source risks, for example, [74] developed a conceptual framework for understanding the relationship between risk and KPIs from the viewpoint of a network of firms in order to address, maintain and reduce risks by forming flexible contracts among/between members. However, a key aspect that was ignored was the absence of SC visibility of external events which, as shown in the right-hand column in Table 2(c), led to disruptions in SC operations, resulting in outcomes such as the accumulation of excess stock. Not considering external events, especially in the source process, meant that the impacts of political events were also ignored despite their inherent natures possibly being agents for change that could impact on the capability to achieve/obtain the overall scope of a SC.

Some researchers [12], [47], [65] used a variety of techniques to identify and mitigate SC risks in the source process of SCM while others [7], [30] integrated techniques from operational methods and financial instruments to measure and address them. However, as shown in the right-hand column in Table 2(d), although existing approaches helped to identify and manage source-based risks from an international perspective, they were incapable of identifying, assessing and managing those arising from external events. In other words, they did not provide external visibility of events that may greatly affect SC operations during the source process.

C. RISK MANAGEMENT APPROACHES TO MAKE PROCESS

The next classification of risk in the SC is the *make* process, the scope of which [63] defined as the use and transformation of the materials obtained into products and/or services. The success of this process is crucial for achieving customer satisfaction as well as determining and improving the flexibility of the SC by decreasing costs and increasing assets. As the two types of risk that affect this process, which are classified as *operational* and *disruptional* [63], influence a supplier's capability to satisfy the anticipated customer demand, they need to be addressed and managed. Table 2(e) presents definitions of each type of risk in this process, its scope, the risk events the authors discuss and the shortcomings of their not addressing those related to external factors.

There are approaches in the literature for identifying, measuring, reducing and forecasting the operational risks in a SC cycle; for example, apart from categorizing SCRM research from 2003 to 2013, [30] focused on defining operational risk, and its types, factors and management/mitigation strategies.

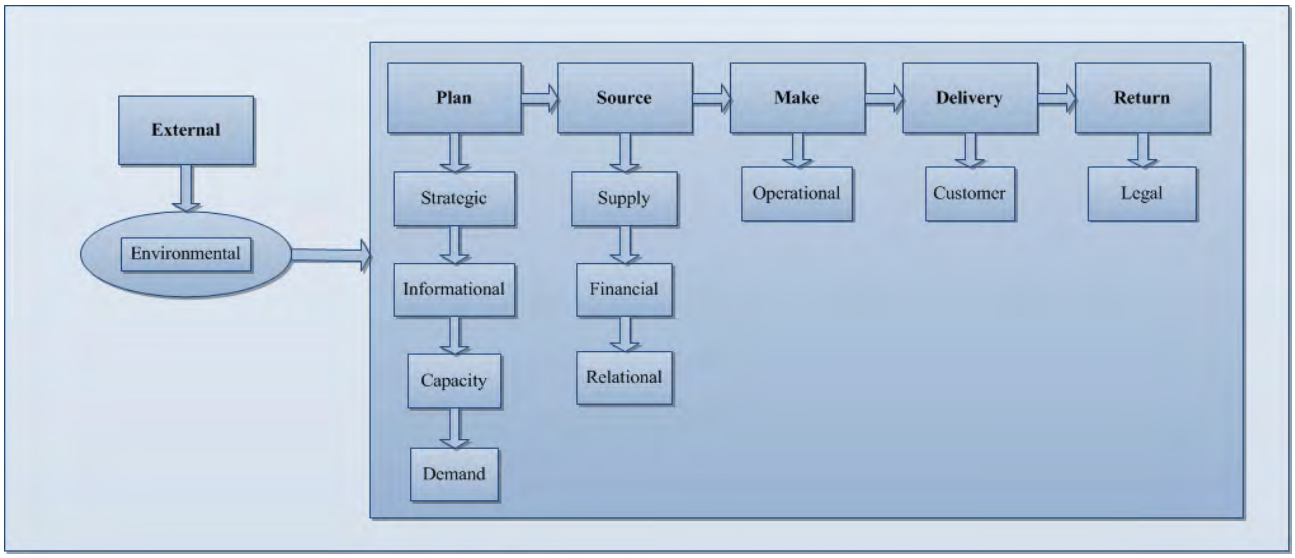

FIGURE 4. Importance of considering both external and internal risk classifications for better SCRM (link between internal and external risk events could assist in identifying risk factors in SCs).

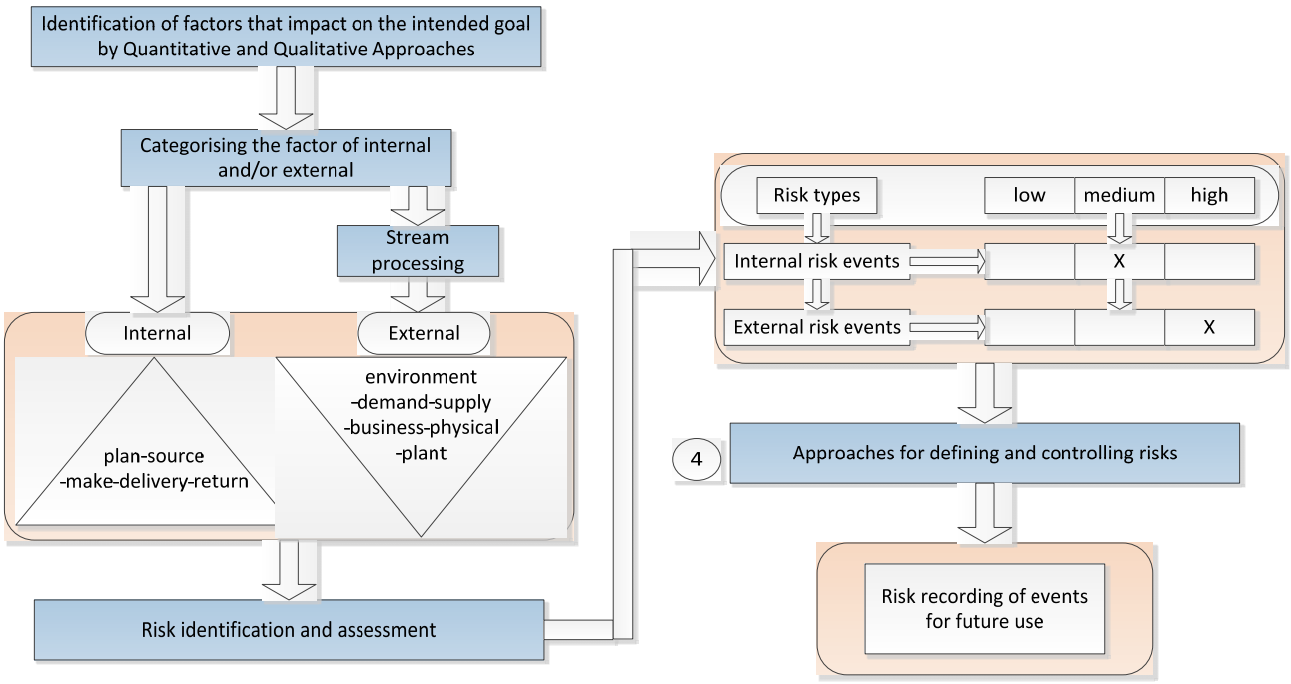

FIGURE 5. Considering both internal and external information in SCRM for identifying and mitigating risk events in SCs.

Other studies, such as that of [12], considered it using a variance-based view to decrease it in the supply and demand processes of a SC through three kinds of collaboration, namely, those of suppliers, internal events and customers. However, as shown in Table 2(e), while existing approaches measured and managed the operational risks arising between internal partners, they broadly failed to consider events external to a SC and determine their impacts on internal processes which leave them vulnerable to disruption and failure. One way in which this can be addressed is by measuring the correlation between the related factors of operational risks that provides their interconnections and interdependencies. Once the external events that affect a certain factor have been identified, this interconnectedness can be used to ascertain their overall impacts on a SC and manage the resultant operational risks. However, approaches that first capture the external events related to factors and then determine their interconnectedness have not yet been developed.

TABLE 2a. Risk types in the SCM *plan* process.

Process	Types of Risk	Author	Definition	Summary of approach used	Example of impact which the external risk events can cause
Plan	Strategic risks that lead to variances in SC including financial risk, downside risk and variance risks.	(Huang & Goetschalckx, 2014)	Reducing the risks by strategically proposing the design of the SC.	Design the SC of a metallurgical company according to the customer demand. Reduces the risks by expanding configuration, as additional capacity is available to respond to changes.	According to a report in May 2017, a strike at an indefinite strike by Chilean customs officials has paralyzed operations of nation's commerce with neighboring states and had a significant impact on operations (MarEx, 2017). This real-world example shows that while existing approaches may be used for designing efficient SC still they are susceptible to operational risks arising from external factors. Hence they need to be considered.
		(Zomorrodi, 2016)	Any phenomenon that highlights the presence of uncertainty in the activity that affects the outcome to be	In the presence of organizational SCs, the importance of risk management in the different classifications of risks proposed by (Rangel et al., 2015)	
		(Snyder et al., 2016)	Disruptions that are caused by natural disasters, intentional and non-intentional actions.	Summarizes different operations research and management science techniques for dealing with disruption risks by sourcing flexibility, facility locations, and interactions with external partners.	
	Information risks that lead to less information about materials and products causing uncertainty in product quality	(Stadtler, 2015)	Identify and avoid the devastating ripple effects that disasters or even minor business disruptions can have in a SC.	Identifies the factors that lead to risks arising from information flows across the SC and develop a plan to manage them.	In Brazil March 2016, Nestlé had to publicly admit a lack of visibility and information shared to external customers and stakeholders because of an incident of potential slave labor. This caused Nestle to lose approximately $600 million (Utkedu, 2017).
		(Heckmann, Comes, & Nickel, 2015a)	The fear of losing an investment.	Highlights the heterogeneity present in having a clear understanding of risk present for its assessment in the SC. Identifies the core elements and types of risks required for its assessment.	
	Capacity risks that impact the achievement of high volume commodity items.	(Snyder et al., 2016)	Lack of flexibility to change with demand.	Identification of critical suppliers and gather supplier intelligence at the company. Summarizes various OR/MS approaches for this process.	In May 2017, sales and operations planning teams of IBM admitted disruptions in the steering gears used in BMW's *1, 2, 3,* and *4-Series* compact cars that made customers return many cars. Reports pointed to the supply disruption which was caused by a bottleneck at an Italian company that supplies the casings for Bosch's electronic-steering systems (Cnbc, 2017). This example shows considering the external information apart from satisfying the demand of capacity to ensure that the
	Demand risks that is a result of uncertainty in the customer demand.	(S. K. Kumar, Tiwari, & Babiceanu, 2010)	Possible deviations from the desired outcomes that reduces at different levels the value added activities.	Using computational intelligence approaches models the inter-echelon process of flow of materials between a SCs. These parameters are modified when the input factors change to adapt the shift in the flow of resources. External factors such as change in the currency are taken into consideration.	When iPhone launched, Nokia failed to identify the decline in consumer demand. Due to this, overtime the Symbian platform became outdated and its sales dropped compared to its competitors. This example illustrates the need to consider external factors relating to demand apart from the internal ones only (Wiredcom, 2017).
		(Nooraie & Parast, 2015)	Events that lead to disasters, cause daily fluctuations that will impact demand and supply.	Emphasizes the need to have visibility across the SC for its better management. Proposes a multi-objective approach that captures information across the SC to minimize the SC risk and cost.	
	Inertia risk that affects the complex network of interactions between system entities	(Norrman & Jansson, 2004)	Inability to deal with uncertainties and risks that influence the related activities and resources.	Emphasizes on the need to have close links with suppliers to be proactive in risk management. This is to ensure the OEM does not fall way behind in responding to risks when it occurs. Takes the example of Ericsson in justifying the point.	In March 2000, Ericsson suffered huge losses because a small fire affected one of its supplier. Even though Ericsson was informed about the fire the lack of it being proactive in the management of risk, arising from this event led to a loss of $400 million. On the other hand, Nokia who was dealing with the same supplier was proactive and avoided losses to the extent as experienced by Ericsson.
		(Bellamy & Basole, 2013)	Scenarios that influence organizations to decrease operational costs and provide satisfactory service.	Presents the SC network strategy and dynamics to study the SC system and address the risks in them.	

Many researchers [7], [12], [30], [47], [65] have used integrated techniques from operational methods and financial instruments to measure and address such risks. As shown in Table 2(f), [16] investigated the role of flexibility and social responsibility in minimizing potential operational risks while [31] used knowledge acquisition as one factor to

TABLE 2b. Summary of recent approaches for plan process and their shortcomings (gaps) from perspective of visibility across the supply chain.

Author	Scope of risk analysis	Techniques used	Gaps
(Chiu & Choi, 2016)	Reducing risks through optimal design of SC	Optimisation and identification of all pareto optimal configurations	The proposed approach was not immune to external events that negatively impact on a SC.
(Mangla et al., 2015)	Proposing techniques for 'green SC' by focusing on sustainable production and resource conservation	Fuzzy analytic hierarchy procedure, with qualitative and quantitative studies to determine/anatomise known risks for defining their importance of anxiety	Although the risks in a green SC were considered, external events were ignored.
(Giannakis & Papadopoulos, 2016)	Identifying SC risks from environmental, social and economic pillars	Analysis of failure mode and effect method for sustainable risk management	While environmental risks, the most serious types for various businesses, were considered, external events, which could have great impacts, were not.
(Samvedi, Jain, & Chan, 2013)	Considering comprehensive risk index limited to available information of SC	Fuzzy analytical hierarchy process (AHP) and fuzzy techniques for defining risk levels	Fuzzy values were modelled from only the perspective of a SC's internal events.
(Badurdeen et al., 2014)	Presenting SC risks at organisational, industry and external levels	Bayesian theory-based approach for analysing conditional relationships between SC events	External events, which could impact greatly on relationships in a SC, were not considered.
(Aqlan & Lam, 2015)	Defining risks originating in manufacturing environment	Bow-tie analysis and fuzzy inference methods	External risks that could impact on business operations were not considered.
(Wu et al., 2017)	Capturing SC risks from social media	Fuzzy and grey Delphi methods for determining reliable attributes that specify uncertainties	Capacity and operations, which had greater impacts than other SC characteristics and are risks that prevented processes occurring, were difficult to detect and control.

reduce them. However, as shown in the last column in Table 2(f), although these approaches assisted in reducing operational risks, the scopes of these authors' analyses were limited to events internal to SCs whereas, as external ones would also have an impact and disrupt operational processes, there is a need to capture, analyses and manage them.

D. RISK MANAGEMENT APPROACHES FOR THE DELIVERY PROCESS

The delivery process in a SC begins when an order is placed, after which it is necessary to ensure the proper transmission of information to different organizations upstream for its production [63]. Risks in this process can arise from any event that affects the supply of a product or service to a customer that has an impact in terms of cost and timely delivery. As mentioned by [11], the sourcing and supply of products and services to businesses and consumers are becoming increasingly complex and need to be managed appropriately. According to [63], the risk in the delivery process is classified as the *customer* type, as shown in Table 2(g).

Several methods for addressing delivery risks have been proposed in the literature; for example, [49] and [88] modeled, quantified, mitigated and solved problems arising from uncertainties that affected the delivery process. Reference [6] designed a network of SCs that included several capacitated distribution centers and retail markets that supplied multiple products under uncertainties. They considered a separate group as potential sites for distribution centers and retail outlets and investigated the impacts of the strategic decisions made. However, while these approaches helped to address the uncertainties that may influence the delivery process, they did not consider the full suite of those arising from events external to the SC, as shown in Table 2(h), and some used techniques such as fuzzy theory and stochastic models.

As shown in Table 2(h), these approaches focus mainly on addressing the uncertainties related to supply, demand and processing, and determining how to manage them better to alleviate the risks arising in the delivery of products. However, as shown in the last column, these approaches failed to consider events external to SC and the impacts they would have on the delivery process.

E. RISK MANAGEMENT APPROACHES FOR THE RETURN PROCESS

Activities in the return process are related to the sale of products or services, including the receipt of material flows, off-specification, dissatisfaction among customers, issues arising from maintenance, and repairing, recycling and

TABLE 2c. Risk types in SCM *source* process.

Process	Types of risk	Author	Definition	Summary of approach used	Examples of impacts of external risk events
Source	Supply risks arising from humans that cause supplier adulterations and cyber attacks	(Harland et al., 2003)	Risks which arise in sourcing of goods due to organizations' lack of visibility of risk to which actors in network exposed or might potentially become exposed	Develops iterative risk management-focused tool that aims to improve process of managing risk from network's point of view	In August 2016, Australia experienced Census Fail debacle. The contracting company IBM failed to adequately test technology and protect the platform with DDoS attacks that led the census website to be offline for a substantial period (Dudley-Nicholson & Bickers, 2017). Later investigations determined that the company failed to consider this external factor as an event that could disrupt the process. This could be an external risk event using cyber-attacks to disrupt the technology that improve the process of SCs.
		(Fahimnia, Tang, Davarzani, & Sarkis, 2015)	Threats caused by multiple sources of inherent uncertainties that influence operations	Classifies existing literature into eight different clusters. However, most focus on analyzing internal events for informed risk analysis	
	Financial risks that have sudden impacts of either increasing or decreasing product prices	(Heckmann et al., 2015)	Potential loss experienced due to SC not achieving its efficiency and effectiveness target values due to uncertain events	Analyses SC from economic perspective, emphasizes need to manage risk by balancing requirements to satisfy efficiency and effectiveness objectives and mentions risk attitude and time-driven aspects as important factors for consideration	BMW Group in spite of growing sales in countries like China, India and Russia experienced serious drops in its profits by changes in exchange rates when converted to Euro. The impact of exchange rates was estimated to be between €2.4bn between 2005 and 2009. This example shows the importance of considering external events in managing financial risks (Wwwftcom, 2017).
		(Wuttke, Blome, & Henke, 2013)	Risks related to financial factors that negatively affect buying firms in SC	Proposes two categories of FSCM to avoid risks in upstream and downstream tasks but analyses only tasks related to factors within SC	
	Relationship risks resulting from lack of cooperation and exchange among partners that may cause performance failures and reduced trust	(Tang & Musa, 2011)	Events which, despite having small probabilities of associated risk, will result in huge consequences when occurring suddenly	Presents literature review that emphasizes need to have end-to-end view of SC to proactively manage risks and mentions need to form strategic decisions and relationships	In October 2016, Aviva was the highest-profile example of this category of risk. It was fined because it failed to ensure adequate controls and oversight of how client money was outsourced (Risknet, 2017). This scenario showed how companies in a chain are impacted by the external workings of their partner companies.
		(Dekker, Sakaguchi, & Kawai, 2013)	Risks that can be alleviated by formal contracts that align parties' interests by coordinating them across boundaries	Presents hypothesized model for improving relationships among SC firms that manages risks in transactions influencing trusted partners with which to collaborate and various control practices that can be used to manage these relationships	

re-using products [63]. Another definition of *return* involves all the activities related to it, such as evasion, gatekeeping, reverse logistics and elimination [54]. Reference [74] defined the risks that occur in this process as being of the *legal*type, as shown in Table 2(i).

Studies by [52] and [86] identified and measured the risks in a SCM's return process while [86] investigated the roles of different factors in the context of varying risk scenarios. More importantly, these relationships were examined regarding two serious risks: legal ones of the rule of law; and supplier ones of non-compliance. While these factors may be related and important for facilitating the return process across the SC, as shown in Table 2(j), the techniques used in these analyses were limited to events within the scope of particular SCs. While they would assist in addressing the risks, they would not be immune to any external event with the capability to introduce many vulnerabilities that could impact on the return process across the SC.

F. RISK MANAGEMENT APPROACHES FOR OTHER PROCESSES

Reference [63] consider that, as factors such as the environment and culture are not directly related to the SC processes of product and service delivery, they are categorized as 'other' processes. Risks associated with environmental factors are defined as events that can influence the SC from outside and are usually economic, social, governmental or technological in origin [14], [63]. They are very common

TABLE 2d. Summary of recent approaches for source process and their shortcomings (gaps) from the perspective of visibility across the supply chain.

Author	Scope of risk analysis	Techniques used	Gaps
(Tang & Musa, 2011)	Categorises risk issues and mitigation techniques in SCRM	Quantitative models that define challenges of, and methods for mitigating, SC risks	This study demonstrated that the lack of information visibility prevents the identification and modelling of SC risk events.
(Bandaly et al., 2014)	Develops integrated technique in SCRM for scrutinising price variability and beer demand uncertainty	Arbitrary optimisation and statistical analysis approaches for defining levels of risk aversion, demand fluctuation and volatility of aluminium charges	Multinational and non-financial risks were simulated with no evidence that information about them was collected.
(Li et al., 2015)	Describes mechanisms for participating in and sharing risk information to enhance financial fulfillment that can be supported by collaborative features	Theoretical model for analysing relationships among firms	Although information sharing is significant for defining internal and external SC risks, this study did not consider them.
(Riley et al., 2016)	Identifies internal incorporation/cooperation, information sharing and training model that point predecessors to organisations' caution and recall capabilities	Q-sorts and confirmatory factor analysis approaches for improving new warning and recall measures	The authors did not consider longitudinal data that included external factors of SC to align supply with demand.
(Lavastre, Gunasekaran, & Spalanzani, 2014)	Proposes theoretical architecture that can aid in decreasing negative influence of risks on SCs and recognise crucial success management for SCRM	Qualitative approaches in terms of hypotheses that demonstrate negative effects of SC risks	The model did not measure risk events and to what extent the internal and exterior ones were negative for the SC procedures.
(Selviaridis & Norrman, 2014)	Assigns and handles risk among prescribed associations across service SC	Risk analysis using agency concept and logistics facility across SC	Even the causes recognised as external to a supplier's control were not considered.

TABLE 2e. Risk types in SCM *make* process.

Process	Type of Risk	Author(s)	Definition	Summary of approach used	Example of impacts of external risk events
Make	Operational risks that result in financial losses, impact on production quality or give rise to delivery problems	(Sayed & Sunjka, 2016)	Disruptions that arise from internal and external factors and impact on performances of constituent entities	Presents framework that has facilities and logistics relationship as key elements for handling SC risks in management of operations	In February 2016, hackers exploited vulnerabilities in the Bangladesh Bank to carry out one of the biggest-ever cyber heists. It demonstrated how external factors, such as cyber-attacks, threaten the operations of SCs and hence need to be monitored (Gopalakrishnan & Mogato, 2017).
		(Tandon & Mehra, 2017)	Events that can lead to failures of organisations worldwide which, if not addressed, will result in losses, such as material, financial and reputational ones, that will then have systematic impacts on others	Presents key factors required for increased operational risk management in Indian banks to ensure efficiency	

and can directly affect all the internal processes of the SC ("supply chain risk," April 2017). However, as is clear from our discussions in earlier sections, it is vital to study operations external to a SC in order to define the potential

TABLE 2f. Summary of recent approaches for make process and their shortcomings (gaps) from perspective of visibility across the SC.

Author	Scope of risk analysis	Approaches used	Gaps
(Daultani et al., 2015)	Explores functions of flexibility and social relationships with alleviation approach which realises operational risks in SC	Multi-period network equilibrium model and finite-dimensional inequality formulations taking into account stakeholders' targets of increasing revenue and decreasing risk	The SC risk was measured in the process of SCM without considering its impact on the entire processes of SC.
(Alexander, Walker, & Naim, 2014)	Investigates decision theory (DT) perceptions in relation to SCM to define operational risks	Abductive technique uses/deliberates two DT concepts for sense-making and decision analysis	A broader approach for managing SC risks using DT while also considering external events was not implemented.
(Hora & Klassen, 2013)	Tests influence of organisation-level factors on knowledge acquisition to measure companies' financial losses	Randomised vignette-based model for determining implications	This study suggested that senior managers need to develop organisational systems and training without defining how this knowledge acquisition could enable the estimation of SC risks
(Ambulkar, Blackhurst, & Grawe, 2015)	Determines wayin which SC disarrangement-oriented companies can promote flexibility	Qualitative Churchill's methodology for making up and assessing reflective scales	This study did not explore firm resilience with different risk types that would clearly reveal the impact of an external disruption on an entire SC.
(Sarker, Engwall, Trucco, & Feldmann, 2016)	Investigates reasons for silo-based risk management pursuits across various organisational levels in most multinational manufacturing firms	Theoretical lenses of limited intellectuality and eventuality theory to illustrate how variations in perceptibility create silo-based risk management procedures	The interdependencies of internal and external SC risks were not determined.

TABLE 2g. Risk types in SCM *delivery* process.

Process	Type of Risk	Author	Definition	Summary of approach used	Example of impact external risk events can cause
Delivery	Customers cancelling their orders impacting on supplier and increasing unpredictability	(Stephan M. Wagner & Christoph Bode, 2008)	Disruption affects SC's performance in terms of its chances of occurring and consequences	Determined relationship between SC's risks and performance	Severe weather conditions in early 2014 resulted in delayed transportation and exposed the lack of adequate contingency plans of many companies (Businessinsidercom, 2017). While such external events cannot be avoided, by using real-time information, companies can develop alternate risk mitigation plans to avoid disruptions.

TABLE 2h. Summary of recent approaches for delivery process and their shortcomings (gaps) from perspective of visibility across SC.

Author	Scope of risk analysis	Approaches used	Gaps
(Baghalian et al., 2013)	Jointly studies order- and supply-side uncertainties to identify capacitated preparation services/tools and delivery centres	Randomised mathematical equation for designing network of SCs that can model multiple products	Building a network assembly of a multi-product SC requires examining the influence of external environmental factors on the SC's internal processes.
(Chen et al., 2013)	Defines three kinds of risks, namely supply, demand and process, associated with supplier, customer and interior cooperation as method for alleviating them	Relationship scheme verified using data gathered from 203 industrial firms in Australia	No theories that estimate the relationships among risk types and how external events impact on them are proposed.
(Heckmann et al., 2015)	Describes existing methods for measureable SCRM that concentrate on defining SC risks and its ongoing processes	Statistical mechanism in SC for defining impact of internal risks	This study confirmed that there is no mechanism that can define potential risks and assess their effects.

risk events emanating from them. Some recent studies emphasized the need to consider shared information but did not consider that of external environmental events, as shown in Table 2(k).

TABLE 2i. Risk types in SCM *return* process.

Process	Types of Risk	Author	Definition	Summary of approach used	Example of influence that the external risk events can effect
Return	Risks arising from various factors, such as legal ones caused by firms breaking laws and regulations; for example, not meeting the agreement for product quality	(Mollenkopf et al., 2007)	Inability to link marketing and logistics due to process for managing returns	Presents qualitative methodology and causal model that integrates organisation's functional requirement, supply chain orientation, strategic policies and external factors to ensure effective returns process	Severe weather conditions in early 2014 resulted in delayed transportation and exposed the lack of adequate contingency plans of many companies (Businessinsidercom, 2017). While such external events cannot be avoided, by using real time information, companies can develop alternate risk mitigation plans to avoid disruptions.
		(Shenoi et al., 2016)	Failures of SC to choose right product, right place and appropriate delivery time which are classified as supply coordination and disruptions risks	Identifies critical factors of risks across SC and mitigation strategies from perspective of manufacturer, with SCRM framework classified into risk sources, performance measures and mediation strategies while mentioning regulatory, legal and bureaucratic factors among others as important to address	

TABLE 2j. Summary of recent approaches for return process and their shortcomings (gaps) from perspective of visibility across SC.

Author	Scope of risk analysis	Approaches used	Gaps
(Wiengarten et al., 2013)	Explores role of risk and risk management exercises in achieving SC cooperation in terms of effects on cost and efficiency	Cross-country survey and secondary country data for identifying variations in value of SC combinations according to risk to accompanying businesses and reduction in effect of SCRM	A serious limitation is the lack of information visibility, i.e., the dataset used to evaluate the risk models did not provide information about response rates and the likelihood of risk.
(McGregor & Smit, 2017)	Identifies SC risks of adverse human rights impacts of operations of majority of businesses	Systematic due diligence program for corporate governance and questionnaires to show what other businesses doing that works and practical steps for governance boards	As this study did not provide a practical approach that could be used to estimate the impacts of internal and external risk events, there was no approach for measuring and identify risk types in SCM.

Risks associated with cultural factors are defined as those events that arise from differences among languages, people and attitudes towards conducting business [63], including factors such as managing and maintaining the reputation of a SC organization for its sustainable performance. This was considered by [37] who applied the logic of bounded rationality to manage the reputation of a corporation and achieve sustainable SCM which confirmed that reputational risk is an important factor in a company's decision to implement sustainable social and environmental management practices in a SC.

IV. IMPORTANCE OF CONSIDERING EXTERNAL RISK FACTORS IN SCRM APPROACHES

In the previous section, we highlighted the wide range of approaches researchers have used to address the diverse types of operational risks in SC tasks and their different techniques for each SC process. While our analysis is certainly not comprehensive or complete, we nevertheless draw on it and the classification of SC risks presented by [63] to highlight the following systemic drawbacks in the SCRM approaches in the literature. They highlight that it is essential to consider both internal and external risk events, for example, environmental factors, in order to effectively manage and control risk events in SCs.

A. TO STOP CONSIDERING A SILO-BASED VIEW OF FACTORS IMPACTING ON SCRM

Existing approaches adopt a silo-based view of the factors that affect risk whereby those related to the risk being managed are immune to the impacts of external events despite studies such as those of [20] and [37] having investigated risk events emanating from external operations and emphasizing

TABLE 2k. Summary of recent approaches for other processes and their shortcomings (gaps) from the perspective of visibility across the SC.

Author	Scope of risk analysis	Approaches used	Gaps
(Wakolbinger & Cruz, 2011)	Analyses influence of tactical information-gaining and -sharing of SC disturbance with SC's effectiveness of risk-sharing agreements assessed	Model comprises three levels of SC players to show attitude of each decision-maker	Despite this study demonstrating that information- and risk-sharing contracts are complementary, it did not discuss to what extent information visibility could help to define the impacts of external risks on SC processes.
(Duhamel et al., 2016)	Determines significance of internal and external cooperation for risk management	Quantitative measures, such as variance and mean, test relationships	Despite emphasising the importance, it did not considers the peripheral collaboration required for better SCRM.
(Zhao et al., 2013)	Investigates experiential relationships among SC risks as well as incorporation/cooperation and firm efficiency in an overall context	Structural Equation Modelling (SEM) and Estimation of Maximum Likelihood (MLE) methodologies validate relationships	While considering the empirical relationships and integrations among SCs important factors, external events and how they impact on an organisation in a global context were not discussed.
(Blome et al., 2014)	Explores impacts of internal and external knowledge on resilience across SC	Qualitative techniques and some surveys measure this influence	The effects of external factors were not considered.

FIGURE 6. Levels at which risk management needs to be considered to achieve informed SCRM process.

that not considering them is still a problem in SCRM. Therefore, as external risk events influence the process of risk management, irrespective of their diverse types, they should be identified and assessed to mitigate risk events in SCs. To facilitate a smooth flow of resources, goods and information across a SC, there needs to be equilibrium with what is happening outside it.

In this paper, we assert that risk managers should consider information both internal and external to a SC for better risk management, as represented in Figure 3 in which it is stated that organizations should have a broad view of information to increase visibility and assist in the better identification and management of risks, with the techniques required to identify these events in SC processes highlighted.

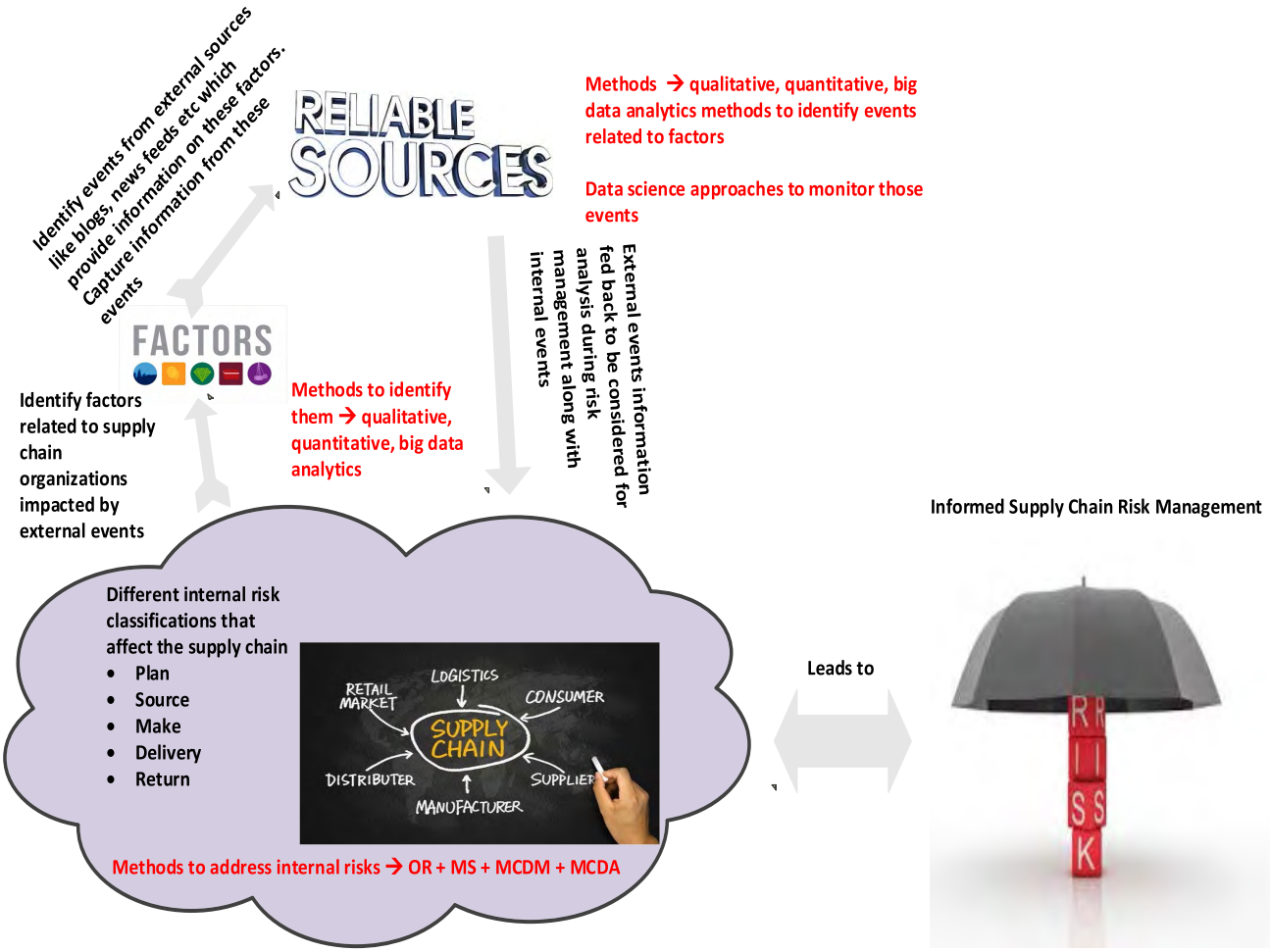

FIGURE 7. Use of external and internal information to improve SCRM and identify risk factors in SCs.

Associating external information with SC processes is proposed in Figure 4, where external and internal risk events that could occur in SCRM are linked. An important difference in this association from that proposed by [63] is that it considers environmental events external to all the SC processes that will affect each separate process. In such a representation, risk managers do not simply take a silo-based approach to external events, as is done currently, but continuously consider relevant information streaming from outside the SC and use it if it is applicable to the SCRM process, as shown in Figure 5.

B. TO CONSIDER SCRM AS DATA SCIENCE PROBLEM

The importance of being proactive in risk management has been stressed in the literature in many different domains and has been achieved in SCRM through the development of various Operational Research (OR), Management Science (MS) and Multi-criteria Decision Analysis (MCDA) methods, as evidenced by relevant survey articles in the literature. A shortcoming of these approaches is that, although they model the information provided to them based on which a risk management or risk mitigation strategy is recommended, our analysis in Section 3 shows that the presumption that information remains the same does not hold true. Data science technique could analyses big data collected from the potential process of SCs in order to mitigate internal and external risk events. Hence, these approaches need to be combined with data science techniques that will enable risk managers to combine their power with OR techniques for the better management of SC risks.

Although some approaches in the literature emphasized the need for Big Data analytics in logistics and SC operations [84], they are focused on using predictive, prescriptive and descriptive processes. While such techniques may provide risk managers with good awareness, unless they are done on a real-time basis, they will not be helpful for risk management. This is because, informed risk management requires risk managers to be proactive in their analysis, which in today's world of data deluge requires the real-time processing of information combined with the traditional qualitative and quantitative approaches for risk management currently in use.

C. TO INCREASE THE LENS OF INFORMATION VISIBILITY TO MOVE FROM END-TO-END VIEW OF SC TO 'SENSE AND RESPOND' ANALYSIS OF INFORMATION

Risk managers need to acknowledge that, in the current era of information overload, risk management can benefit from

TABLE 3. Potential for recent failures in SC operations to be better managed through monitoring of related external events.

Event	Impact	News providing early warning of incident
On 24th May 2017, an indefinite strike by Chilean customs officials paralysed its operations and had a significant impact on the nation's commercial relationships with neighbouring states	The exporter Rojo mentioned that the movements of goods worth five million U.S. dollars a day to and from Chile were impacted, causing the private sector to lose money and the entire SC to be paralysed (Santiagotimescl, 2017).	In a statement long before the strike, the National Association of Customs Officers (ANFACH) said that the Government had ignored previous agreements signed on May 2015 and November 2016 by submitting a counter-proposal which did not take into account the commitments made with customs workers (Fletcher, 2017) By using this information, risk managers could have identified this as a risk factor in their assessment models before using OR techniques to model them and, thereby, reduce the impacts when the strike occurred.
Nokia did not respond to the change in demand for the iPhone (Wiredcom, 2017)	The Symbian platform aged over time and its sales decreased compared with those of iOS and, later, Android.	In this case, by using external information such as Google Trends, Nokia could have determined how the demands of its competitors had increased while, at the same time, those for its products had dropped. By using this information, risk managers could have developed plans to arrest the sliding trend before it became a problem.
In 2015, automakers in the Indian city of Chennai were forced to shut down production due to heavy rain.	They faced a loss of Rs 180 crore (Rains, 2017) and, while such disasters cannot be avoided, it was mentioned that the response to such events could be better by reducing their impacts and protecting economic growth through obtaining information from outside the SC for use in developing plans for risk management.	In this case, external online data from the available weather datasets and prediction tools, such as deep-learning methods, could have been used to provide an early warning of events that could impact on operations and better manage them.

an increase in the lens of information visibility. Rather than taking only an end-to-end view of a SC and using OR techniques to model and manage the risks that start at Level 2, as shown in Figure 6, risk managers need to adopt a 'sense and respond' analysis of external information that directly feeds into the analysis models from Level 2 upwards. The current literature [3] highlights the integration of OEM with tier-level suppliers but fails to consider external information while other researchers, such as [80], emphasized the need to better manage the information flow.

It can be seen from the analysis presented in Tables 2(a) to (j) (Section 3) that existing approaches for risk analysis in each SC process adopt either a qualitative or quantitative approach to risk management, with none combining existing methods and data science as input that feeds into the OR/MS/MCDM/MCDA model, as identified as their drawbacks. Recent work has begun to use Big Data analytics to help risk managers increase their lens of information visibility which will enable them to be aware of external events and consider them on a real-time basis in order to be proactive and make informed and timely decisions regarding risk management. Figure 6 illustrates how risk managers should first use qualitative and quantitative approaches to identify the factors indicating external events that need to be monitored and then use data science techniques to capture them before feeding that information into Level 2 and above where OR/MS/MCDM/Big Data methods can be used to discover hidden insights that will lead to better SCRM.

V. SUGGESTIONS FOR FUTURE RESEARCH ON SCRM USING DATA SCIENCE TECHNIQUES

The modern Web's fascinating range of tools, such as social media and news feeds, provides organizations in SCs with valuable information that can be read, understood, shared and used for their operations. It has become a 'laboratory' for understanding the pulse of humanity and, to make sense of large social and information networks, a range of techniques has been proposed.These approaches fall within the research area of Social and Information Network Analysis (SINA). Figure 7 shows how these data science techniques can be conjointly used with existing OR/MCDM/MCDA methods to inform risk management in SCs. Using such models to analyze data allows SC managers to understand and differentiate behaviors between information of interest and expected phenomena to gain insights.

The following approaches have been applied in many different areas.

Organizations listening to customers' product reviews to reinvent themselves: recently, many organizations have restored their profits by changing their ways of operating in response to what their customers have said in reviews [64]; for example, Best Buy, Nascar and Yahoo took the proactive step of paying attention to this external information and translating it into action. Other recent works, such as that of [53], adopted the perspective of new product developers and scanned external information in the form of product descriptions of related products to identify which of their

features could be used in future versions of the reference product. In a SC, organizations can apply these techniques to observe shifts in customer demand for new products and then use this information in their planning and sourcing processes.

Using real-time information from sensors to recommend changes to avoid disasters: while every organization makes its operational plans according to its goals, progress has also been made by recommending changes based on the real-time monitoring of information to avoid disasters, for example, [92] developed an approach for monitoring driver fatigue and determining its level on a real-time basis which transportation companies could use to ensure that drivers showing symptoms of fatigue were not allowed to continue driving. Similar devices have been applied successfully in high-end luxury cars, such as the Mercedes Benz Attention Assist System [40], and healthcare services [48], [59]. An organization using these techniques can observe deviations occurring in its SC's parameters and take proactive steps before there is a detrimental impact on its operations.

Using real-time information from news feeds to change operational plans to achieve success: there have been many cases of companies relying not only on published information but also regularly updating their knowledge as real-time information was obtained to ensure they achieved success. A study by City College of New York [35] showed that the ridership of New York buses increased by around 2% from January 2011 through December 2013 because transit riders were provided with real-time updates about their bus's status rather than having to rely on the printed timetable available at a bus stop which allowed them to be less stressed and plan their activities accordingly. Similar initiatives have been adopted by other transportation companies; for example, the Transport Canberra (http://www.nxtbus.act.gov.au/#/liveDepartures) website allows customers to search for live departure times 90 minutes in advance. This also enables car drivers and users of GPS systems to re-route their journey if informed of a deadlock or traffic jam on their current planned path. In a SC, organizations using these techniques can be more agile in terms of changing their operations to meet their expected outcomes which will help them in their *make*, *delivery* and *return* processes.

Table 3 presents examples of circumstances in which the operational risks from the real-world incidents mentioned in Section 3 could have been managed better if external events had been considered as part of SCRM. It is clear that these events play an important role, not only in achieving the predefined operational goal but also in ensuring that those that occur after that goal has been formulated are negotiated before they have a detrimental impact. It can be seen from the survey of risk management approaches presented in Section 3 that none of those used in SCRM incorporates data science techniques as inputs to capture external information prior to the use of the OR/MCDM/MCDA model for risk assessment and management. As shown in Figures 6 and 7, we stress the need for risk managers to employ such an input process and consider risk management as a combined process of data science and existing operational research-based approaches for obtaining an informed SCRM. To achieve the abovementioned vision, research needs to be carried out in numerous directions, with the following providing some suggestions.

(a) Develop a taxonomy of common factors in a SC and link them to events emanating from external sources from which related information can be captured. Although these factors are organization-specific, as Figure 7 shows that there is possibly some commonality among them across SCs, they could be used by different organizations.
(b) Following the development of the above taxonomy, use qualitative approaches and conduct interviews with practitioners and CEOs to identify and monitor organization-specific factors and related external events that impact on the operations of their organizations. Another research question is using quantitative and bid data analysis approaches to analyze data of past major disruptions and use it to identify factors which need to be monitored.
(c) Although numerous data science techniques to capture information on a real-time basis such as network graph, knowledge graph, sentiment analyses, are used widely in the literature, not all are applicable for every scenario. The challenge is to identify the most beneficial combination of technique and analysis that achieves the required objective.
(d) To achieve research objective (c), a pivotal requirement is not only to have the required data but also to acquire it in the correct format at the right time which falls under the categories of data representation, management and access, and the timely processing of information. Appropriate techniques need to be developed that will enable risk managers to use relevant data in a short timeframe that is beneficial for managing SC risks.
(e) As not all data on the Web is reliable and trustworthy, a key research issue is to study its provenance to ascertain its reliability and trustworthiness before using it for analysis.
(f) While existing risk management approaches use the OR/MS/MCDM model, when new information about external events needs to be considered, the research issue is how to readjust the risk management process so that both streams of information, which are disparate but related, can be rationalized and used for the goal-oriented management of SC risks.

VI. CONCLUSION

In this study, we reviewed the risk classifications proposed by [63] with the aim of making an informed representation of risk management in SCs. Our objective was to emphasize to risk managers the importance of considering external events and their impacts when performing their risk management tasks. While this has been highlighted by some researchers, based on a survey of some current approaches

for conducting each SC process, we concluded that it was not being done which leaves a SC vulnerable to external events, as we demonstrated using real-world examples. We presented our justifications for risk managers to change their practices and highlighted the necessity for a data science approach to SCRM to be adopted conjointly with existing OR/MS/MCDM methods. This would require a systematic shift in focus to combining quantitative, qualitative and data science techniques. Despite big data being applied in SCRM, it feeds information to an OR/MS/MCDM/MCDA method rather than embracing a data science perspective. We propose that organizations need to be more proactive in managing their ever-increasing operational risks that impact on the management of their SCs.

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