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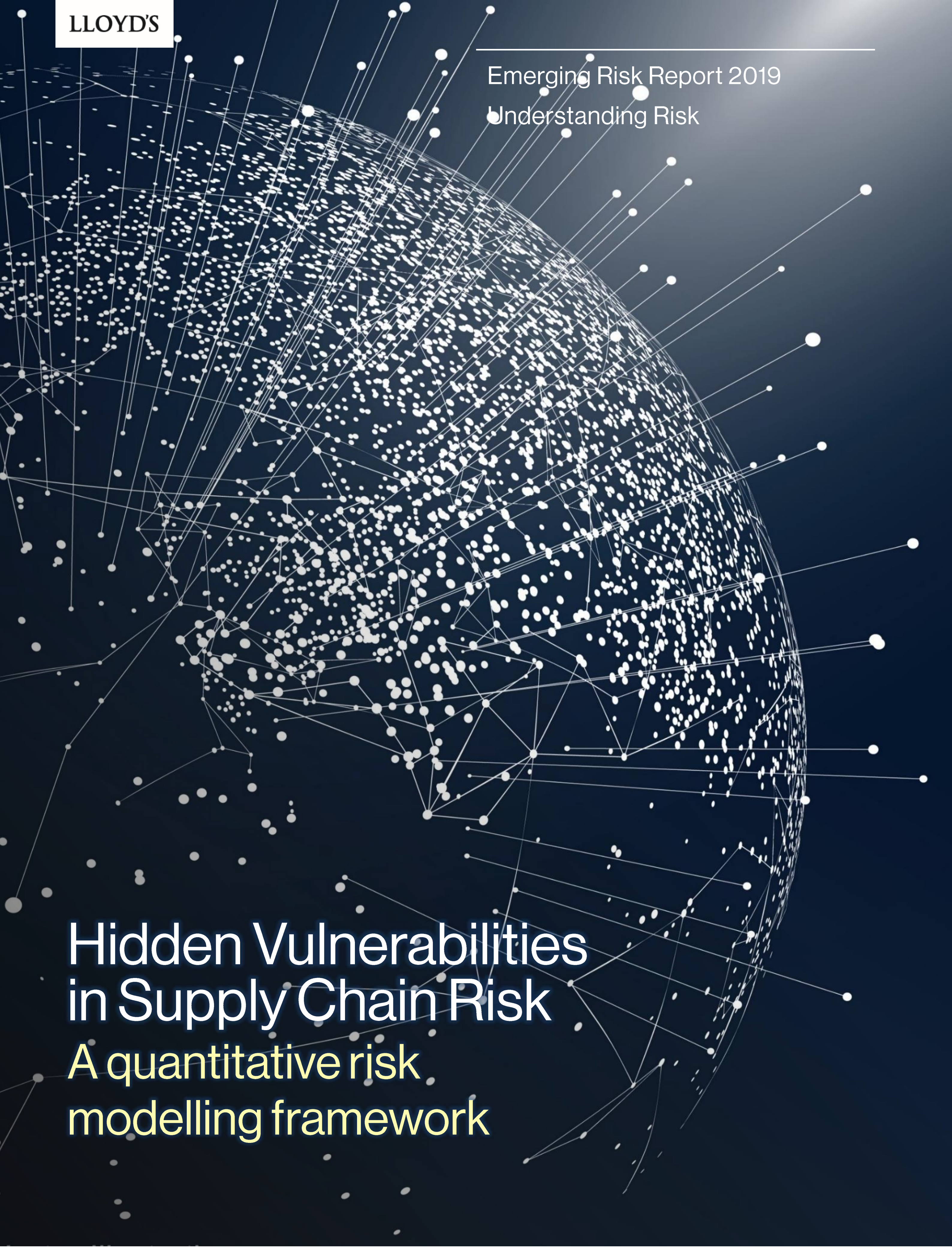
Emerging Risk Report 2019
Understanding Risk



Hidden Vulnerabilities in Supply Chain Risk

A quantitative risk modelling framework

AIR airmic
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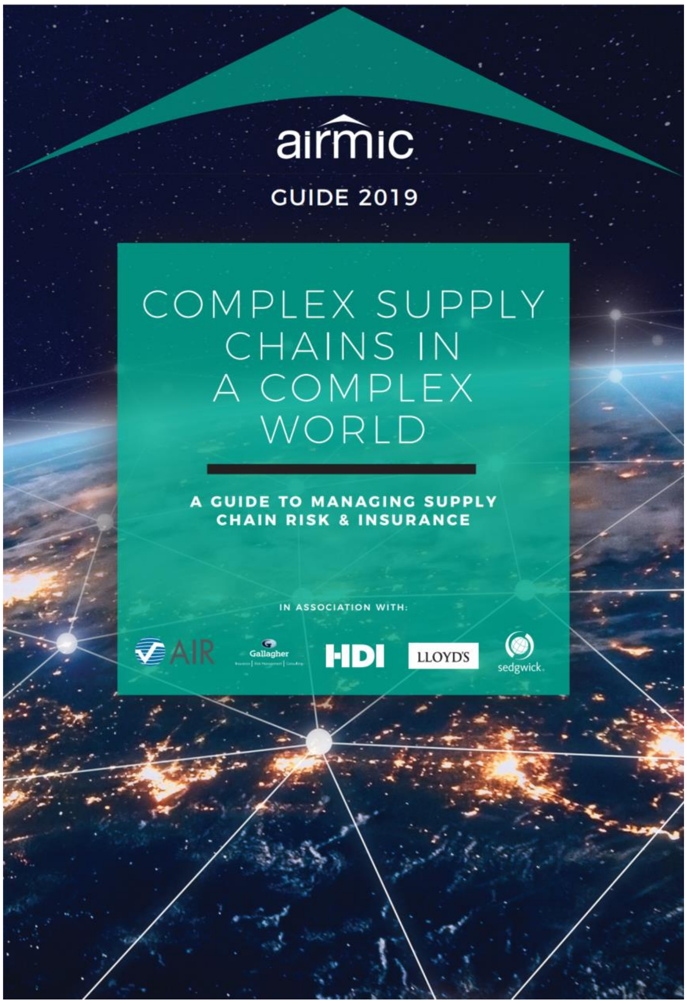
This report has been published alongside Airmic's **Guide 2019 – Complex Supply Chains in a Complex World**



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GUIDE 2019

COMPLEX SUPPLY CHAINS IN A COMPLEX WORLD

A GUIDE TO MANAGING SUPPLY CHAIN RISK & INSURANCE

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Contents

Executive summary

The World Trade Organisation (WTO 2017) estimated the 2016 global trade in merchandise to be around $15.46 trillion. Much of which has been facilitated by the integration of national economies into a global economic system characterised by supply chains.

In other developments, there has also been the adoption of cloud technologies by corporations. A cloud outage or a cyber attack on a company's virtual network can wreak havoc on physical systems and cause huge economic losses. As an example of this, a recent report (Lloyd's Cloud Down 2018) presented a scenario where a 3-5-day cloud outage in the United States could generate $8.6 billion of losses for manufacturing alone.

As the division between physical and virtual supply chains narrows and even starts to vanish, we are seeing the growing importance of managing the consequence of interconnected risks. These risks are made more complex and potentially costlier through the impact of climate change. Rising sea-level and temperatures can alter global manufacturing and procurement patterns.

As supply chains have evolved and become more complex, insuring interconnected business interruption risks has grown more challenging. With a scarcity of historical claims data and the evolution of unforeseen threats in value chains, there are few systematic methods for an insurer or a corporate risk manager to quantify a supply chain's risk and none that are sufficiently thorough to fully foresee future aggregation scenarios.

The 2011 Tohoku earthquake and the Thailand floods highlight the complex interdependencies that exist in today's supply chains. Even companies with exceptional business continuity planning were taken aback by the far-reaching consequences of the 2011 events, which for the Thai floods alone, the World Bank estimated $45.7 billion of economic impact. Although these events have led to advancing the development of qualitative risk assessment tools, there is still a dearth of quantitative risk models to assess value chain risks.

In this study, a five-step quantitative risk modelling framework is proposed to evaluate contingent business interruption risks. The framework leverages probabilistic modelling and predictive methods to bridge some of the existing data and knowledge gaps in assessing supply chain risk.

The proposed modelling framework was first used in a probabilistic setting to assess supply chain risk to the automotive and computer and electronic products manufacturing industries. In the second set of analyses, the modelling framework was used in a deterministic mode to assess a diverse set of scenario events. A discussion on the validation work performed on the modelling framework is included in the report. As an additional insight, the impact of resilience on contingent business interruption was investigated using the framework.

The probabilistic modelling framework outputs quantitative metrics, such as average annual loss (AAL) or exceedance probability curves (EP), which can be used as the basis for indexed risk scores. These indexed scorecards can enable underwriters and corporate risk managers to transition from qualitative faith-based to quantitative data-driven decision-making processes.

While there has been a growing awareness of the potential threats posed by interconnected risks to businesses, the take-up rate of business interruption policies remains minimal. To become resilient to emerging vulnerabilities in value chains, insurers, corporations and risk modelling companies should work together to develop data and analytics products to address market demands. Closing the protection gap before the next catastrophic supply chain disruption is critical for business and community resilience to mitigate the rising threat of interconnected risks.

1. Introduction

Supply chains

Although there is no clear consensus on the definition of supply chains, the Association for Supply Chain Management (APICS) offers this definition:

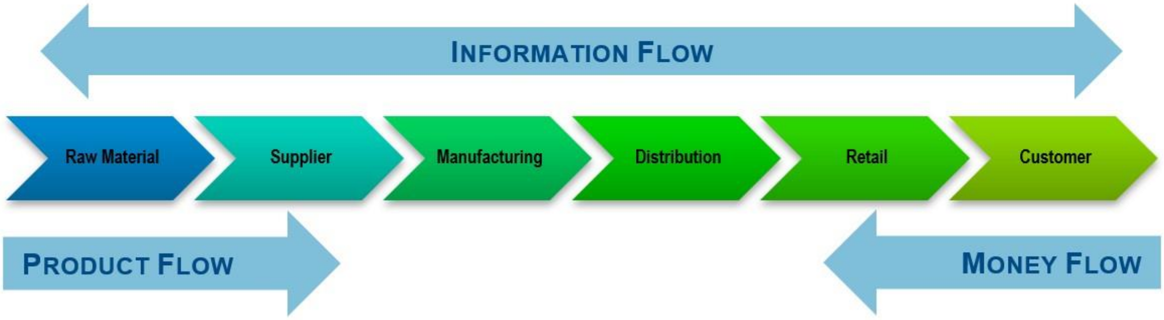
> *"… a network of organizations, people, technologies, activities, and resources involved in moving materials, information, products, and services all the way through the manufacturing process: from the original supplier of materials to the end customer."*

Supply Chain Management (SCM) involves coordinating and integrating the flow of

- Products
- Information
- Finance

from within and among suppliers in the supply chain network of an organisation (Figure 1).

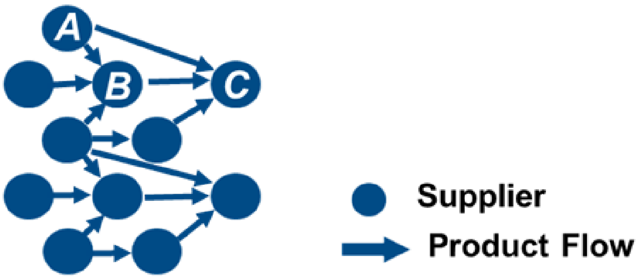
Figure 1: Supply chain process flow



To gain a competitive advantage in a commercial market, businesses continually optimise their supply chains by synchronising material flows and stability with required production volumes.

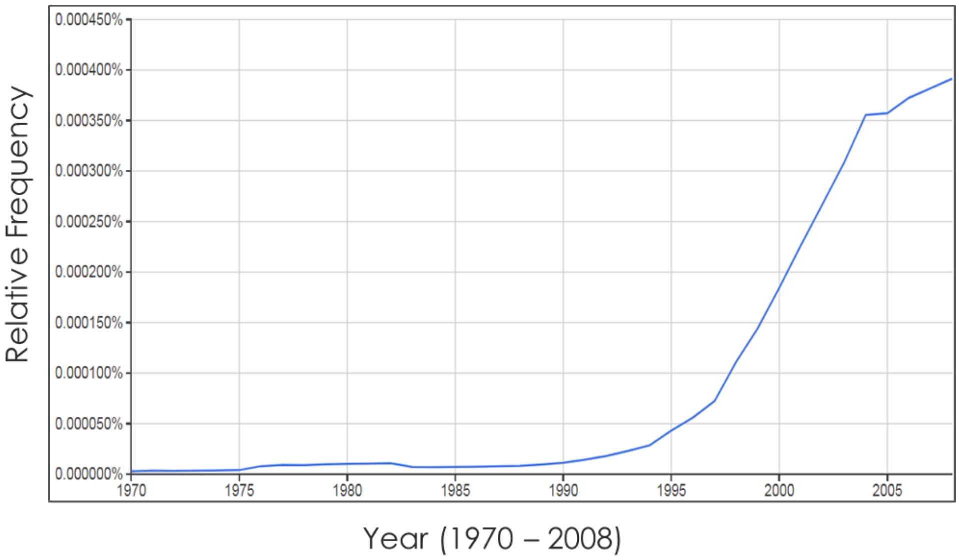
Figure 2 provides an example of a supply chain network, where each node represents suppliers in the network, and the connections represent a direct relationship between the suppliers. Typical supply chain networks are analogous to directed acyclic graphs, which means that none of the nodes and arcs can be traced backwards while following the direction of product flows.

Figure 2: Schematic of supply chain network



Maintaining the function and flow of the network is an operational imperative for organisations to manage their businesses, particularly in the era of "Just-In-Time" and "cost-optimisation" supply chain practices. These two cited manufacturing practices advocate low levels of inventory that are quickly used in production so that minimum costs are achieved with less waste.

Figure 3: Google Ngram viewer analysis for “supply chain + business interruption + contingent business interruption”; Ngram plot shows the relative frequency of a term versus an expression over time



Disruption to any of the suppliers in a network can disrupt the normal working of the network. Even small interruptions can traverse through the value chain and manifest as a significant loss to the chain’s stakeholders. With the complexity of expanding supply networks creating numerous interdependencies and exposures, only recently have progressive companies put their focus on supply chain resilience. To build resilience against disruptions, businesses develop:

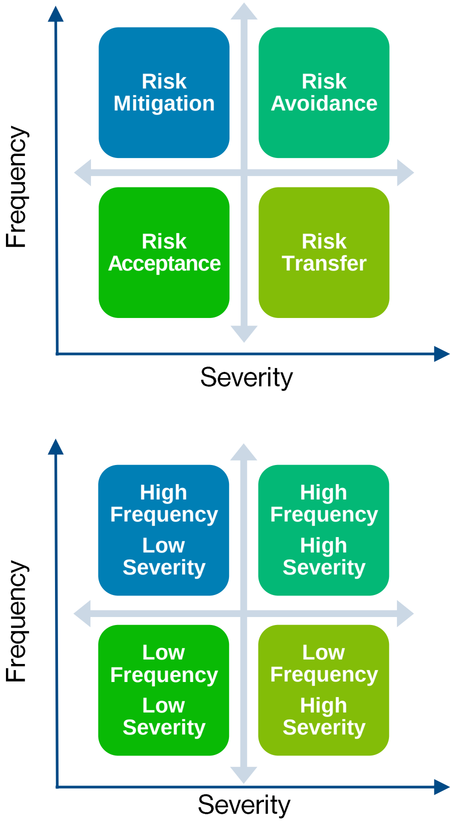
- Reserves (inventory).
- Redundancy (alternate suppliers).
- Resilience measures, as part of the Business Continuity Planning (BCP) process.

According to PwC (2016), companies that include resilience as part of their supply chain management strategy saw market share gains and a 7% premium increase in their stock price. Consequently, the area of SCM has become very popular in the last few decades as evidenced by marked increases in practitioner and academic publications in the field (Figure 3).

There are two important factors to consider in understanding supply chain risk: frequency and severity. Frequency corresponds to the probability of a disruption happening, and severity corresponds to the magnitude of the disruption. For example, disruptions due to power outages could be more frequent compared to a Category 5 hurricane. The resulting economic loss from a Category 5 hurricane, however, could be more severe than the economic loss resulting from a power outage event.

As part of their Enterprise Risk Management (ERM), businesses develop risk management frameworks notionally responding to risk as shown in Figure 4, where low-frequency/high-severity events, (e.g., M_w 8.5 earthquake) generally lend themselves to risk transfer through (re)insurance. Similarly, gauging the potential impact of high-frequency/high-severity events, (e.g., industrial fire), before they happen is also critical for corporations if they are to develop robust risk mitigation strategies.

Figure 4. Risk management framework design



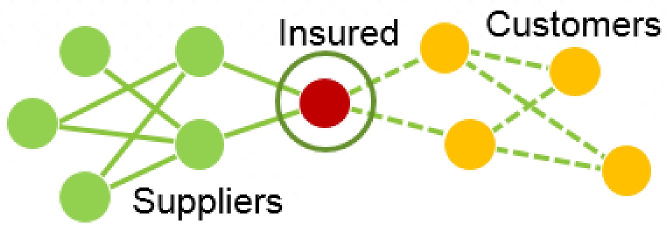
According to FEMA (2019), nearly 90% of smaller companies fail within a year following a disaster, unless they can resume operations within 5 days. After the 2011 Thailand flood, Western Digital's quarterly shipment of hard drives fell by 51%, allowing rival Seagate Technology to capture some market share (IHS Markit 2012).

In summary, prolonged downtimes due to supply chain disruptions can result in significant impacts to organisations, including but not limited to: loss in revenue, brand reputation risk, loss in market share and decline in stock price. These challenges are not new, but they are becoming increasingly urgent in the interconnected world (both physical & virtual), where corporate risk managers are looking for more sophisticated solutions to manage their interconnected supply chain risks that go beyond damage to physical assets. The non-physical risks to supply chains can manifest either as business interruption (BI) or contingent business interruption (CBI) losses.

Business Interruption and Contingent Business Interruption

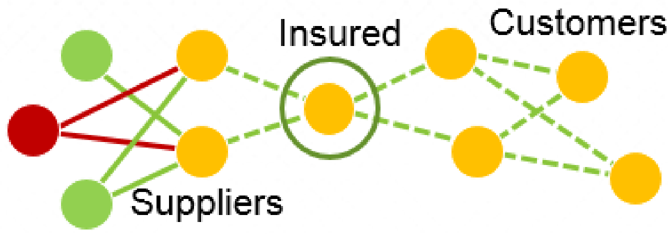
Business interruption (BI) coverage corresponds to the physical damage to the insured's own assets that causes a suspension of business activities and a loss of business income (Figure 5).

Figure 5: Schematic of business interruption loss



Contingent business interruption (CBI) coverage corresponds to the loss of business income caused by a disruption stemming from a member of the network on which the insured is dependent (Figure 6).

Figure 6: Schematic of contingent business interruption loss



In both figures, the red solid node in the network represents the source of disruption. Most insurance companies provide BI & CBI coverage as an endorsement to an insured's property policy. However, some insurers provide standalone CBI policies with limited coverage.

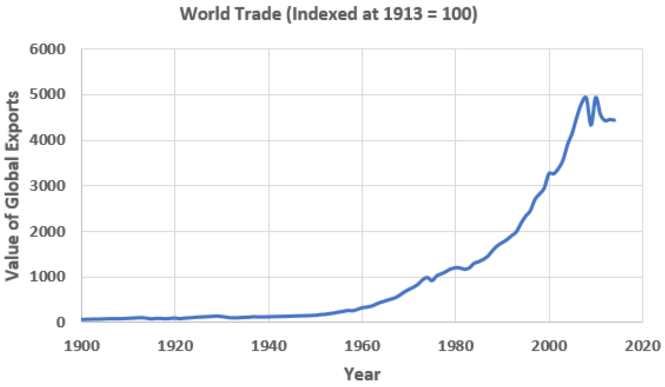
Managing the inherent uncertainty

There is no clear distinction between risk and uncertainty in assessing supply chain networks and hence (re)insurers limit the coverage by offering policies that are sub-limited, covering only "named" suppliers with a designated waiting period or excluding certain risks in some geographies. Typical premium rates for these policies are in the range of 1% to 10%. Policies are available for full supply chains, but these are rare and the supply chain must be simple enough to be fully understood.

Increasing complexity of supply chains

The globalisation of national economies, an economic feature that has emerged over the last century, has resulted in the significant growth in trade among countries. The value of the world's exports over the period between 1900 and 2014 is shown in Figure 7. Exports today are more than 4,000 times larger than in 1913, highlighting the exponential growth of international trade over the last century.

Figure 7: World trade (Estimates are in constant prices (i.e., adjusted to account for inflation) and indexed at 1913 values



Source: Federico and Tena-Junguito, 2016

A modern illustrative example may be: a company retailing in the United States might have its manufacturing facilities in China and Taiwan, with most of its component suppliers located in Europe. Figure 8 illustrates this increasingly complex global footprint for supply chain networks.

Figure 8: Increasing complexity in the global supply chain

The Thailand Flood of 2011 resulted in many claims coming from manufacturers outside Thailand – underlining the complex interdependencies that exist in today's supply chains. To grow and thrive in a highly interconnected world and have adequate financial protection, corporations are looking to CBI insurance for essential protection.

Supply chain events and their economic impacts

The trigger for a supply chain disruption can be either a natural catastrophe (flood, earthquake, tropical cyclone, etc.) or a man-made event (industrial fire, cyber incident, political unrest, port closure, etc.). Every year, supply chain disruptions cost organisations billions of dollars in revenue losses, and these losses are increasing. To manage this growing loss, developing supply chain resilience is crucial. Below is a summary of some recent supply chain disruptions and their economic impacts.

Tohoku earthquake (11 March 2011)

For the Tohoku earthquake, ground shaking was followed by a powerful tsunami; their combined destructive power destroyed many cities in the Tohoku area and triggered the failure of the nuclear power plant in Fukushima, Japan. The affected region contributed 2.5% to 3.8% to the total Japanese economy and comprised approximately 80,000 business enterprises in the tsunami-affected area and 740,000 business enterprises in the earthquake affected zone. The main businesses in the Tohoku region consisted of heavy chemicals for automakers, integrated circuit manufactures, electrical components and telecommunications (Government of Japan 2011; Ono et al. 2015).

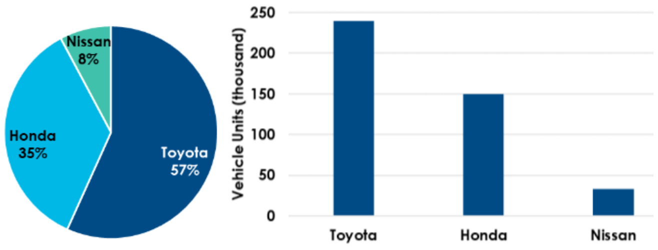
Because of the large amount of damage in the region, production capacity was weakened through direct and indirect business interruption, much of which was caused by lower tier products. In the tsunami-damaged area, over 90% of production capacity was lost by the end of August 2011, when compared to the same month of the previous year. Per Japan's Ministry of Economy, Trade and Industry (METI), the Tohoku region's industrial output suffered declines that year of 47% to over 90% for petroleum products, chemicals, iron and steel. This loss was then propagated to other manufacturers in the Kanto, Chubu and Kyushu regions of Japan where industrial output for transportation equipment (i.e., motor vehicles and parts) shrank by more than 40% (Ono et al. 2015).

Varying lengths of time for recovery were observed. Within Japan itself, some production was recovered for some types of industries, on average, within a month, where 100% recovery was observed within an average of two months; however, the transportation industry took more than three months, on average, to regain full operational status. For overseas manufacturing, in North America for example, some production volumes had to be adjusted down to 20% for over a month at some Toyota locations, while Toyota's China manufacturing production was adjusted down to 30%-50% (Chujo et al. 2013, Ono et al. 2015). In all, economic losses from the Tohoku earthquake are estimated between 210 to 300 billion USD, with insured losses of 35 to 40 billion USD (III 2019a; SwissRe 2012).

Thailand floods (25 July 2011 – 16 January 2012)

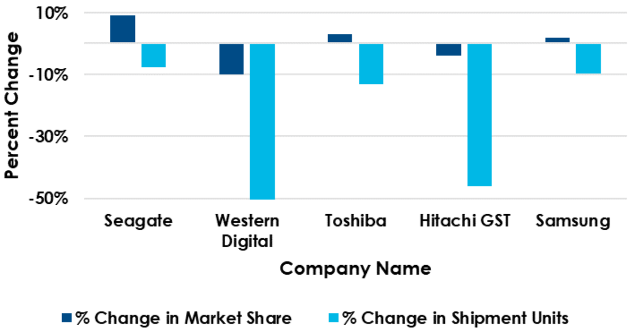
The Thailand floods widely disrupted manufacturing within the country and flood depths of 4-5 meters were reported for industrial parks in Ayutthaya Province (Aon Benfield 2012). In the most severely inundated industrial estates of Ayutthaya and Pathum Thani provinces, draining the floodwaters took up to two months, after which cleanup and recovery for the factories could be started. Measures taken to save inventory and equipment from the floodwaters—such as relocating them to upper floors—were undermined by the high humidity (and contamination) generated by the extensive standing water. The World Bank estimated that an overall economic loss of USD 45.7 billion resulted from the Thailand floods, with the total insured losses estimated at USD 15 billion, as of February 2012 (Baker and Lui 2012).

Figure 9: Production losses for three major Japanese automobile manufacturers as a percentage and number of vehicle units



In particular, the Thailand floods disrupted both the automobile industry and the hard disk drive (HDD) industry. Three large Japanese automakers—Toyota, Honda and Nissan—were hit by losses in vehicle production (Figure 9). Reports cite that the locations were flooded, but much of the production downturn was due to a lack of motor vehicle parts available in the supply chain. Similarly, the HDD industry was affected even though some of their manufacturing locations were not directly in the flooded zones. This was due to product supply dependencies propagating the effect of disruption through from lower tiers (Haraguchi and Lall 2015).

Figure 10: Change in HDD market share and shipment units from Q4 to Q3 in 2011 due to Thailand floods



Five main manufacturers of hard disk drives were directly and indirectly affected from the flooding. Western Digital was forced to shut down factories in Navanakorn and Bang Pa-In for 46 days after they were flooded up to a depth of two meters (Haraguchi and Lall 2015). Other HDD manufacturers that were not directly flooded were then able to make strides in acquiring market share. In Figure 10, a 9% gain in market share was observed for Seagate between 2011 Q4 to 2011 Q3, despite a decrease in units manufactured. Western Digital experienced an approximately 50% decrease in production between 2011 Q4 to 2011 Q3, which translates to a decline of 10% in market share (IHS Markit 2012).

Tianjin industrial fire (12 August 2015)

The Tianjin industrial fire was actually a series of explosions starting with an overheated container of dry nitrocellulose in a container storage station at the Port of Tianjin, China. Fire from the explosion spread, and on August 15 a series of smaller explosions rocked the port. More than 8,000 new motor vehicles manufactured by Hyundai, Kia, Volkswagen, Renault and Toyota were destroyed. Half of Tianjin's stored polyethylene resin was incinerated in the incident; the detonated chemicals stored at the site were excessive quantities of improperly stored sodium cyanide, calcium carbide, ammonium nitrate and potassium nitrate (TIME 2015).

In the aftermath of the fire, 173 fatalities (Associated Press 2015) and 798 casualties (Sohu 2016) were reported. In addition, 304 buildings, 12,428 cars and 7,533 intermodal containers were damaged (Sohu 2016); the cost to businesses was estimated at USD 9 billion (Resilinc 2015), with insured losses at USD 4 to 6 billion (Asia 2016). Some well-known companies affected included Airbus, Caterpillar, Emerson, GlaxoSmithKline, John Deere, Hyundai, Mitsubishi, Motorola, Panasonic, Toyota and Volkswagen.

Kumamoto earthquake (16 April 2016)

A recent earthquake in 2016 shows that manufacturers are still working on shock proofing their supply chains, despite the previous events of 2011.

On April 16, 2016, at 01:25 JST, the Kumamoto mainshock of Mw 7.0 hit beneath Kumamoto City, Kumamoto Prefecture, Kyushu Island, Japan. More than 100,000 buildings were damaged, less than 1% of which were non-residential and non-public structures. Despite this deceptively small percentage of damage, manufacturing shutdowns fuelled a large economic repercussion (APEC 2016). Renesas at Kawajiri (microcontrollers) had been damaged and stopped operations immediately after the foreshock on April 14. And the Aisin Kyushu site (engine and body components) was significantly damaged and was forced to stop production immediately. Aisin relocated equipment, moulds and personnel to 14 different alternative production sites, and restoration of the damaged location was completed in the second week of August 2016. Production then resumed on August 22, 2016 (Aisin 2017).

As a consequence of this supply chain interruption, Toyota had to suspend production for 26 of 30 production lines in Japan and the disruption was expected to cost USD 277 million in operating profits (Forbes 2016). By April 20, Toyota planned to resume production at 18 of the suspended production lines near the end of April. From a study by AIR, CBI losses for Toyota were expected to be 12% of total Japan's automakers' contingent business interruption losses if an assumption of no inventory was used (AIR 2016).

Hurricane Harvey (25 August 2017)

Tropical cyclones are also known disruptors of global supply chains. After making landfall on August 25, 2017, as a Category 4 storm, Hurricane Harvey stalled over southeast Texas, which resulted in unprecedented rainfall and subsequent flooding. The hurricane significantly disrupted Houston's economy by damaging homes, vehicles, businesses and infrastructure. The maximum observed storm surge was more than three meters, with sustained wind speeds of 130 mph (213 km/h) and rainfall in excess of 50 inches in parts of Houston. Organisations located in the flooded area in Texas were mainly categorised as manufacturers of petroleum and coal products, in addition to chemical manufacturing and oil and gas (AIR 2017).

News articles after the event reported that local organisations were estimated to have suffered USD 15 billion in physical damage, not taking into account the economic damage for the region, which was valued at USD 10 billion per week before the hurricane. Preliminary estimates for the total damage from Harvey ran as high as USD 75 billion, which includes both physical damage and economic losses (Houston 2017). Insurance payouts from the hurricane were estimated at almost USD 9 billion for the nine affected states (III 2019b).

Current methods to track supply chains

As “Big Data” quickly becomes the new standard for technology-driven enterprises, advanced data analytics has become one of the key drivers of competitive advantage in many fields, including supply chain risk modelling and mitigation. Corporations are investing heavily in capturing and digitising their supply chains and recording the physical and virtual interconnections between different nodes of their value chains. However, deriving actionable insights from these multi-gigabyte or even petabyte-sized data sets with mixed multi-dimensional variables is challenging. Methods for tracking supply chains range from traditional traceability platforms to new technologies such as blockchain, web-scraping and Radio Frequency Identification (RFID).

Traceability platforms

Identifying and digitising suppliers are now critical steps in the supply chain management process. The hierarchical mapping of suppliers is labour- and time-intensive and consequently does not scale well for complex products. Most companies therefore do not have full visibility into their supply chains. To address the need of mapping and managing suppliers, traceability companies provide Software-as-a-Service (SaaS) or Platform-as-a-Service (PaaS) models to help corporations map suppliers. Using these services, a manufacturer can progressively map one supplier at a time. After mapping their direct suppliers, the platform can then cascade the mapping process through each tier until the end of the supply chain is reached; however, the success of the traceability process is highly contingent on the engagement and participation of suppliers in each tier.

Blockchain

Blockchain technology is a distributed ledger database that is shared and synchronised among multiple users, rather than one central participant. Blockchain technology builds transparency and traceability into the supply chain network. Each record of the blockchain stores data about the product (transactions, shipment, procurement and distribution) across the entire supply chain and makes it possible to share information among manufacturers, suppliers and other vendors.

A blockchain is computationally expensive as the chain grows successively longer with each transaction. Secure by design, a blockchain is decentralised and public so that the data is authenticated by the collective self-interest of all parties. When a blockchain is held privately, which may occur for supply chain applications, transaction authentication becomes centralised to fewer entities, which could lead to human error and record tampering.

Web scraping

Web scraping is another technology that is being increasingly adopted to identify and compile interdependencies across supply chains. Web crawler bots are automated programs that systematically scan the World Wide Web for indexing purposes. For example, after a major supply chain disruption event unfolds, web crawler bots can scan the web to identify all businesses that reported disruption, along with reported downtimes and affected product groups.

Unstructured data from the internet now becomes a structured database from which meaningful inferences about the supply chain may be drawn. This approach is only capable of finding interdependencies after an event arises, however, and is limited to businesses that publish downtime estimates and revenue losses. For companies that want to proactively manage their supply chains, this approach does not capture hidden vulnerabilities or impending risk in their supply chains.

Radio frequency identification (RFID)

Another maturing technology, RFID uses a tag consisting of a microchip and an antenna. The microchip stores a unique serial number, which the antenna transmits to physically track the tag. RFID technology relies on tracking the tag and linking the serial number with associated information on a database through the Internet.

The RFID tags are placed on items involved in the supply chain (individual parts or whole products) and are recorded as they pass through the supply chain. While this method solves the problem of accurate data capture, tracking and traceability, it does not solve the problem of complete data capture, as not all suppliers may participate within a network. Without full participation, there will be gaps in supply chain network mapping.

Although these technologies have advanced our efforts in data capture, mapping and digitising supply chains, we are still far from gaining full visibility into supply chain networks. Artificial intelligence and machine learning are other promising techniques that can help us improve identifying patterns in the various and diverse supply chain data and continually improve our understanding of this risk.

Data and knowledge gaps

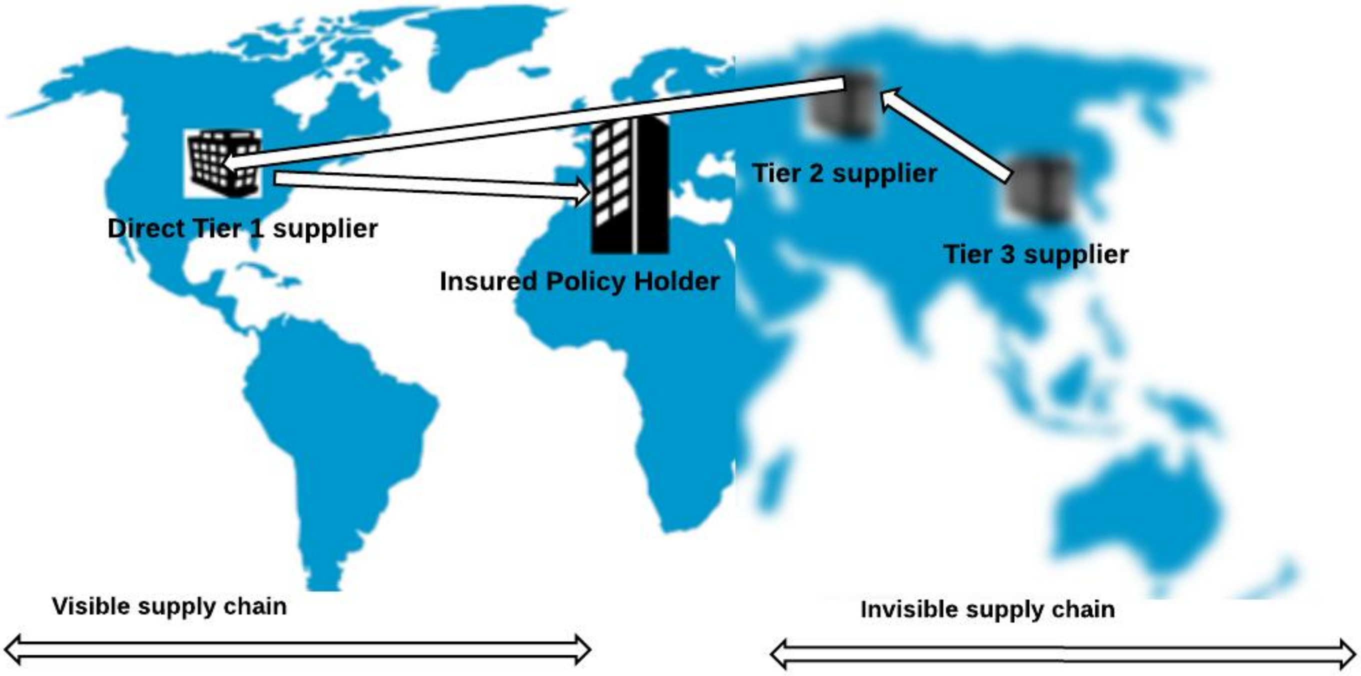
Supply chain data typically resides on disparate and ubiquitous systems across the enterprise, and so coalescing this fragmented data to bring about a partial view of the supply chain is difficult. Corporations tend to look at supply chains more from a “cost” or ”spend” perspective and thus put more effort into mapping out suppliers based on spend. In this process, companies frequently overlook the most vulnerable part of the network from a risk perspective. Current methods to track the supply chain are both time- and labour- intensive and do not scale well for companies that manufacture complex products. Even companies with mature supply chains do not have full visibility into their supply chains (Figure 11).

Typically, businesses employ a piecemeal approach by mapping their supply chains based on reactive strategies after the disruption happens. In a Business Continuity Institute survey of global corporations, nearly 69% of respondents said they did not have full visibility of their supply chains (BCI 2017). According to KPMG, 54% of Chief Procurement Officers admit that their firms don’t have visibility beyond their direct (tier 1) suppliers (KPMG 2014).

An additional survey by Deloitte (2018) indicated that 54% of the final respondents had limited visibility below tier 1 and only 6% of them had full transparency of the supply chain. With limited data on an insured’s supply chain, (re)insurers are often faced with the dilemma of making “faith-based” underwriting decisions. This could lead to severe underestimation of risk and expose (re)insurers to risk aggregation that might be happening in the invisible part of supply chain.

Currently, a typical “Data Standard” for CBI underwriting does not exist in the (re)insurance industry. Developing a data standard would allow the insurance community to identify and harmonise key attributes they need to collect about enterprises to make informed underwriting decisions. In addition, an insurance data standard would create awareness and incentivise the corporate community to start gathering relevant data in return for better policy coverage and premiums. The application of “quantitative” supply chain risk modelling is still in its early stages of research and needs to be actively explored.

Figure 11: Schematic of the invisible supply chain shows visibility receding from the insured policy holder as supplier layers increase



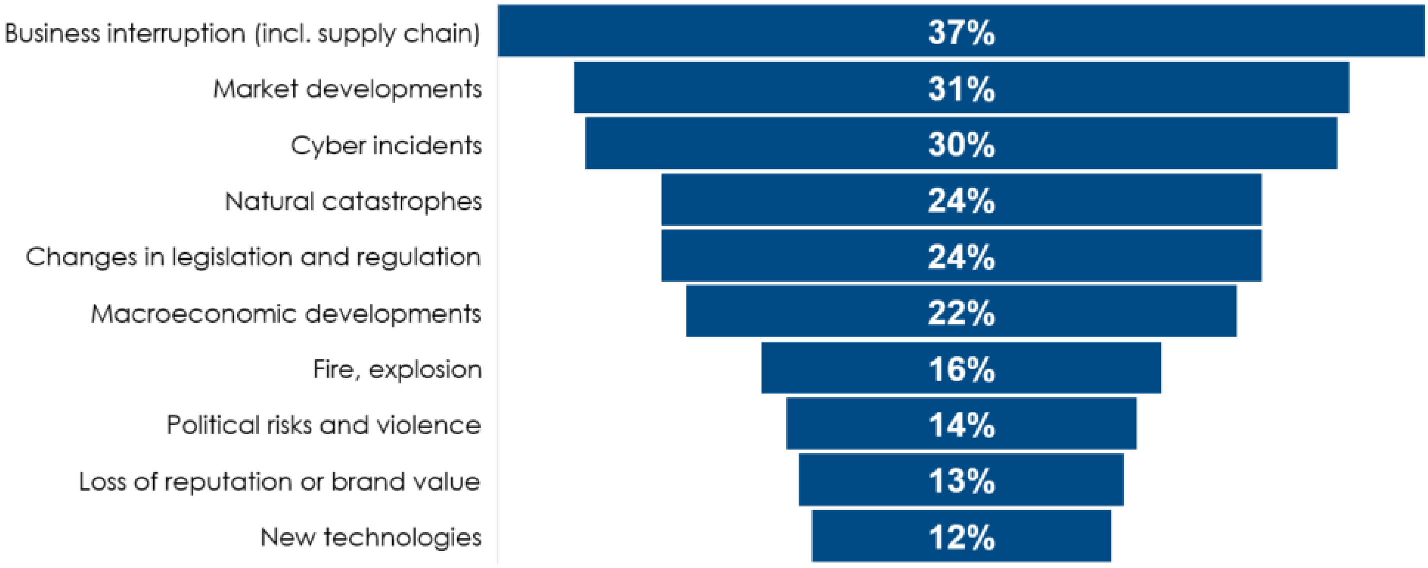
Emergence of interconnected risks

Today, floods on one side of the world affect economies on the other side through global supply chains. Similarly, a disruption to a data centre or a cloud service provider in the United States can result in significant business interruption losses for businesses in Europe and the Asia-Pacific region due to virtual supply chains. Imagine a scenario where a cyber disruption causes a port shutdown:

How could this impact regional and global economies? In this case, the risk is a combination of supply chain, cyber and port disruptions. We are starting to see the rise of interconnected risks and the major impacts they have had on corporations and insurance communities. During both the 2011 Tohoku earthquake and tsunami and Thailand flood events, most of the major claims came from regions outside of the directly impacted areas, which draws attention to the complex interdependencies we see in today's supply chains

According to a survey conducted by Allianz, business interruption (including supply chain disruption) is the top risk for global corporations (Figure 12). From the other top risks identified in the survey, we can surmise that the risks ranked between 2 and 10 can, in fact, be a trigger for a supply chain disruption. Also, analysis of insurance claims demonstrates that BI claims are on average 36% higher than the average property damage claims (Allianz 2017).

Figure 12: Top 10 business risks of 2017 from an Allianz survey of over 1,200 risk managers. Since respondents choose up to three business risks as the most important one for their company in 2017, percentages do not sum to 100%



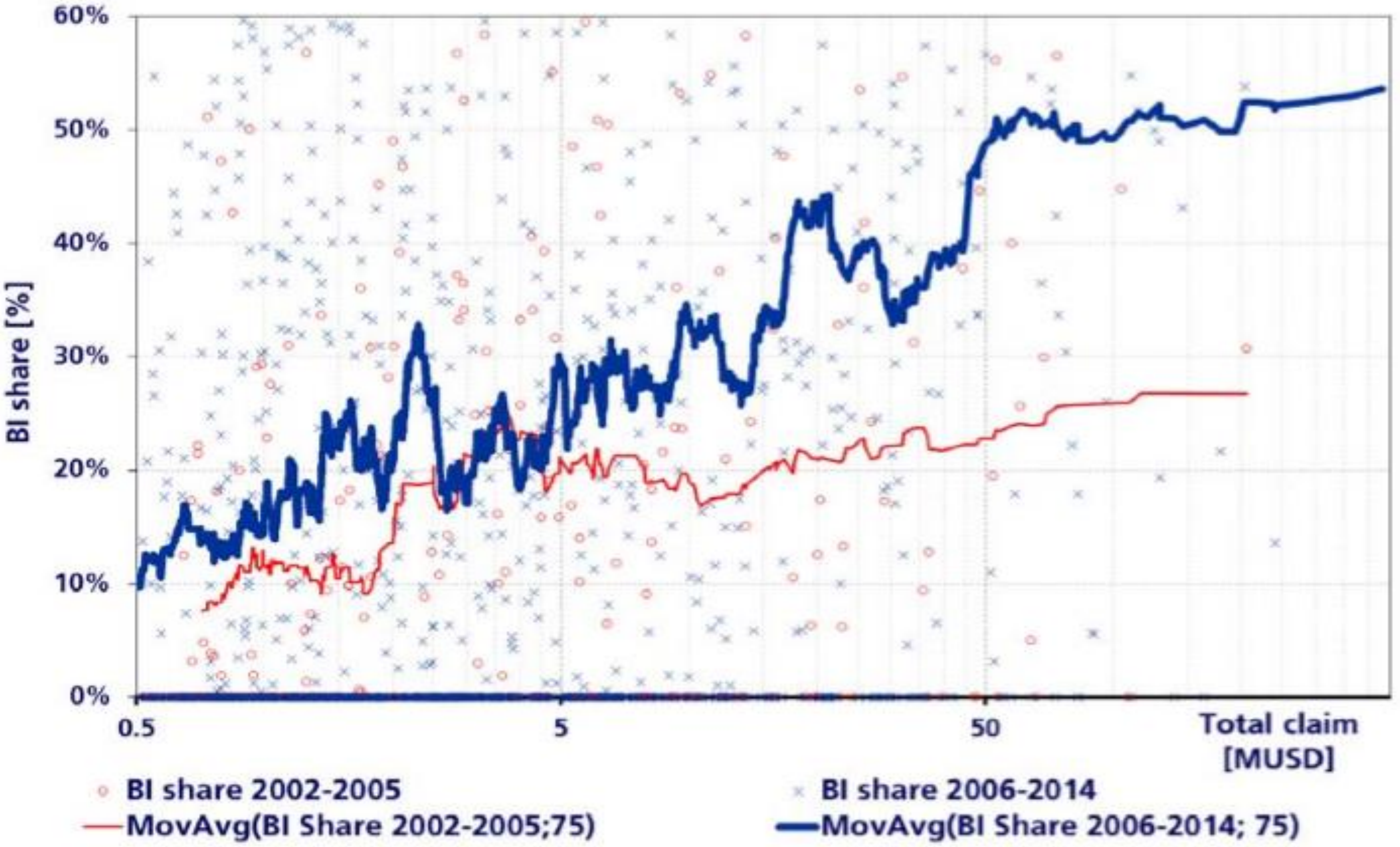
Source: Allianz, 2017

Not only are business interruptions a top concern for global corporations, the severity and frequency of BI insurance claims are increasing over time. A study by Zurich (Mizgier et al. 2018) analysed a large number of historical claims data from 2002 to 2014 to identify trends in BI claims. In Figure 13, historical claims data used in the study are split into two time series, from (a) 2002 to 2005 and (b) 2006 to 2014, and are sorted based on the total amount for each claim.

Moving averages for the two time-series were then calculated by considering 75 claims at a time. The study concluded that the average BI share of losses (compared to property damage) has risen significantly over the time period from 2006 to 2014. During the same period, as the claim size increased, the BI share of the claim also increased; for example, BI share jumped from 45% for claims less than USD 2.5 million to 80% for claims exceeding USD 100 million.

In the last decade, another major development has been the adoption of cloud technologies by corporations. A cloud outage or a cyber attack on a company's virtual network can wreak havoc on the physical systems and cause huge economic losses (Lloyd's Cloud Down 2018). Similarly, a cyber attack on a public utility has the potential to disrupt a wide swath of industries (Lloyd's Business Blackout 2015). As the division between physical and virtual supply chains starts to vanish, it is reasonable to assume that the intensity and frequency of supply chain losses will continue to increase. To be resilient against these new vulnerabilities and threat vectors, it is important for the insurance industry to take a holistic view of assessing supply chain risk.

Figure 13: Increasing moving averages of BI percentage of claims for 2002-2005 (red line) and 2006-2014 (blue line)

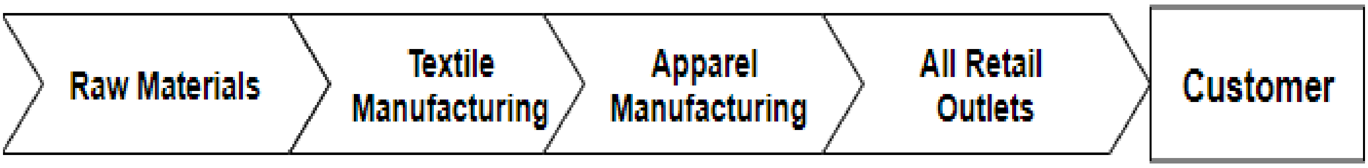


Source: Mizgier et al. 2018

Simple vs. complex supply chains

Supply networks come in varying degrees of complexity. The supply chain for apparel has fewer components than the one for a passenger car. A T-shirt starts as the raw material cotton; the cotton is combed into thread and knitted into cloth; then the cloth is sewn into a T-shirt as the finished product. The manufacturing process is straightforward and simple (Figure 14).

Figure 14: High-level view of a simple supply chain, apparel manufacturing

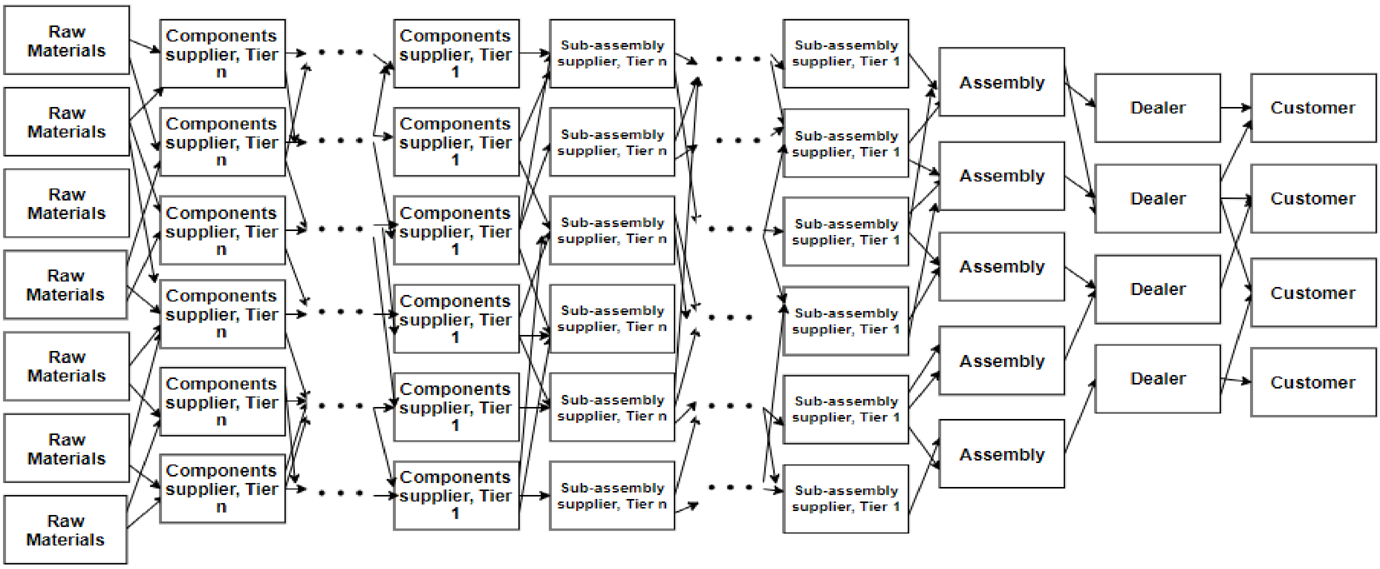


However, a passenger car has many parts; per Toyota Motor Company, a single vehicle has approximately 30,000 parts, including the fasteners and screws (Toyota 2019). This implies that automakers have complex supply networks with many suppliers with multiple layers of manufacturing between the finished product (passenger car) and its raw materials (Figure 15).

The challenging treatment of a more complex supply chain comes from the many interdependencies that can exist among the many parts, which do not always flow linearly from one to another. For example, steel is used in many components of a motor vehicle: for parts, in the engine or for metal stamped components of the body.

Therefore, a disruption in steel production in a particular region of the world has the potential to disrupt certain locations of engine production or motor vehicle body production, depending on global trade flows and procurement patterns. In this respect, it is more problematic to identify how a disruption can affect a complex supply chain rather than a simple one

Figure 15: High-level view of a complex supply chain, automobile manufacturing



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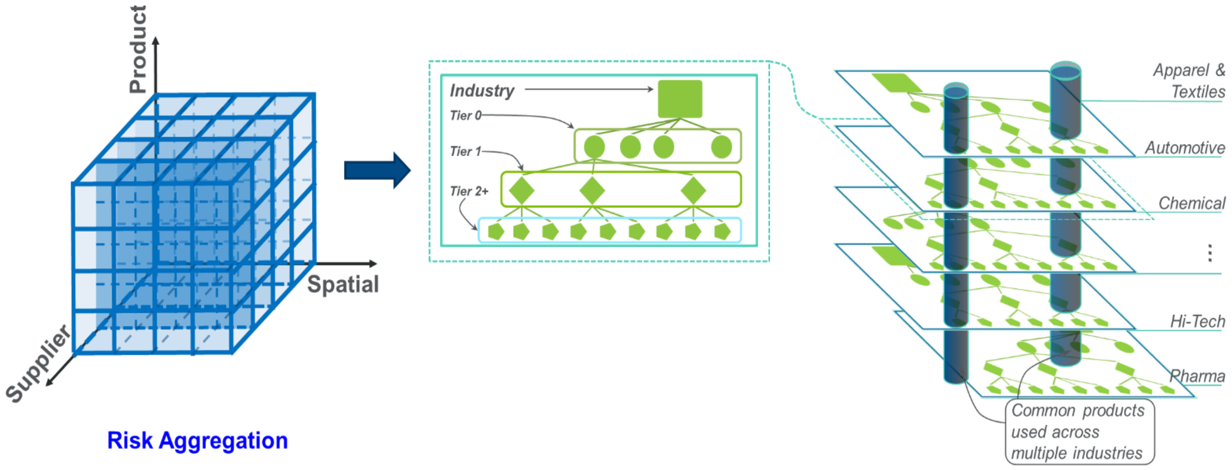
Hidden correlations and risk aggregation

As supply networks have become more global in the past decades, insuring interconnected BI and CBI risk has grown more complicated. Typically, insurers price cover based on previous claims' histories, but this data may not be available for interconnected supply chain risk. Also, the lack of full visibility into an insured's supply chain makes exposure and risk assessment challenging. To account for the uncertainty arising from data gaps and knowledge limitations, insurers typically offer policies that are highly sub-limited with narrow coverage. These data gaps for CBI underwriting can lead to risk aggregation (Figure 16) creeping into the insurer's portfolio either in the form of (a) spatial, (b) product/industry and (c) supplier correlations.

Figure 16: Correlations and risk aggregation



Spatial correlation

Spatial correlation can rise to importance when many exposures in an insurer's portfolio are geographically clustered. The spatial footprint of "engines and engine parts" manufacturers (NAICS 336310, North American Industry Classification System) are shown in Figure 17. The map shows large concentrations of exposure in the northeastern United States, Europe, Japan and some locations in China and India. If a catastrophic event strikes the northeastern United States, then an insurer with exposure to the automotive industry could expect to see claims from multiple policies in their portfolio.

Figure 17: Exposure for NAICS 336310 (manufacturing and/or rebuilding motor vehicle gasoline engines and engine parts)

Product/Industry correlation

As part of the portfolio management process, (re)insurers should also focus on aggregation across certain product groups in their portfolio. Disruption of a widely used (sub)product could affect more than one industry.

For example, if bauxite, from which aluminium is derived, were to suffer a prolonged disruption in mining (i.e., flooding, labour strike or political unrest), then, in addition to automakers being potentially affected by a scarcity of aluminium, perhaps computer and electronic products manufacturers could also be affected. Understanding product correlation allows insurers to not overexpose themselves to certain product groups that might affect multiple industries.

Supplier correlation

CBI losses may also occur when a critical supplier is down, which could stall manufacturing for more than one company. Microchips are used in a large variety of products, such as automobiles or office equipment.

One of the largest semiconductor companies in the world, Renesas Electronics, was severely affected by the 2011 Tohoku earthquake. Its Naka factory in Ibaraki produced almost 20% of its customised microcontrollers and sustained partial damage to the ceiling, walls and electric wiring and internal damage to manufacturing equipment (Renesas 2011). An essential supplier for many automakers, automobile parts and other customers worldwide, Renesas's lack of production meant that the automobile industry was forced to curtail production domestically and overseas.

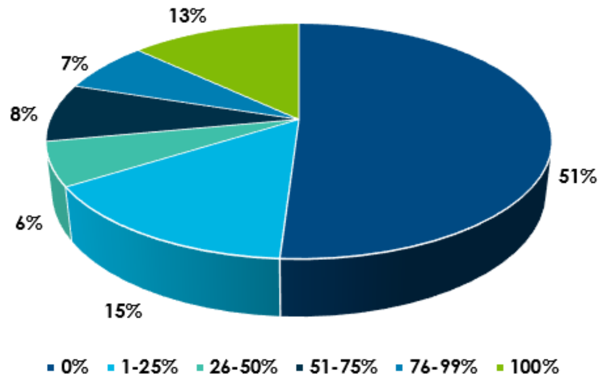
Protection gap in supply chain insurance

An extreme protection gap exists in the supply chain insurance space, and the take-up rate for CBI insurance is minimal. The Business Continuity Institute did a survey on global corporations to determine the extent of coverage these companies had to cover for CBI losses in 2017. The results from the survey are shown in Figure 18, with nearly 51% of the surveyed companies reporting zero coverage (uninsured) and only 13% of the surveyed companies having full coverage.

The main driver for the prevailing low take-up rates can be attributed to (a) coverage being inadequate or unavailable and (b) cover being too expensive. For this emerging risk, the insurance industry cannot rely on old techniques of taking historical data and projecting it forward. Investment needs to be made in exploring and developing the following: (a) data standard for CBI risk underwriting and (b) new modelling techniques for CBI risk quantification.

A better understanding of the hidden vulnerabilities in supply chain risk would assist the re(insurance) industry to develop insurance products with better policy terms, allowing for an increased take-up rate of CBI insurance and ultimately closing the protection gap in the supply chain insurance space.

Figure 18: Percentage of Insured CBI Loss in 2017



Source: BCI, 2017

2. Modelling approaches

Overview of traditional approaches

Corporations employ the bottom-up approach for mapping their supply chain and constructing a flow model (Figure 19). This approach involves starting with the parent company and traversing successive tiers of their supply chain to identify and map each supplier in their network. Identifying each supplier is a time- and labour-intensive process.

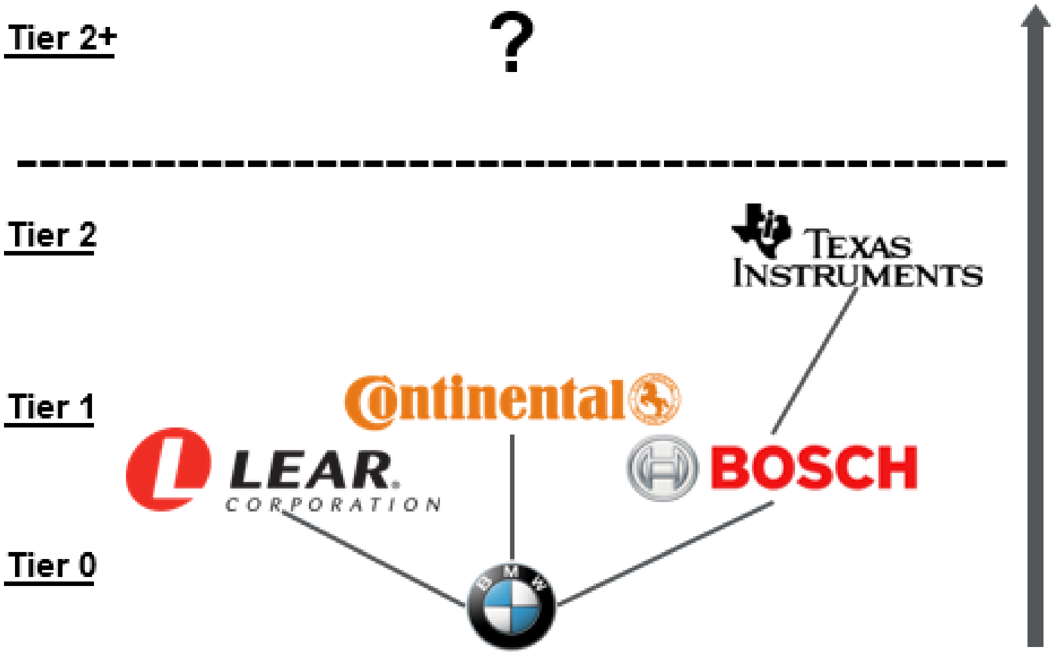
After building the mathematical flow model of the corporation's supplier network, with nodes for supplier sites and arcs for transportation connections, the nodes and arcs are opened or closed and their effect on the network is studied. In this way, a scenario analysis where a certain node is turned off can be run for a deterministic result. Or, a Monte Carlo simulation can be run several hundred times, where a random supplier site is turned on or off and the results can be used to describe the likelihood of various events and impacts in the supply chain.

The advantage to the bottom-up approach is that the results can be very detailed for the known or "named" suppliers. Given the time-intensive and participatory nature of the bottom-up mapping process, however, corporations typically end up with a partially mapped supply chain. For the (re)insurance industry, making underwriting and pricing decisions based on a partially mapped supply network can be arduous for the following reasons:

1. captures disruption only where suppliers are known
2. low degrees of interconnectivity between nodes due to small number of identified suppliers.

This can lead to underestimation of risk due to the hidden vulnerabilities in the invisible or unmapped part of the supply chain network.

Figure 19: Traditional bottom-up hierarchical network modelling approach

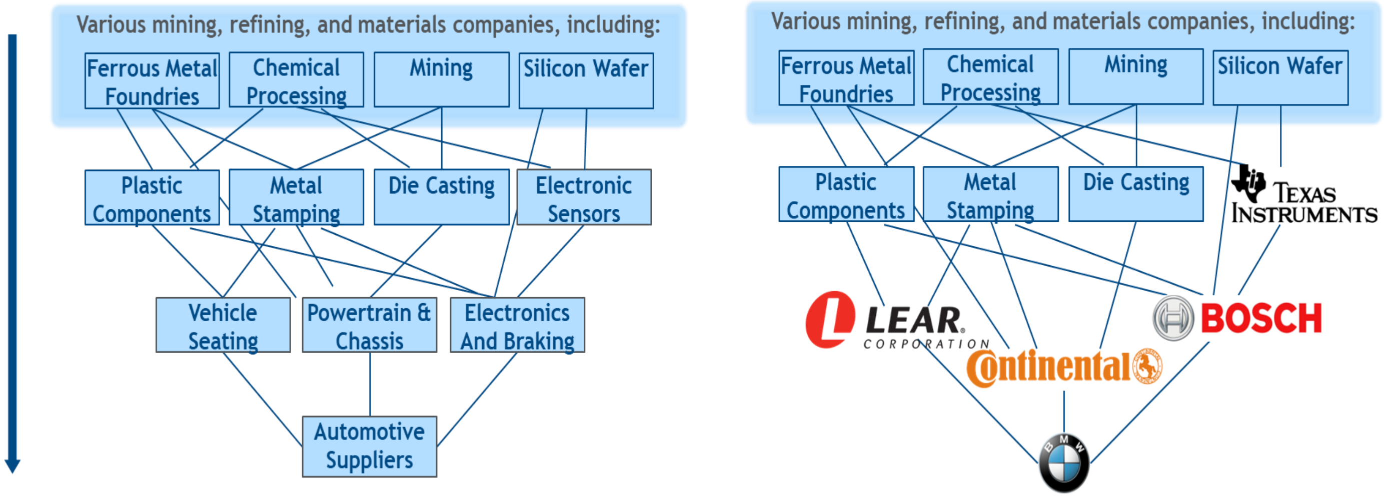


Hybrid modelling

Alternatively, the top-down approach to supply chain mapping takes an aggregate view of supply chain risk by mapping the product hierarchy instead of named supplier nodes. The top-down approach allows for understanding the macro-economic trends and impacts on different entities. This approach scales well and enables greater visibility into the entire product flow network (all the way to raw materials) that a manufacturer of a particular product is dependent on.

This research study attempts to bridge the data and knowledge gaps discussed in the earlier parts of the report by introducing a novel hybrid modelling framework that uses predictive algorithms to capture the causal interdependencies in the invisible part of the supply chain network. Such a hybrid risk quantification framework has the unique benefit of being able to capture the hidden correlations and interacting risk factors to infill the invisible part of the supply chain network and to account for both local and global effects. Figure 20 shows the abridged schematic of the top-down product flow mapping for automotive industry and how mapping can be used to infill the invisible part of the supply network. Using the hybrid network, (re)insurers can stress test the policy for several edge cases before making underwriting decisions.

Figure 20: Top-down product flow mapping (left) and hybrid product flow (right)



Five-step modelling framework

The supply chain risk model draws together a five-step solution for quantifying contingent business interruption risk (Figure 20). The proposed approach is industry-agnostic, so it can be applied to any industry (e.g., automotive, computer and electronic products, etc.) and/or product group of interest.

Step 1: Define industry

The first step of the process is to define the industry and the final product(s) for the target company of interest. For example, Daimler AG would belong to the automotive industry and the product line may be passenger cars. After identifying the product lines, this step also involves progressively mapping out the constituent intermediate parts and their associated product hierarchy. In addition, we have built a Supply Chain Industry Exposure (SCIE) database with nearly 3.2 million suppliers covering different product groups across multiple industries. At the end of this first step, the model would have hierarchically mapped all the product groups that the target company would rely on and all plausible suppliers for each of the products.

Step 2: Define network

In the next step, the hybrid network is created by combining named suppliers and procurement data from the insured with the product flow map created in step 1. Information from the SCIE and global trade data is used to infill the invisible parts of the supply chain and empowers the model to capture the unknown correlations that might exist in the insurer/insured portfolio.

Step 3: Calculate disruption

This step involves calculating the initial seed disruption for the perils for which the insurer might be interested in offering coverage. The insured's portfolio, along with the infilled supplier data from the SCIE, is run through various peril models to generate initial disruptions for both historical and probabilistic events. Generating the seed disruption through these models captures the spatial and temporal correlation associated with natural catastrophe events. This framework is not limited to natural perils, and can also be used to analyse port disruptions, cyber attack, riots or other non-natural disruptors.

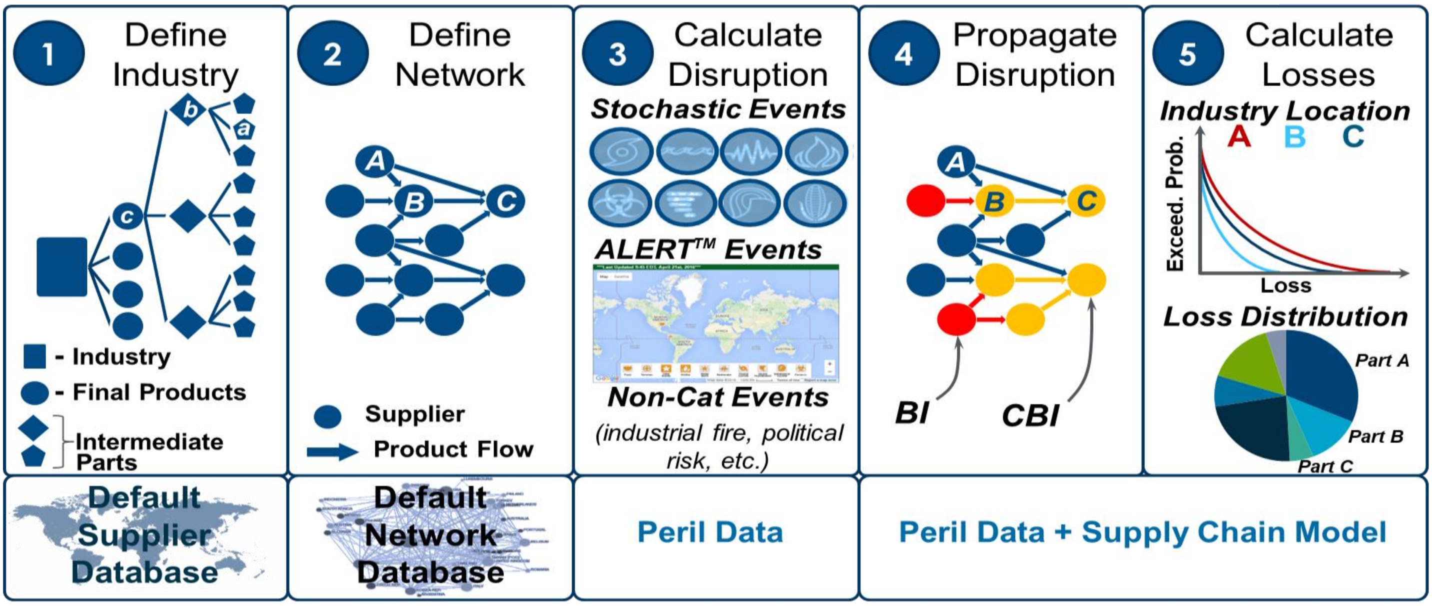
Step 4: Propagate disruption

For each event, the seed disruption that was calculated in step 3 is propagated through the supply chain network constructed through steps 1 and 2. As the disruption is pushed through the hybrid network through the interconnected links, calculations are performed at each node to estimate and aggregate the impact of the disruption. The hierarchical propagation of CBI through the network enables an insurer to identify critical nodes and risk hot spots so that they can tailor policies to suit their risk appetites.

Step 5: Calculate Product Value at Risk

The final step of the process is to calculate the Product Value at Risk (PVaR). PVaR is calculated by multiplying the CBI (days) calculated in step 4 with the annual revenue of the target company (or any other desired financial measure). Stress testing PVaR can be done by examining different "inventory" scenarios. The resulting PVaR from the supply chain risk model can be used for policy structuring, industry benchmarking studies and reserving.

Figure 20: Supply chain model risk quantification framework



Advantages of quantitative assessment of risk

Both the corporate and insurance industries traditionally employ qualitative methods to assess risk in supply chains by building "*Risk Scorecards*" and "*Decision Tree*" frameworks. The standard practice in the industry is to use a questionnaire as shown in Figure 21, or some variant of it, to collect information for CBI risk underwriting. This method of risk assessment relies on a consensus of expert opinion by gathering the results from a series of repeated questionnaires answered by subject professionals. Each subsequent questionnaire includes replies from the previous one; participants are encouraged to reconsider and adjust their replies after examining the replies of the entire group. In such a way, a consensus can be reached to assign relative risk probabilities and arrive at an underwriting decision.

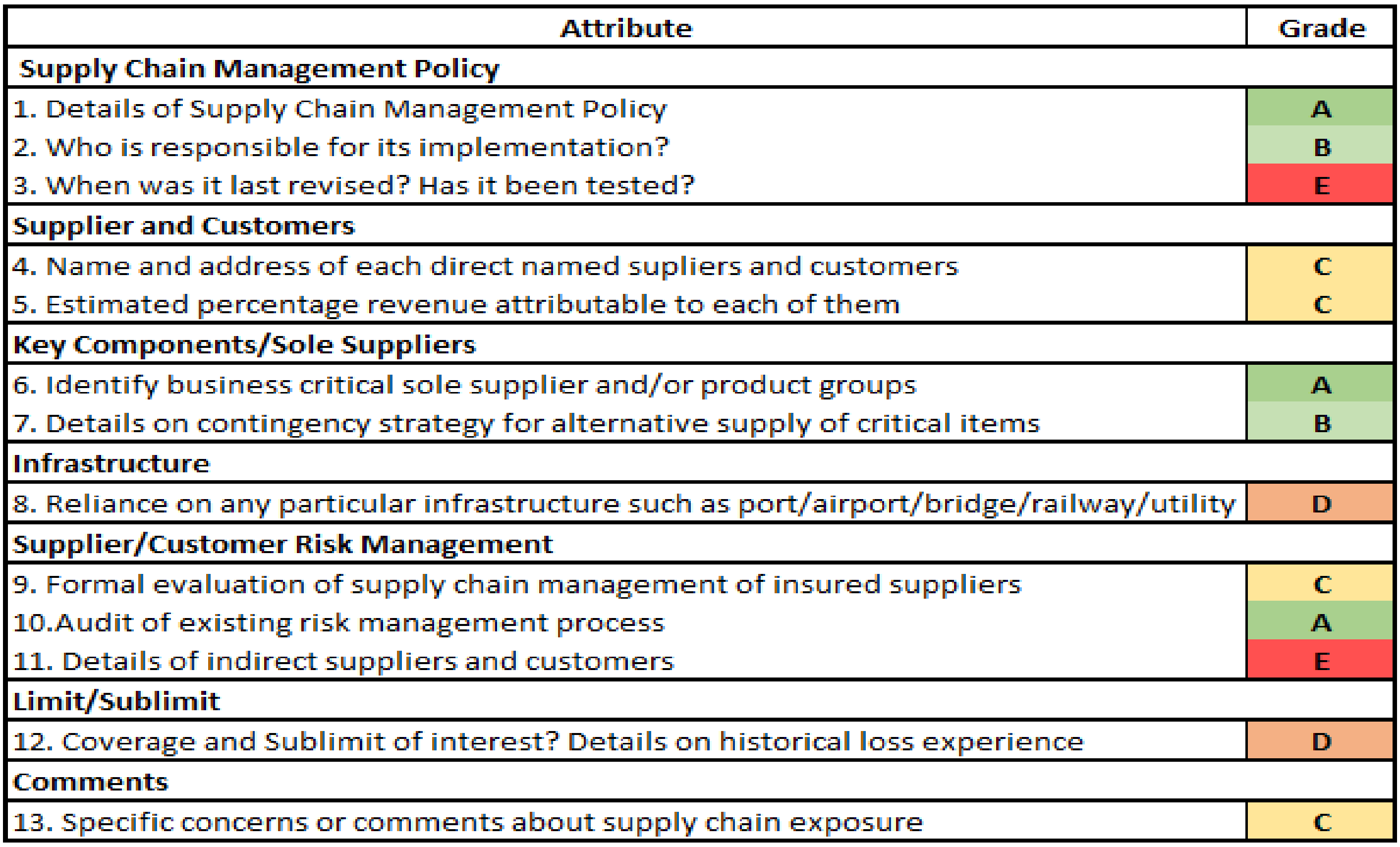
Although this method is an effective tool to track and measure supplier performance and can be used to understand basic facts about supply chain risk, it does not deliver a detailed and nuanced view of the risk. An expert opinion may not accurately reflect the risk involved as its development could be based on past event bias or emotional bias rather than an objective point of view. In addition, the traditional qualitative methods are "reactive" in nature, as they retrospectively identify interdependencies and risks from historical events.

The proposed quantitative model allows risk managers and insurers to transition from "reactively" to "proactively" managing supply chain risks by identifying interdependencies *before* events happen and future-proofing the portfolio against probable impending contingencies. Predictive methods are used to infer product hierarchy and dependencies for any given industry, and the quantitative modelling framework explicitly accounts for:

1. Lack of information
2. Uncertainty of exposures
3. Correlation (accumulation management)

The quantitative model, in a probabilistic analysis framework, calculates a 1-in-100-year loss (or any return period of interest) and average annual loss (AAL) risk metrics that are more appropriate for making underwriting decisions and in complying with Solvency II standards. Another advantage offered by quantitative risk metrics is the ability to transform risk analytics into automated rules for CBI risk underwriting, which can enable insurers to more effectively scale up their underwriting process to cover Small and Medium Enterprises (SMEs)

Figure 21: Suppliers and Customers Questionnaire (adapted from LMA 9020, the standard questionnaire developed by Lloyd's for CBI underwriting)



Attribute	Grade
Supply Chain Management Policy	
1. Details of Supply Chain Management Policy	A
2. Who is responsible for its implementation?	B
3. When was it last revised? Has it been tested?	E
Supplier and Customers	
4. Name and address of each direct named supliers and customers	C
5. Estimated percentage revenue attributable to each of them	C
Key Components/Sole Suppliers	
6. Identify business critical sole supplier and/or product groups	A
7. Details on contingency strategy for alternative supply of critical items	B
Infrastructure	
8. Reliance on any particular infrastructure such as port/airport/bridge/railway/utility	D
Supplier/Customer Risk Management	
9. Formal evaluation of supply chain management of insured suppliers	C
10.Audit of existing risk management process	A
11. Details of indirect suppliers and customers	E
Limit/Sublimit	
12. Coverage and Sublimit of interest? Details on historical loss experience	D
Comments	
13. Specific concerns or comments about supply chain exposure	C

3. Data and analytics component of the modelling framework

The supply chain modelling framework proposed in this study relies on four critical components:

1. Trade data
2. Supply chain industry exposure
3. Product flow network
4. Stochastic event catalogue

Trade data

Supply chain modelling involves understanding trade patterns across regional economies. The United Nations Commodity Trade Statistics Database (UN Comtrade) contains detailed import and export statistics by country and commodities for the world. In 2017, the total global volume of merchandise exports exceeded USD 15 trillion and merchandise imports exceeded USD 16 trillion trade. In this study, 2017 UN Comtrade data is applied and covers nearly 170 countries and some 5,000 commodities classified by Harmonised System (HS) codes.

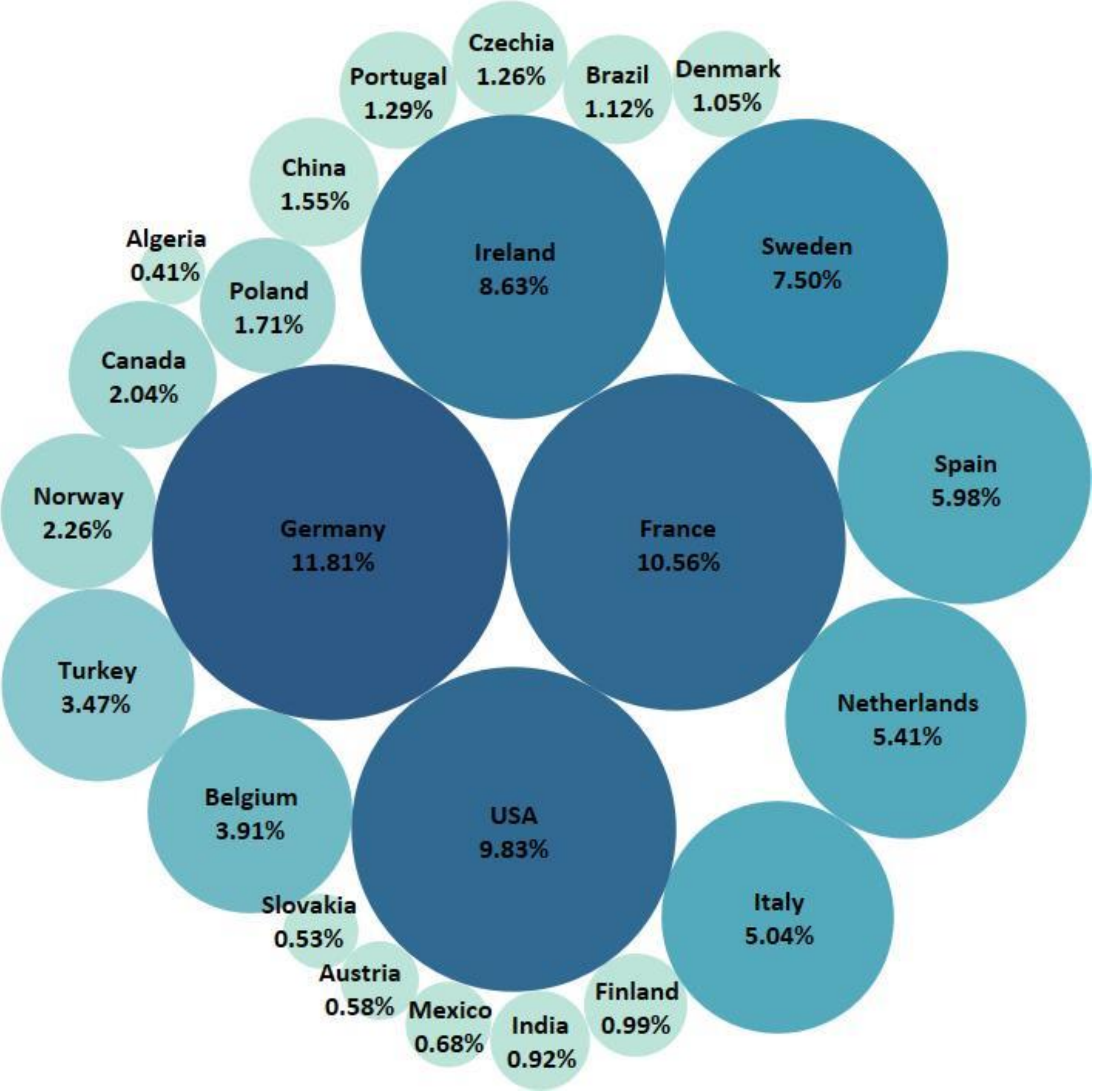
In the absence of any detailed procurement data from an insured, a trade-data based network approach provides a simple yet powerful tool for analysing the global exchange of commodities. In addition, this framework facilitates modelling a generic corporate supply chain without any knowledge beyond the industry to which the company belongs.

For example, lithium-ion batteries (Li-ion) are widely used in many products, including - but not limited to – smartphones, tablets, cameras and laptops. These batteries are starting to be widely used in electric vehicle manufacture (Lloyd’s Unearthing Opportunity 2018). Figure 22 shows the top exporters of lithium-ion batteries in the world, which include the United States, Singapore, China, Indonesia and Japan. A prolonged supply chain disruption in Southeast Asia has the potential to cause a major shortage of lithium-ion batteries, and this disruption can manifest as losses for companies in either the automotive or computer and electronic products manufacturing industries.

Figure 22: Top exporters of lithium-ion batteries

Macro-economic events such as economic sanctions, trade embargos and recessions can alter import and export patterns of the global economy, which can lead to widespread trade disruptions. As an example of potential disruption, Figure 23 shows the top importers of steel from the United Kingdom. Being part of the European Union's single market system, the steel produced in the United Kingdom is mainly exported to the other EU member states, namely Germany, France, Ireland, Spain and Italy. When Brexit concludes, EU tariffs may be imposed on steel trade with the United Kingdom; this could potentially drive up manufacturing costs across industries because steel is integrated across several different value chains. The potential shift in trade patterns could signify a change in exposure footprint for certain suppliers or new vulnerabilities emerging for an insured or insurer's portfolio.

Figure 23: Top importers of steel from the UK



Supply chain industry exposure

While the flow of goods in the supply chain model is primarily governed by international trade data, the spatial distribution of manufacturers characterises the hazard to which each industry is exposed. Due to challenges in mapping out suppliers, even corporations with mature supply chains have difficulty with full visibility into their procurement. Addressing these data limitations, this model relies on a propriety database of nearly 3.2 million companies worldwide covering different product groups across multiple industries. This database was created by curating publicly available data (e.g. census data) and Verisk's propriety databases to create a customised view of the supply chain industry exposure.

The database allows the insured or insurer to run queries such as: *"Who are the engine manufacturers in the world?"* and *"Where are the printed circuit manufactures located?"* For example, Figure 24 shows the spatial footprint of storage battery manufacturers in the world, and there is a very large exposure concentration in Southeast Asia. Identifying risk hot spots by product group aids (re)insurers to mitigate their exposure to certain product groups that may pose a bigger accumulation risk in their portfolio. In summary, this database can identify plausible suppliers (not company-specific suppliers) of different product groups that can be used to identify the hidden vulnerabilities in the insured's supply chain.

Figure 24: Storage battery manufacturers. (NAICS Code 335911)

Product flow network

An important step in supply chain modelling is enumerating and associating the physical parts required to construct a final product. Generally, smaller and less complicated component parts and raw materials are required to make larger products.

A company may know all the larger components within its product's supply chain, but often the raw materials (e.g., iron ore, copper, and silica) and smaller parts (e.g., wiring harness, bolts and gaskets), which are required, are not fully visible to a final product manufacturer.

A manufactured product is typically composed of many sub-products, which are in turn composed of many more basic sub-products. The concept is easily illustrated by an automobile, for which mined metals are required to make metal products such as sheet metal, bolts and gears. These metal products are required to manufacture metal parts such as the chassis, engines and transmissions required to make a finished automobile.

Separate product lines are similarly required to make plastic, electronic, glass and other components involved in automobile manufacture. Ideally, all interconnections between parts are known, so that any disruption to a small part is propagated onward to (or "felt" by) the next larger part in the network.

For a product network, the exact connection between each part is challenging to define without detailed knowledge of a company's specific manufacturing process, which may even vary between different companies within the same industry. Default relationships between groups of analogous parts, however, can be defined, leading to the concept of product groups or categories. Each category manufactures a collection of similar products that are in turn required by other groups to make sub- products. For example, the "automotive engine parts" product category would manufacture products such as spark plugs, pistons and fuel injectors.

Each product group can then be further categorised by defining its tier within each industry classification. A notional product definition structure is illustrated in Figure 25. The tier number represents the separation between the product group and the final product of the industry classification, defined as "tier 0". For example, the "printed circuit boards" product group might be two categories removed (i.e., tier 2) from the computer and electronic products industry, but five product groups removed (i.e., tier 5) from the automotive industry.

Figure 25: Schematic of product dependency structure using industry groups

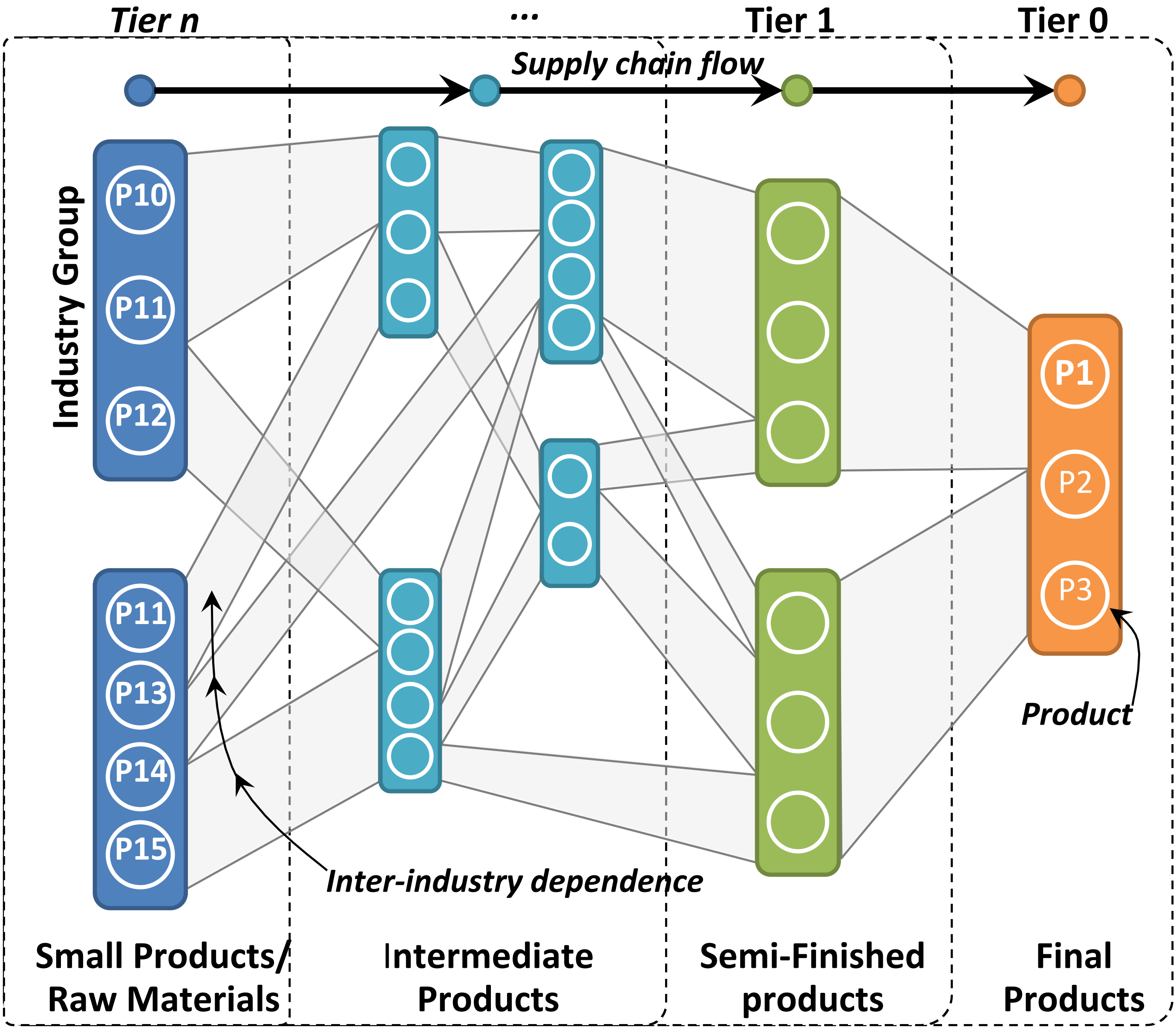


Figure 26 and Figure 27 show examples of abridged versions of the product flows for the computer and electronic products and automotive industry, respectively. Flowing from left to right, each product network has many interconnected product categories (nodes), which implies that a disruption may start at any node in the network and then traverse multiple paths before reaching the target company of interest at tier 0.

For instance, an industrial fire at one company has the capacity to disrupt multiple product groups that rely on this supplier; a real-life example of this occurred last year in 2018, when an explosion and fire at Meridian Magnesium caused up to two weeks of CBI for automakers (AIR 2018). The abrupt lack of magnesium die-cast components affected multiple product groups that use engine/radiator supports, liftgates, crossmembers and instrument panel components.

Figure 26: Product flow network for the computer and electronic products industry (abridged version)

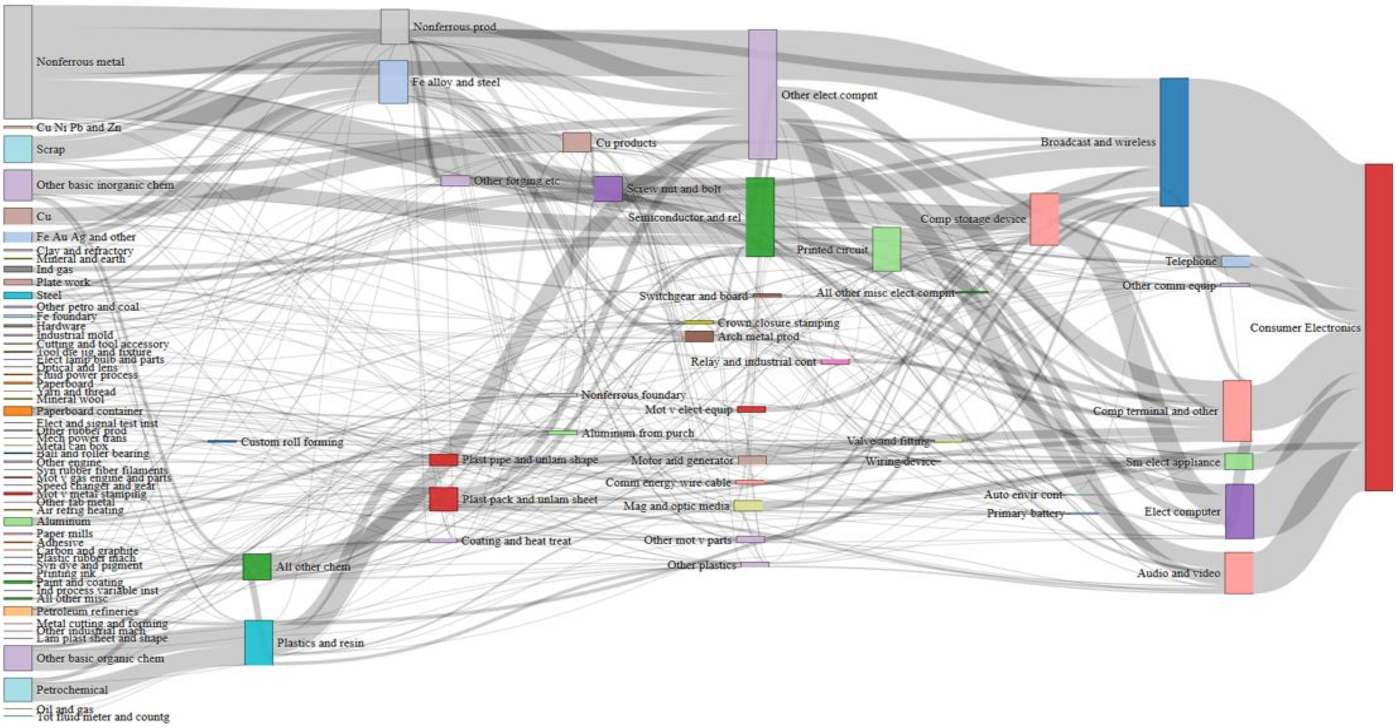
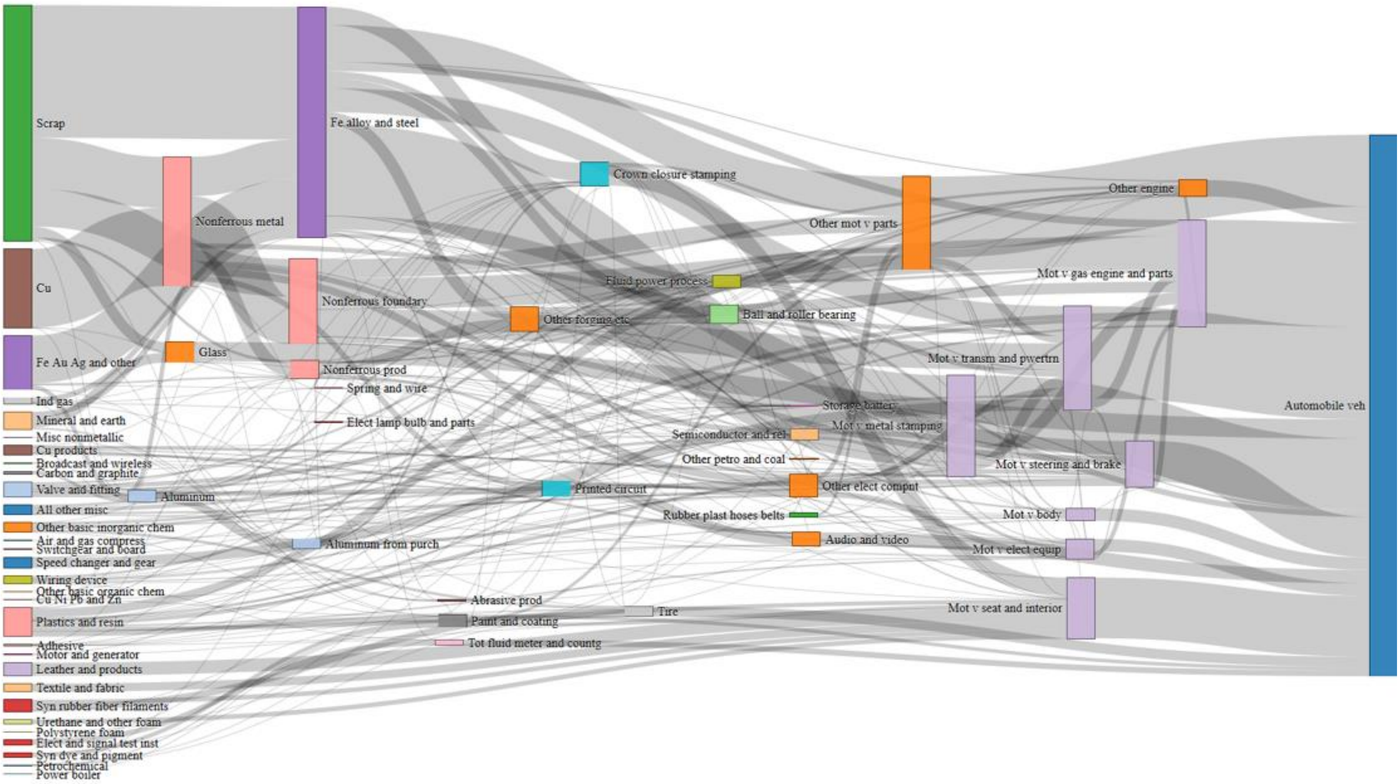


Figure 27: Product flow network for the automotive industry (abridged version)



Stochastic event catalogue

As supply networks have become more global in the past decades, insuring interconnected BI and CBI risk has also grown more complicated. Insurers typically price cover based on previous claim histories, but this data may not be readily available for interconnected supply chain risk. Historical databases of events are inherently limited due to the relatively short timeline of human records; for example, Figure 28 shows Atlantic hurricane historical storms over a period of ~160 years.

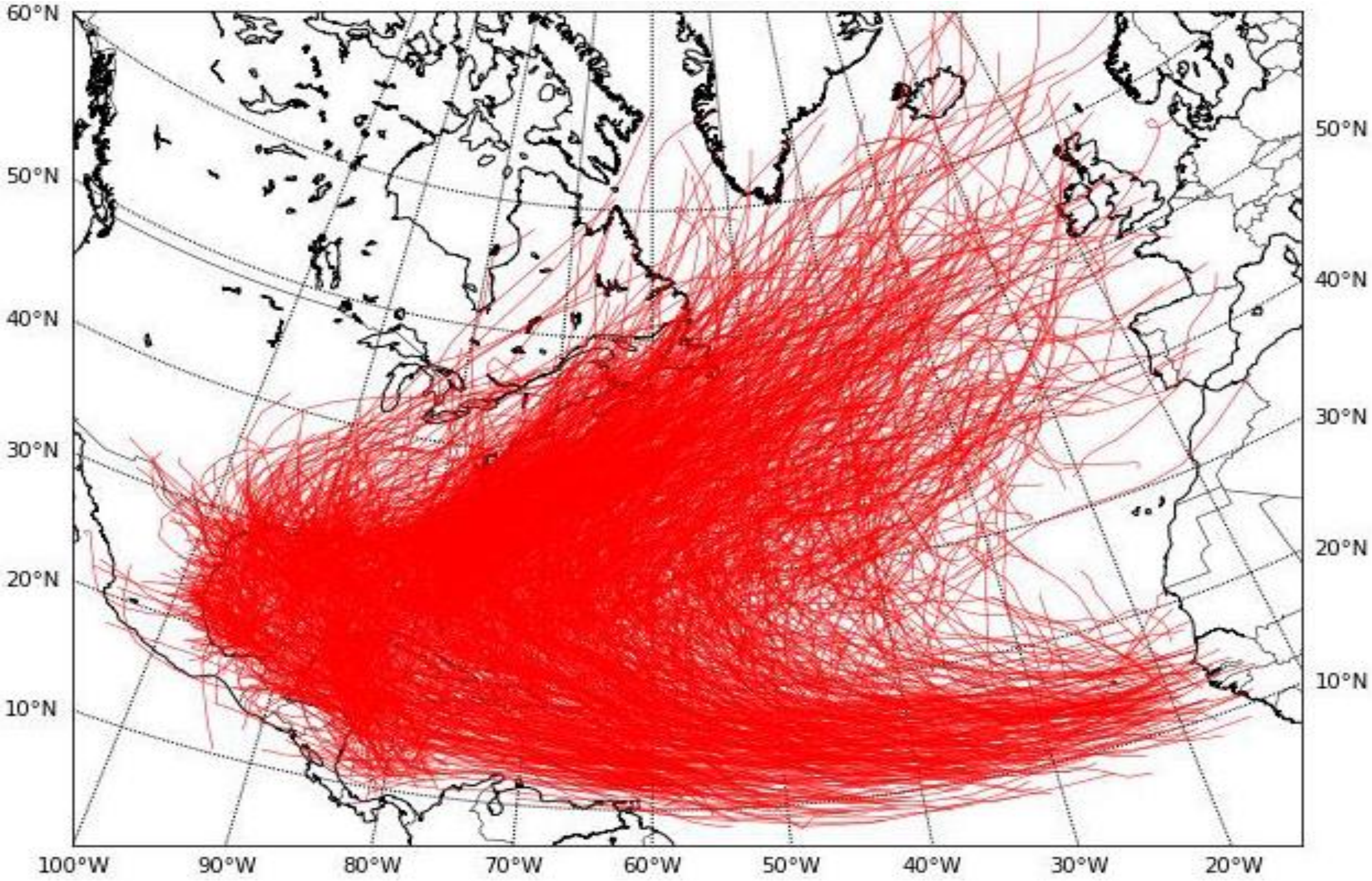
Thus, probabilistic, or stochastic, catalogues are sets of simulated scenarios using statistics derived from the historical documentation to develop a more reliable assessment of events expected in any given year. The stochastic catalogue can then be used to stress-test a portfolio for all plausible events that can potentially impact the insurer.

This study uses AIR's Touchstone® catastrophe risk modelling platform, which supports stochastic event catalogues of 10,000 simulated years of tropical cyclones, earthquakes, floods and other natural catastrophe events.

Figure 29 shows AIR-modelled countries in Touchstone®. Each event in the stochastic catalogues is evaluated using regionally appropriate hazard intensity calculations that estimate the event's extent and severity. The resulting spatially-distributed hazard intensities are primary inputs for calculating the initial seed disruption, which can then be propagated through the supply chain network to calculate the economic impact at each node in the network.

Figure 29: AIR-modelled countries

Figure 28: Atlantic hurricane historical storms (1851-2014)

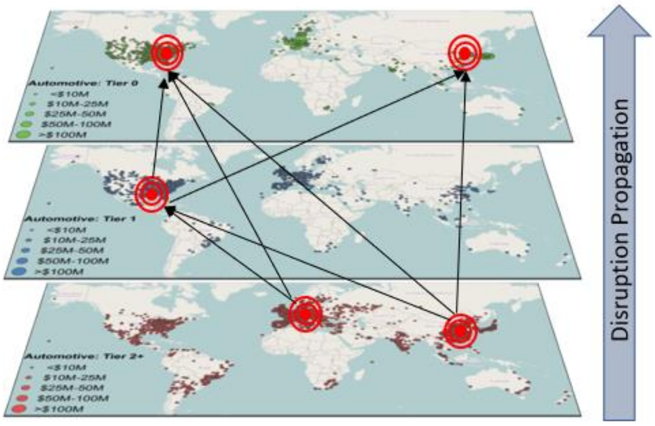


Unique framework enables comprehensive approach

Integrating the four data sets (Figure 30) in the modelling framework allows the supply chain model to account for a lack of information, uncertainty of exposures and correlation. The predictive methods used to infill the invisible part of the multi-tier supply chain network facilitate identifying product interdependencies across multiple policies and industries in an insurer's book of business.

Overlaying these product flow networks on the Supply Chain Industry Exposure enables identification of exposure concentrations and spatial footprints of plausible suppliers that may impact the supply chain of the insured. Running a probabilistic analysis on the constructed network by using a stochastic catalogue of all possible events that may potentially impact the insured explicitly accounts for spatial correlations. Joining this complex information together creates a unique framework for evaluating and quantifying risk in a comprehensive approach.

Figure 30: Assimilating data layers



Validation studies on the model

Multi-level validation studies were undertaken to evaluate different components of the model. These validation studies include:

- Industry exposure validation
- Product flow validation
- Loss validation

Industry exposure validation

To check the completeness of the industry exposure used in this study, supply chain data from public sources were evaluated to see how much of the data is represented in the industry exposure.

For example, Ford Motor Company, as part of Ford World Excellence Awards, publishes an annual list of top-performing global suppliers. Data from annual reports between 2005 and 2013 were compiled, and there are nearly 210 unique suppliers in the collected list.

The spatial footprint of these suppliers is shown in Figure 31, and the suppliers are mainly concentrated in Japan, Europe and the U.S. Midwest. The industry exposure database is then queried to see how many of the named suppliers are represented in the industry exposure. Figure 32 shows an overlay of Ford's named suppliers on industry exposure, and more than 80% of Ford's named suppliers had a corresponding match in the industry exposure.

Figure 31: Ford Motor Company supplier footprint

Figure 32: Overlaying Ford's data on industry exposure

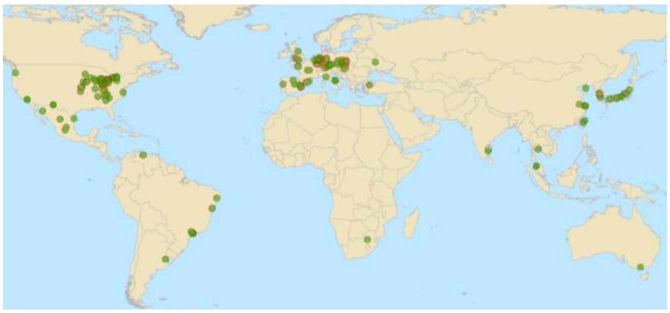
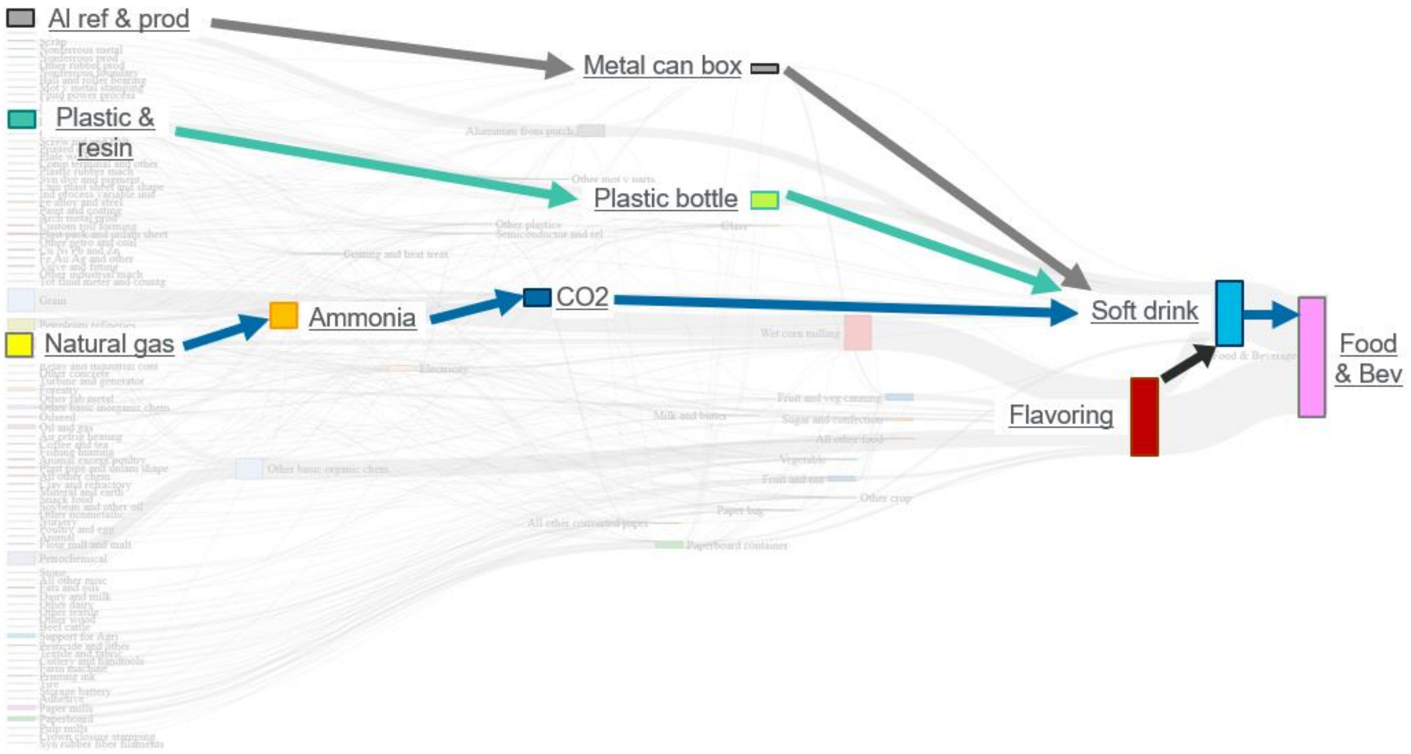


Figure 33: Uncovering hidden correlations using AIR predictive analytics



Product flow validation

In the summer of 2018, a CO_2 shortage across Europe impacted the Food & Beverage (F&B) Industry. Some of the F&B companies temporarily paused production lines. Upon investigating the cause of the CO_2 shortage, companies found out that food grade CO_2 is a by-product of ammonia manufacturing, and many fertiliser manufacturing plants were shut down simultaneously for essential maintenance.

The increased price of natural gas, which is a key component for ammonia manufacturing, also impacted the timing of the fertiliser plants' shutdowns. Although companies were able to recover without experiencing much loss, the CO_2 shortage highlighted the hidden vulnerabilities in value chains. Since CO_2 is difficult and expensive to import, prolonged downtimes to local CO_2 production can result in revenue losses to these companies.

To evaluate if these inherent product interdependencies are captured in the modelling framework, the different paths in the default F&B product flow networks were studied. From the analysis it was found that one of the existing paths is Natural Gas → Ammonia → CO_2 →Soft Drinks (Figure 33), and it mimics the observed linkages during the event. By leveraging these predictive product flow networks, companies can proactively capture underlying interdependencies before a disruption event unfolds

Loss validation

The third level of validation study involves estimating the modelled loss for a recent historical event and comparing the modelled estimates with reported losses. For this study we use the 2016 M7.0 Kumamoto earthquake, which struck Kumamoto City (Japan) on April 2016. Kumamoto Prefecture has a large concentration of auto component manufacturers, including body and engine parts maker Aisin Seiki, which has three manufacturing plants there. Because of the earthquake, Japanese automakers were forced to suspend vehicle production at their assembly plants across the country due to a shortage of auto parts.

Using AIR's default automotive supply chain industry network, and global industry exposure databases, the AIR Loss Estimates in Real Time™ (ALERT™) scenario was analysed in Touchstone® to assess the direct BI losses from the event.

The Kumamoto earthquake scenario footprint along with the affected manufacturers is shown in Figure 34. The direct BI outputs from Touchstone® are subsequently evaluated using the supply chain modelling framework proposed in this study, which calculates estimates of the CBI losses, both in Japan and in other countries that are indirectly impacted by the event.

Figure 34: Kumamoto earthquake footprint with affected manufacturers

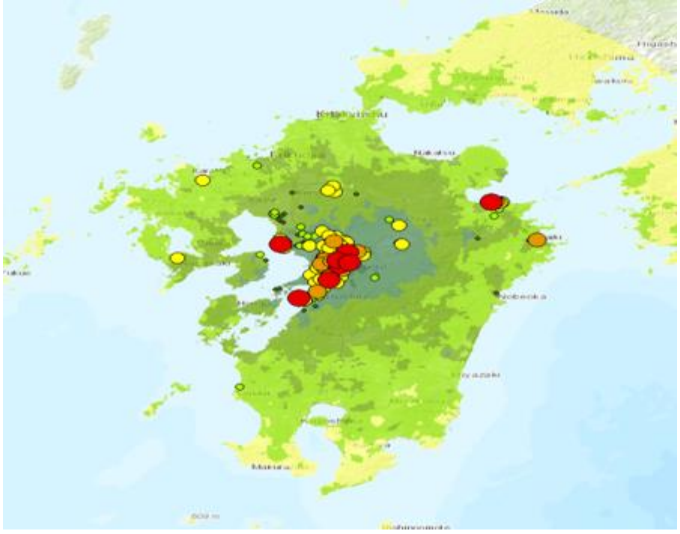
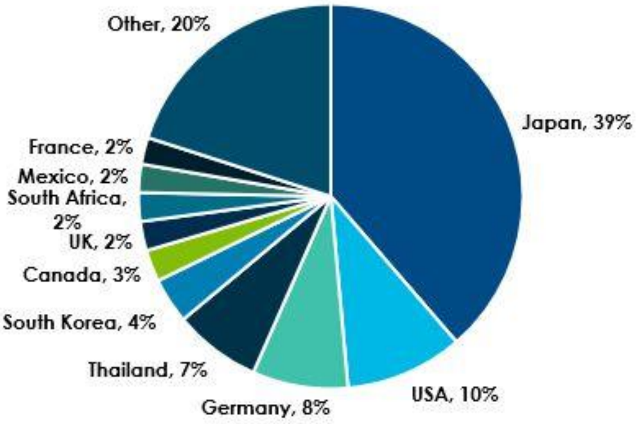


Figure 35 shows the breakdown of modelled CBI losses by country. As expected, Japan incurs the largest proportion of the loss, which is in part because more than 93% of the vehicles purchased in Japan are manufactured in Japan. Due to this high consumption of vehicles made in the country, disruption to auto parts manufacturing in Japan can have adverse effects on Japan's automotive industry.

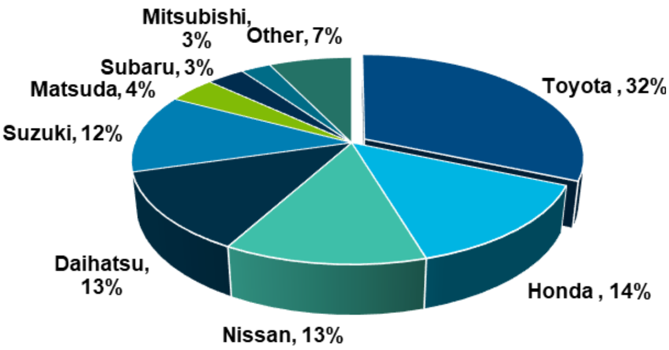
Figure 35: Automotive industry CBI loss distribution by country



The impact of the Kumamoto earthquake on automotive manufacturing spans beyond regional and national boundaries. For example, production shortfalls in the automotive sector also include General Motors, which announced two weeks of production suspension at four plants in North America due to the shortage of parts from suppliers in the Kumamoto Prefecture (Automotive Logistics 2016). The modelled CBI losses also extend to automotive production in other regions where losses from this event may be latent, such as the United States, Germany, Thailand and South Korea.

A corporate market share approach additionally allows for the industry-level impacts of the event to be distributed to leading automotive manufacturers. For example, Figure 36 shows the market share of automakers in Japan, and these percentages can be applied to country-level estimates to arrive at company-specific losses.

Figure 36: Market share of Japanese automakers



Source: Statista, 2016

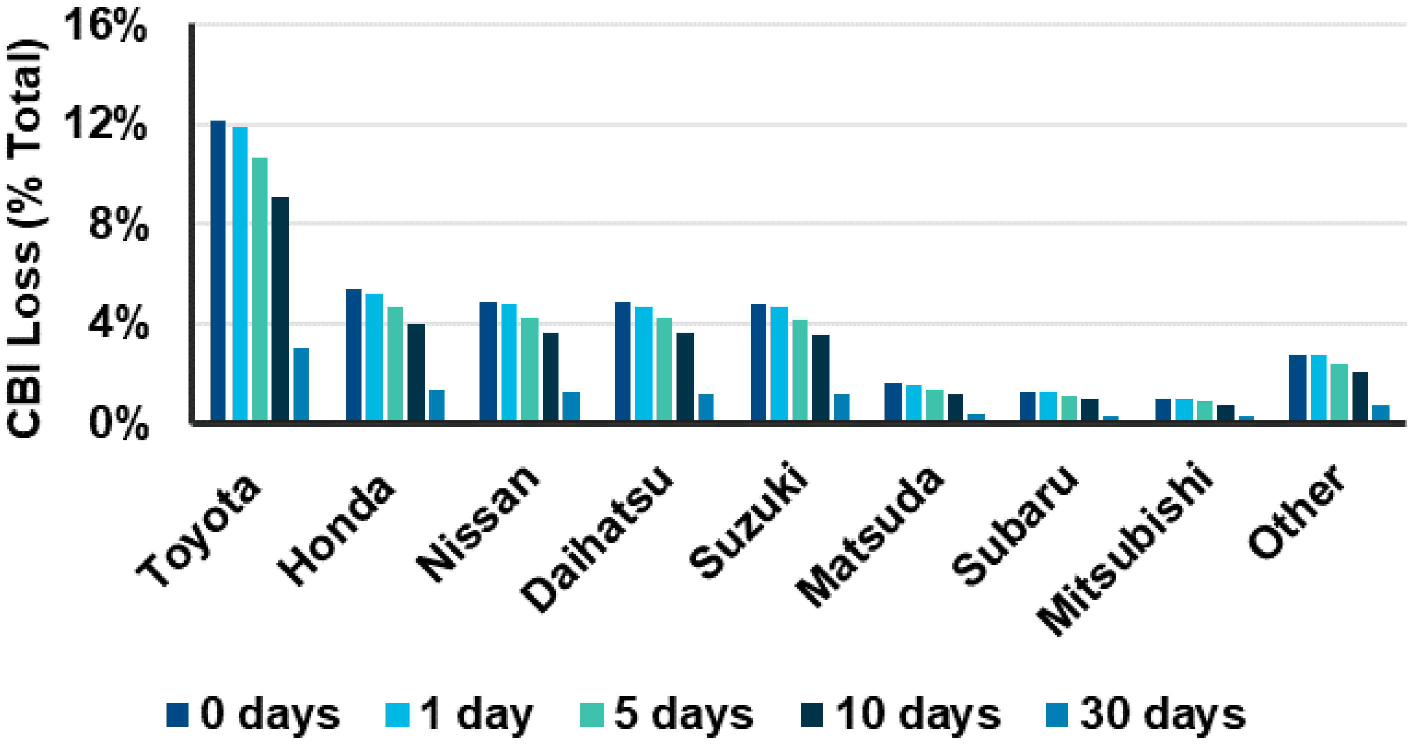
Reserves, redundancy and resilience constitute the 3R's of managing risk to a supply chain; to account for these mitigation measures, scenario analysis was done for different inventory levels. The zero-day inventory condition refers to the worst-case scenario (baseline), and the 30 days of inventory corresponds to the best-case scenario. Additional inventory levels (1 day, 5 days and 10 days) were also analysed to study the marginal impact of different resilience thresholds on the supply chain risk.

The estimated distribution of modelled CBI losses to individual automotive manufacturers in Japan for different inventory levels is presented in Figure 37. These distributed losses provide rapid impact estimation for corporations; insurers can use these analytics for benchmarking their insureds with the rest of the industry. Toyota's Japanese operations saw profits reduced by USD 277 million as a result of downtime associated with the earthquake (Forbes 2016).

Reports also indicate that Toyota, Honda, and Nissan are the automakers most impacted by this event in Japan (Reuters 2016), which is consistent with the modelled results. Figure 37 illustrates the dramatic impact of the 3R mitigation assumptions for reducing expected losses.

In this analysis, 30 days of mitigation, gained through inventory, dual-sourcing, back-up suppliers or disaster response activity is demonstrated to decrease disruptions to Japanese automotive manufacturers by more than 75% when compared to the baseline case.

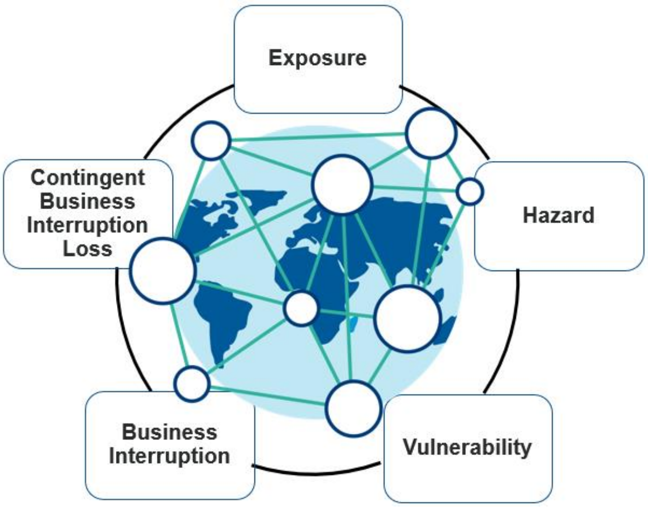
Figure 37: CBI loss distribution by leading automotive manufacturers in Japan based on market share analysis



4. Probabilistic modelling of supply chain risk

Probabilistic modelling of supply chain risk for the automotive and computer and electronic products industries is evaluated in this study. The probabilistic risk modelling framework (Figure 38) consists of five primary components: exposure, hazard, engineering, business interruption (BI) and contingent business interruption (CBI) losses. AIR's Touchstone® risk modelling platform is leveraged for the hazard, engineering and BI components. The resulting BI outputs from Touchstone® serve as the input to the supply chain model, from which CBI loss estimates are calculated.

Figure 38: Risk modelling framework



The exposure module consists of databases that characterise the suppliers and products that constitute an industry or an insured of interest. Attributes such as geocodes, product classification, occupancy types, and revenue information are included in the exposure module. The exposure databases provide a foundation for modelled loss estimates for simulated events from a stochastic catalogue, the reanalysis of historical events and for actual events unfolding in real time.

Exposure footprints of suppliers used in the automotive and computer and electronic products industry analyses are shown in Figure 39 and Figure 40, respectively. The main exposure concentrations are in Asia, Europe and North America.

Figure 39: Exposure map for automotive industry analysis

Figure 40: Exposure map for computer and electronic products industry analysis

The hazard module of AIR's Touchstone® platform includes a probabilistic assessment of the earthquake, tropical cyclone (and associated precipitation-induced and coastal flooding for some countries), non-tropical cyclone flood, and extratropical cyclone/winter storm hazards.

These models are based on regional information of historical event parameters, physical properties (e.g., land use/land cover, topography) and historical intensity recordings (e.g., wind speed, rainfall, flood depth). Using this historical information, AIR develops stochastic event catalogues, which comprise 10,000 simulated years of event activity and allow for the determination of the probability of exceedance of different levels of hazard intensity at any location within the modelled domain.

The engineering module consists of vulnerability functions that relate hazard intensity to damage levels for each of the construction and occupancy pairs contained in the exposure database. These damage levels, or mean damage ratios (MDR), represent the percentage of the total replacement value of a structure that has been damaged in an event. For example, an MDR of 1 indicates that 100% of the value of a structure has been damaged, and it will cost the entire original value of the structure to rebuild.

The business interruption loss module combines data from the hazard, exposure and engineering modules to generate probabilistic estimates of BI loss. The BI outputs from this module underpin the subsequent CBI calculations in the supply chain model. The CBI module calculates the spatially distributed losses for each event in the stochastic catalogue and then aggregates all stochastically simulated losses to generate useful statistics. The resulting CBI losses are associated with different probabilities of exceedance, which provide different views of the risk for individual exposure locations, product groups or countries.

For example, these results can be used to determine the loss that a supplier or a country has a 10% probability of exceeding in the next 10 years. These losses are also presented in terms of a Mean Return Period (MRP), which is the inverse of Exceedance Probability (EP) and represent the average recurrence interval for a modelled CBI estimate.

MRP and EP results are generated using the loss for each simulated event in each modelled year. As in the historical record, certain modelled years may have multiple events, while others may have a single event or no events.

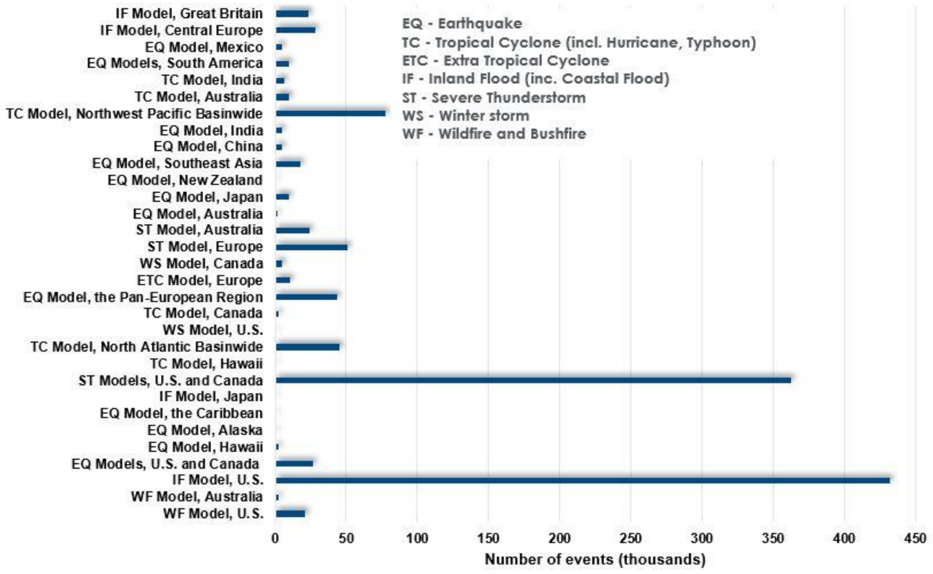
The modelled losses in each year are then ranked from highest to lowest and annual losses are calculated as either *occurrence loss* (i.e., based on the largest event loss within each modelled year) or *aggregate loss* (i.e., based on the sum of all event losses of each modelled year). Finally, EPs corresponding to each loss—occurrence or aggregate—are calculated by dividing the rank of the loss year by the number of years in the catalogue. Thus, for a 10,000-year catalogue, the top-ranked (highest loss) event would have an EP of 0.0001= (1/10,000) or 0.01% annual EP, the 20th-ranked event an EP of 0.002 = (20/10,000) or 0.40% annual EP and the 100th-ranked event an EP of 0.01 = (100/10,000) or 1.00% annual EP. As noted previously, the mean return period for a loss level equals the inverse of the EP. For example, EPs of 0.01%, 0.20%, and 1.00% correspond to 10,000-, 500-, and 100-year MRP, respectively.

Average annual loss (AAL) is the mean value of a loss EP distribution, or the expected loss per year, averaged over many years. It is computed by summing all the *aggregate loss* estimates for each year for all the events in the stochastic catalogue and dividing the total by the number of years the catalogue considers. For example, if all losses generated using the 10,000-year catalogue sum to $1,000 million, then AAL for the catalogue period would be $1,000 million/10,000 years = $0.1 million AAL

The MRP defines the time period over which, on average, a particular event can be expected to occur or be exceeded. For example, and quite hypothetically, assume that in Country A an event with a modelled CBI of 20 days is associated with a 100-year mean return period, which means that a CBI disruption of 20 days has a 1% chance of happening in a given year.

As part of the probabilistic analysis, nearly 1 million stochastic events covering tropical cyclones, earthquakes, floods, thunderstorms, winter storms and wildfires were analysed. Figure 41 shows a breakdown of the number of events covered in the analysis. The US inland flood model has the greatest number of stochastic events.

Figure 41: Breakdown of different modelled regions and number of events covered



By running stochastic simulations of all plausible events that may potentially impact an industry's or an insured's supply chain, (re)insurers and corporate risk managers can future-proof businesses against intangible aggregation scenarios.

For each event in the stochastic catalogue, a country-wide weighted average BI is calculated using the importance of each supplier (which is a function of annual revenue) in each country for each industry. The resulting event-BI vector is used to provide the initial supply chain disruption for the CBI calculation.

Country-level aggregation is necessary because of the resolution of the global trade data used to define the network relationships for each industry. To make the analyses manageable and computationally feasible, trade flows between 52 countries across 5,000 product groups are considered. This represents nearly 92% of the global trade flows.

The modelled CBI risk profiles for computer and electronic products and automotive industries, across selected countries, are presented in Figure 42 and Figure 43, respectively. Exceedance probability (EP) curves are shown for all perils, which include but are not limited to earthquakes, tropical cyclones and floods. For the computer and electronic products industry, the loss profiles indicate that the United States has the highest losses at both the high (i.e., MRP > 100-year) and low (i.e., MRP < 20-year) return periods. Germany, on the other hand, is exposed to minimal losses when a 500-year MRP event impacts the computer and electronic products industry.

Similarly, for the automotive industry, the United States has the highest losses across all MRPs. However, at a 500-year MRP, China has the least amount of losses attached to the automotive industry. (Re)insurers can use these MRP loss estimates and correlate the losses with their exposed limits across different countries and products to investigate regions where they might have overexposed their portfolios and use the derived insights to manage their books of business.

Figure 42: Loss profile by country for all perils –computer and electronic products

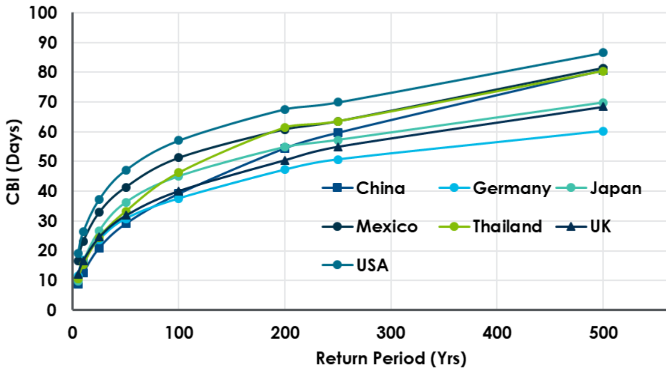


Figure 43: Loss profile by country for all perils – automotive

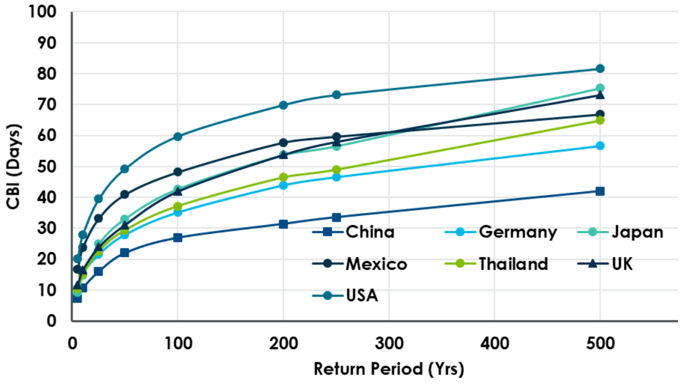
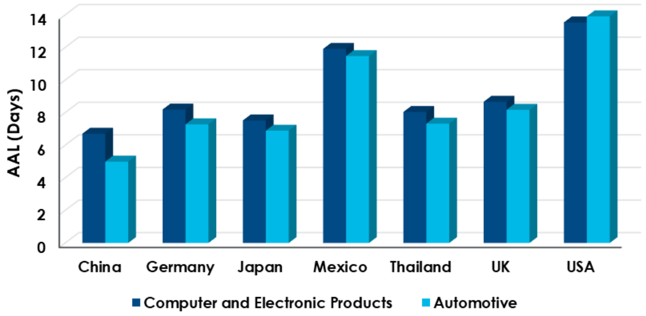


Figure 44 shows an all perils AAL comparison by country and industry. With an AAL of ~13 days, the United States has the highest loss potential followed by Mexico, the United Kingdom, and Germany. It should be noted that these numbers represent the worst-case scenario of zero-day inventory. It is also observed that AAL for computer and electronic products and automotive industries are similar for each country.

Figure 44: All perils AAL comparison by country and industry



To study the risk drivers, contribution to AAL by peril is presented in Figure 45 and Figure 46. Earthquake is the dominant peril, followed by flooding and tropical cyclone.

Figure 45: Contribution to AAL by peril – computer and electronic products

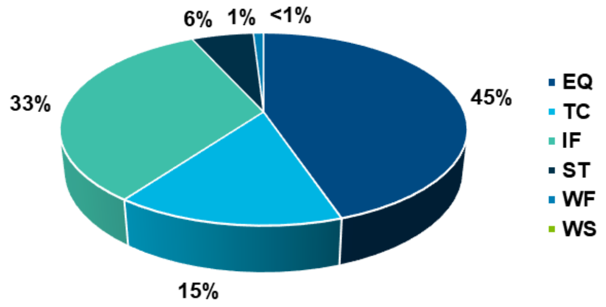
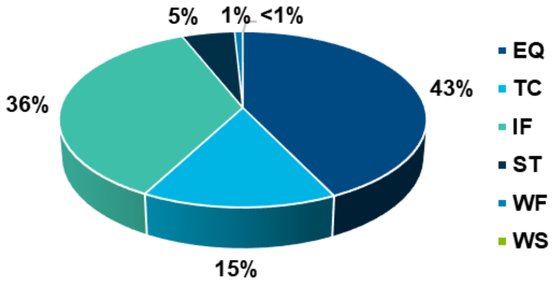


Figure 46: Contribution to AAL by peril – automotive



The impact on a downstream product caused by a disruption in an upstream part (i.e., a part required to make the product) is dependent on several factors. The presence of inventory, or reserves, of a commodity or raw material reduces the expected amount of downtime that will result from a disruption.

To measure the impact of 3R mitigation measures on the resilience of the automotive and computer and electronic products industries, sensitivity tests were performed by considering 5, 10, and 20 days of inventory levels for the United States inland flood model, and comparisons of the modelled (inventory) results were made with the base-case scenario (zero-day inventory).

Figure 47 and Figure 48 show the model results conditioned on the 3R mitigation assumptions implemented. For the automotive industry (Figure 47), having 5 days of inventory can result in an 8.7% drop in the AAL, and 20 days of inventory results in a 17.4% reduction in AAL. The reduction in AAL is less pronounced for the computer and electronic products industry (Figure 48). These results highlight the combined number of days of disruption that can be avoided through pre-emptive actions: by building inventory and dual-sourcing, or by carrying out reactive measures such as repair coordination and increased production.

Figure 47. Impact of inventory on automotive industry

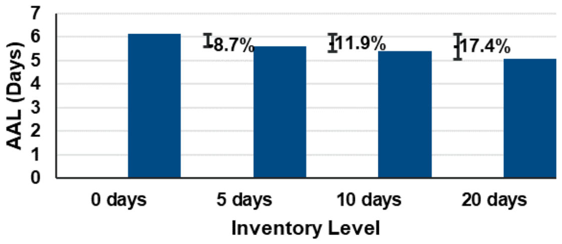


Figure 48. Impact of inventory on the computer and electronic products industry

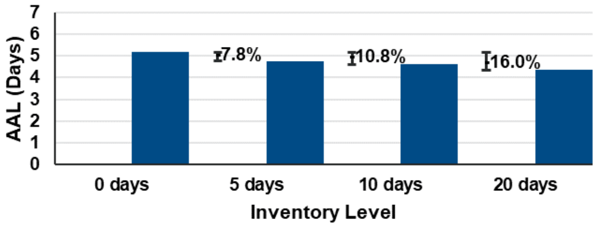
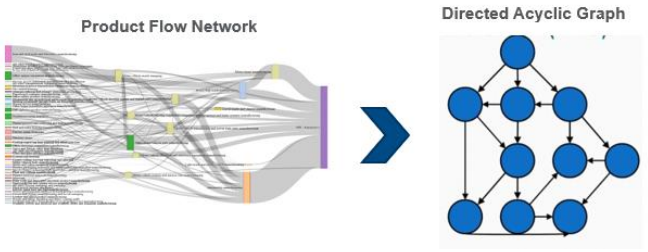


Figure 49: Product criticality



As an additional insight into understanding risk drivers, product criticality is evaluated for both automotive and computer and electronic products manufacturing. This is done by first transforming the product-flow network into a directed acyclic graph network, shown in Figure 49. In graph theory, the network centrality measure identifies the most important node within a graph.

Degree centrality, which measures the number of links incident upon a node, is evaluated for both the automotive (Figure 50) and computer and electronic products (Figure 51) manufacturing.

While basic materials that feed into the manufacture of industrial goods have a higher criticality score, it is of interest to observe semiconductors and printed circuit boards being denoted as critical products for the automotive industry as well as computer and electronic products.

Figure 50: Criticality score for automotive industry

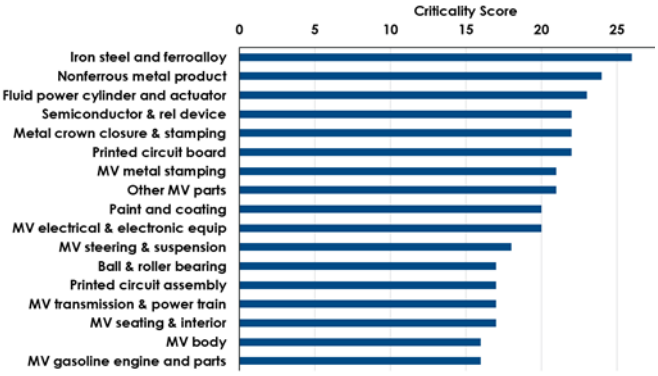
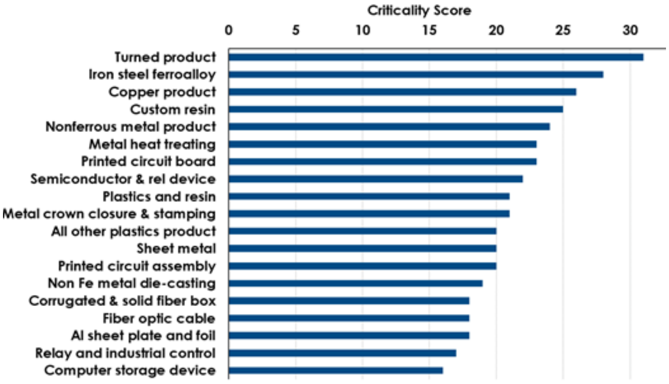


Figure 51: Criticality score for the computer and electronic products industry



It is observed that probabilistic results from the automotive and computer and electronic products industries may be similar. With increasing growth of information technology and computing power, advanced sensors and electronic components are being heavily integrated into the automotive industry. For example, the ABS (anti-lock braking system) and ADAS (advanced driver assistance systems) technologies have transitioned automobiles from hardware-driven machines to software-driven electronically controlled machines. It has been estimated that electronics comprise nearly 40% of a vehicle's cost (CRS 2011).

In addition, basic raw materials such as aluminium/bauxite, magnesium, cobalt, lithium and copper are found to have a high utilisation by both the automotive and computer and electronic products manufacturing industries. Companies such as Hitachi Metals manufacture products for both the automotive and computer and electronic products industries, and a potential disruption to a Hitachi Metals facility can trigger claims from policies across multiple industries.

During the 2011 Thailand flood, both automotive and computer and electronic products companies suffered major direct and indirect losses, highlighting the interdependencies between the two industries. Understanding the correlation across product groups and industries allows insurers to better manage risk aggregations.

5. Scenario analyses

Scenario analysis enables insurers and corporate risk managers to stress-test their portfolios for varying assumptions. This section highlights how the risk modelling framework discussed in the study can be wielded to perform scenario analyses for the following deterministic events:

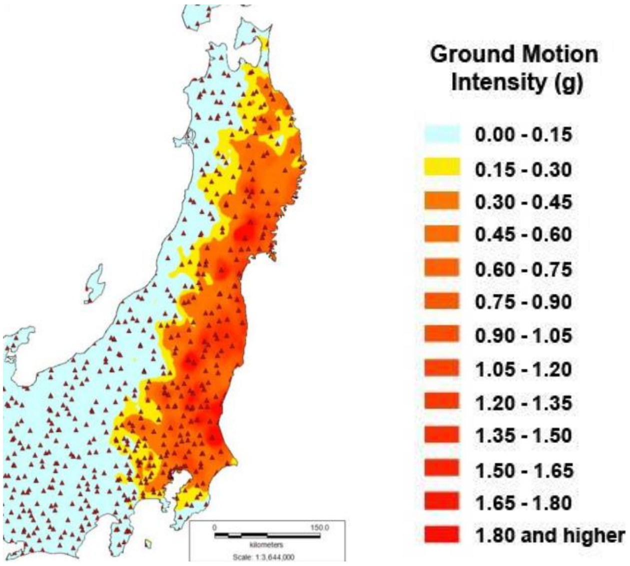
1. 2011 Tohoku earthquake
2. 2011 Thailand floods
3. Impact of remote cyber disruption on an engine-powertrain company in New York, United States

2011 Tohoku Earthquake and Tsunami

The Tohoku earthquake was a major event that resulted in significant disruption to the automotive and computer and electronic products industries. Figure 52 shows AIR's modelled spectral acceleration footprint for the event. In this study, the hazard footprint of the event is overlaid on the supplier exposure footprint to first assess the direct impact on Japanese manufacturers. Once the direct impact is assessed, the resulting disruption is propagated through the value chain to assess how this disruption manifests as losses across other countries. The base-case analysis would involve analysing the event with the zero-day inventory condition. Sensitivity tests with different inventory conditions are analysed to assess the range of disruption downtimes that we can expect from this event. Example outputs from this analysis are shown in Figure 53 to Figure 56.

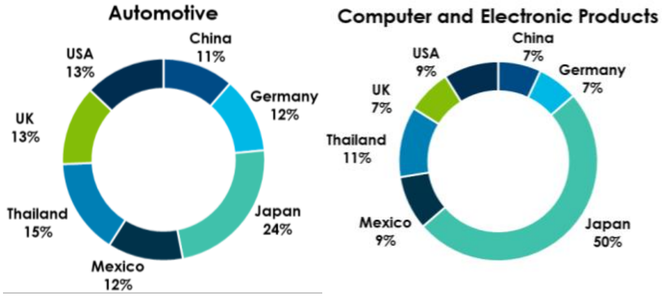
Showing the effect of the Tohoku event for selected countries, Figure 53 shows the percentage of CBI for a country's automotive manufacturing with respect to the sum of the selected countries (left) and for a country's computer and electronic products manufacturing (right). For automotive manufacturing, among these countries, Japan suffers almost 24% of the expected CBI from the earthquake. The other countries show a smaller effect from the Tohoku event. This trend underscores the trade ties that Japan has with China and the United States; a shortage of automotive supply parts from Japan may begin to affect both of these countries, which is supported by historical reports (discussed in the previous section: Supply chain events and their economic impacts).

Figure 52: Modelled Sa at 0.3 s based on interpolated observational data (coloured contours) with locations of recording stations (red triangles) of the 2011 Tohoku earthquake



Source: AIR, 2019

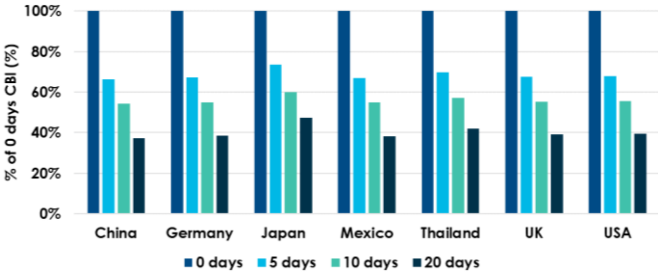
Figure 53: Automotive manufacturing (left) and computer and electronic products manufacturing (right) CBI loss distribution from seven countries



However, for computer and electronic products manufacturing, the proportions of CBI for Japan, China, and the United States show that the supply shortages from the Tohoku earthquake and tsunami had a greater effect on Japan itself and smaller effect on China and the United States. The data implies that Japan relies on products from the Tohoku region for electronics and computer production but less so for automotive manufacturing. Demographic industrial data gathered after the Tohoku earthquake and tsunami supports this inference. In the affected region, intermediate products from electronics and integrated circuits are the highest percentage (15.3%) that is shipped to the rest of Japan; automotive parts represent only 2.5% shipped to the rest of Japan (Ono et. al. 2015). The disparity in proportional consumption by Japan from the Tohoku area may be contributing to the difference between Japan's CBI results for different industries.

A comparison of results from the Tohoku scenario analysis are shown for several levels of inventory for automotive and computer and electronic products manufacturing (Figure 54 and Figure 55). Inventory is recognised as reserves, redundancy or resilience that will mitigate the disruption. The zero day, 5 day, 10 day and 20 day inventory cases are assumed for each location in the industry exposure and then modelled in the supply chain. Both figures show the data as a fraction of the zero day inventory results; therefore, for each country, zero day inventory results are shown at 100%, and every result thereafter as a fraction.

Figure 54: Automotive industry CBI distribution by analysing a range of inventory quantities



It is observed that five days of inventory at all locations of a supply network can have a substantial effect on the CBI. And, of course, as inventory days increase, CBI is expected to decrease. The advantage of having inventory is anecdotally known; the quantitative analysis from the supply chain model shows that the effects of inventory (or reserves) are not linear as they cascade through the supply network. A 10 day inventory does not always produce twice the effect of a 5 day inventory. In addition, the nonlinear propagation for inventory on CBI may not be the same for different products or across countries. For example, note that 5 days of inventory produces different amounts of reduction of CBI for Japan, China and Thailand in this scenario. Scenario estimates such as these can help insurers structure their policies and pricing based on different inventory levels.

Figure 55: Computer and electronic products manufacturing CBI distribution by analysing a range of inventory quantities

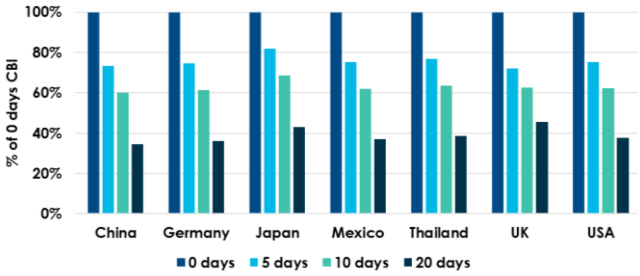
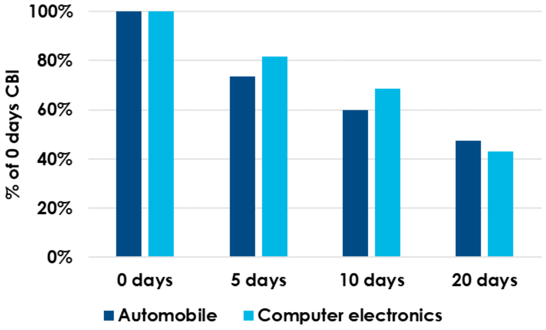


Figure 56: Comparison of Japan's % decrease in CBI for automotive and computer and electronic products manufacturing



As another example, the Tohoku scenario in Figure 56 shows the effect of inventory on Japan. Inventory's effect on automotive manufacturing is slightly stronger for 5 and 10 day inventory than for computer and electronic products manufacturing, but not as effective for 20 day inventory in computer and electronic products manufacturing. The plot supports the suggestion that inventory and its effect on CBI have nonlinear behaviour, which is influenced by several factors, including exposure, hazard and trade patterns.

The scenario results from the supply chain model are not based on claims data, nor is a comparison suggested. Because CBI insurance continues to evolve, claims data may be under-reported for claims or may be subjected to a latency period after a disruption. A more instructive comparison for the computer and electronic products manufacturing CBI results is UNESCAP's statement that the 2011 Great East Japan (Tohoku) earthquake and tsunami caused a 1% shrink for Japan (UNESCAP 2011). A calculation from the modelled CBI results and trade data gives an estimated decrease for the automobile manufacturing industry of 0.7% and, for the computer and electronic products manufacturing industry, a decrease of 0.8% for Japan. These two estimates from the supply chain model are in reasonable agreement with UNESCAP's estimate for impact on Japan.

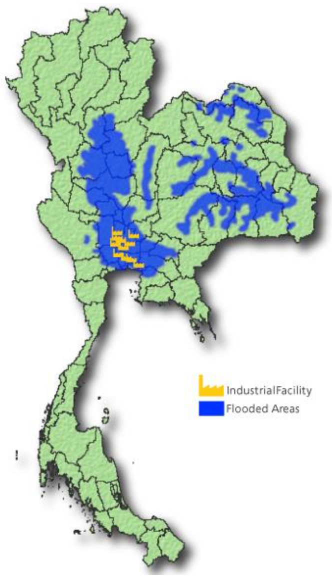
2011 Thailand Flood

In addition to the devasting earthquake in Japan, the year 2011 also saw major supply chain disruptions due to flooding in Thailand. Even before the Japanese electronics and auto manufacturers could fully recover from the impacts of the Tohoku earthquake, they were faced with the reality of dealing with another major disaster impacting their supply chains. For this deterministic scenario analysis, correlation between these two events was not considered.

Thailand is the world's second largest manufacturer of hard disk drives and an automotive manufacturing hub. When the height of flooding struck in October 2011, hundreds of factories were shut down, and the disruption resulted in BI and CBI claims around the globe. Figure 57 shows the spatial footprint of the flooded area along with the locations of industrial facilities.

Because the Thailand flood footprint is available only as a geospatial layer within AIR's Touchstone® platform, historical data, such as hard disk drive shipments (IHS Markit 2012), were used as a guideline for creating the scenario analysis. The estimated BI for intermediate products were input into the supply chain model, and the resulting impacts on the computer and electronic products and the automotive industries are presented. These CBI results are based on indirect disruptions that propagate through the value chain to reach the final products for computer and electronic products manufacturing or automotive manufacturing.

Figure 57: Location of major industrial facilities in Thailand



Source: AIR, 2019

Using a worst-case scenario of zero day inventory (or reserves), the supply chain model calculated the CBI for computer and electronic products manufacturing, and Figure 58 shows the CBI in annual percentage for a selected seven countries. In the scenario, loss results indicate that the computer and electronic products manufacturing industry in Thailand may be expected to fall by 19%; while production in other countries, such as the United States, may drop by 2% from indirect impacts of the disruption.

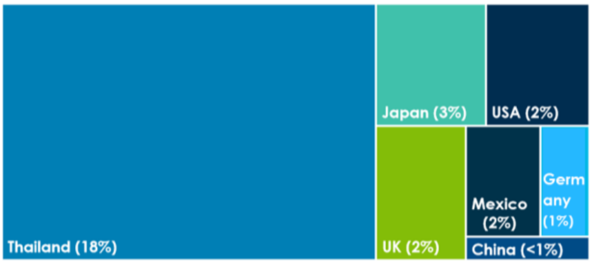
To assess the results, if an estimate for the loss in computers manufactured is calculated from the modelled CBI by applying global trade data, a mean global annual decline for production of 1.6% may be inferred. News reports from early 2013 cite that global PC shipments fell 3.2% in 2012, some of which is attributed to a rise in smart phones and tablet computers (Focus Taiwan 2013). Although historical data for a decrease in PC shipments cannot be compared directly with modelled results, the magnitudes of the decreases are in line with each other.

Figure 58: CBI (%) for selected countries for computer and electronic products manufacturing. Loss is shown as a percentage of a year for the indicated country

Automotive industry results from the supply chain model for the Thailand flood scenario are shown in Figure 59 for selected countries. A slightly lower CBI percentage of 18% was observed for Thailand. An estimate using CBI results and global trade data yields a global decrease in automobile production of approximately 1.9%.

This compares favourably with an estimate from UNISDR, which cites a drop in global industrial production of 2.5% directly from the Thailand floods (UNISDR 2012). With a low insurance take-up rate, it is reasonable to expect divergence between insured and economic losses.

Figure 59: CBI (%) for selected countries for automotive manufacturing. Loss is shown as a % of year for the indicated country



Engine manufacturer in New York

The Internet of Things (IoT) and the adoption of cloud technologies by companies have exposed weaknesses in supply chains to cyber attacks. According to the National Institute for Standards and Technology (NIST), nearly 80% of all information breaches originate in the supply chain, and nearly 24% of supply chain disruptions are caused by cyber attacks (RSA 2016).

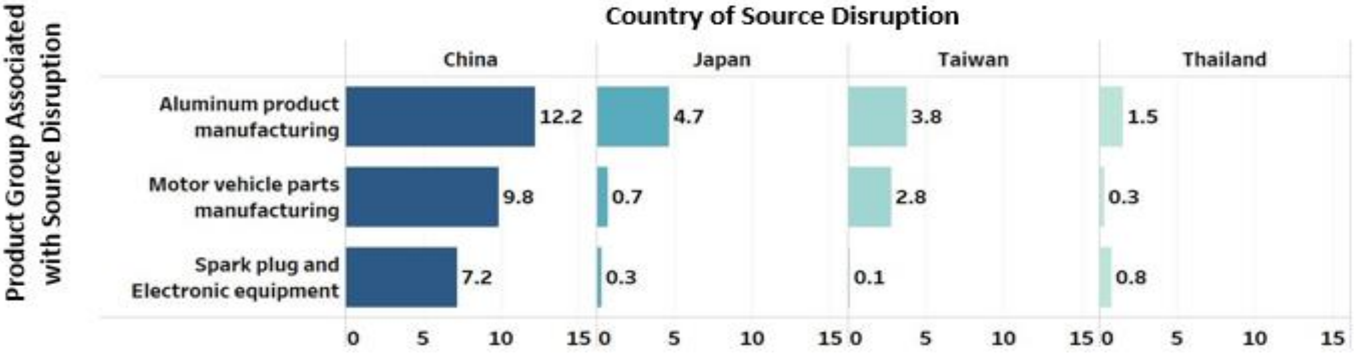
For example, in March 2019, a cyber attack on Norsk Hydro, one of the world's largest producers of aluminium, caused the shutdown of its automated production lines. The Norsk Hydro cyber attack highlights the interconnected nature of physical and virtual supply chains. Similarly, cyber attacks on critical infrastructure, such as ports, can bring global supply chains to a sudden halt.

This scenario analysis develops a cyber attack-induced supply chain disruption risk matrix for an automotive engine manufacturer in New York (Figure 60).

The resulting CBI losses from the analyses are presented in Figure 61 *(overleaf)*. The figure indicates that a two-week amount of cyber disruption to aluminium product manufacturing in China results in 12.2 days of CBI loss for the New York automotive engine manufacturer which sources aluminium products, motor vehicle parts and spark plugs & electrical equipment from suppliers in China, Japan, Taiwan and Thailand. For benchmarking purposes, two weeks of cyber-induced disruption applied to suppliers at each country-product combination is used to assess the resulting supply chain losses for the New York automotive engine manufacturer. Product flow networks for the engine manufacturer are created, and the source (cyber disruption of two weeks) is propagated through the value chain.

Figure 60: Automotive engine manufacturing plant in New York, United States

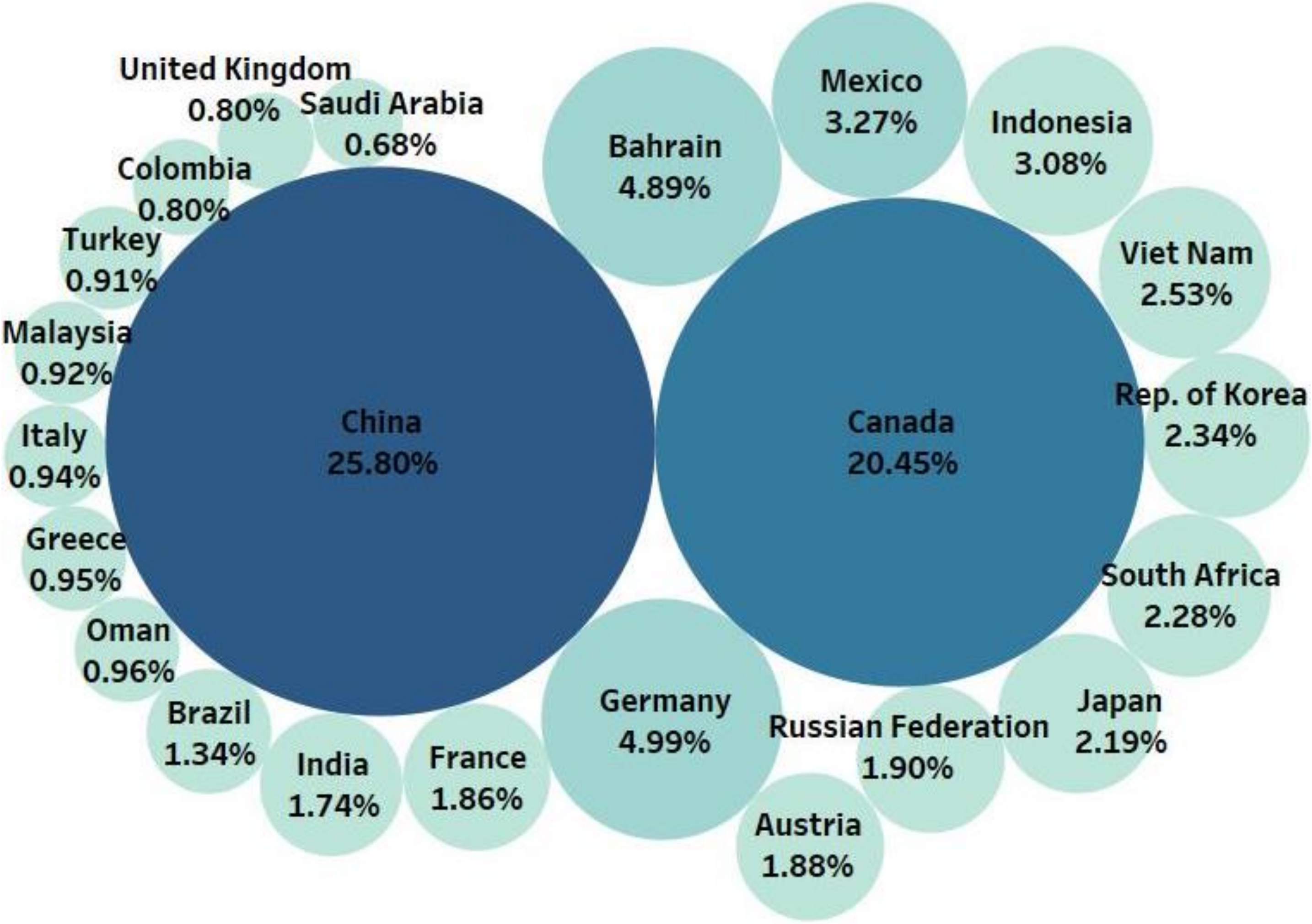
Figure 61: CBI loss (days) for an automotive engine manufacturer in New York



China is one the leading producers of aluminium in the world, and the United States imports nearly 26% of all aluminium products from China (Figure 62). With 7.5 million tonnes of annual production, China's Hongqiao Group is the largest producer of aluminium in the world. Disruption to this primary metal manufacturing facility can impact supply chains across the world, especially for tier 1 and tier 2 producers.

In contrast, the same two weeks of cyber disruption to spark plug & electronic equipment manufacturing in Thailand results in only 0.8 days of CBI for the automotive engine manufacturer in New York. Overall, disruptions in China, be they cyber or natural hazard–induced, have the most significant impact on the New York automotive engine maker. To enable data-driven risk selection and mitigation, insurers and corporate risk managers can use these risk matrices to identify risk hot spots, benchmark suppliers and product groups.

Figure 62: Top aluminium exporters worldwide



6. Modelling assumptions

Supply chains are inherently complex. The theoretical modelling framework discussed in this study simplifies and constructs abstract data from these complex real-world systems by making modelling assumptions about the knowledge gaps. The framework accounts for the scarcity of information, investigates product importance and constrains network flow (directionality).

Due to the global nature of supply chains, the model assumes that disruptions in any part of the world can potentially have a direct or an indirect impact on an insured's supply chain.

Network analysis is fairly straightforward when the relationships among each part of a supply chain and the amount of goods traded within the network are known. However, very few corporations or insurers have the full spectrum of information required to model their supply chains end to end.

To overcome the lack of information, the supply chain model leverages industry exposure, international trade data and recognised product relationships to design default networks that are representative of individual industries. The default networks can then be used to calculate the expected impact for an entire industry, and market share information can be used as a reliable first order approximation to arrive at losses to businesses.

It should be noted that while the supply chain model relies on default values and global averages *only* in the absence of company-specific information, custom product and supplier networks are easily integrated by using built-in model functionality, if that information is made available.

Companies rely on a multitude of parts to manufacture their products. There are several ways in which product importance can be accounted for, for modelling purposes, two of which are discussed herein. The first option is to treat all parts as equally important. For example, an automotive engine, and subsequently an automobile, cannot be produced without very inexpensive engine gaskets and seals.

The other method is to assume that the importance of a part to the final product is relative to the value of that part compared to all other parts required to make the product. Restated, the importance of a part is relative to its monetary value. Intuitively, it is reasonable that automotive manufacturing will be minimally impacted by a disruption in the supply of a bolt but will be largely dependent on the supply of an engine.

However, the Meridian Magnesium fire incident (AIR 2018) and the Xirallic paint disruption (Reuters 2011) proved otherwise, which underscores that supply chain networks are only as strong as their weakest link. In this modelling framework, it is assumed that all products are equally important to manufacture a final product.

Product flow feedback cycles exist in supply chains when one product category is used to manufacture another, which is then used to manufacture the initial product category. From an economic perspective, these cyclic relationships are indeed present.

For modelling purposes, however, these cycles represent infinite loops when regarding the directional flow of materials modelled in a supply chain analysis; loops in which disruptions can stagnate and eventually saturate the network with the impact of a lower-tier disruption on a final product. The supply chain solution employs an algorithm that iteratively eliminates this behaviour by removing links between industry groups that can create product feedback cycles. The resulting directional network is then used to calculate the impact on a downstream product caused by disruptions to higher-tier products.

7. Model limitations and sources of uncertainty

The generalised modelling framework proposed in this study is peril-agnostic and can be easily customised to analyse diverse disruption triggers (e.g., earthquake, industrial fire, cyber). The supply chain probabilistic analyses results presented in this report, however, are contingent on the natural catastrophe models that are currently supported in Touchstone® (Figure 29). While the Touchstone® platform includes most countries vulnerable to natural catastrophe disruptions, the model coverage is biased toward countries where insurance penetration is higher.

In addition, the supply chain model uses annualised trade data to model the flow of goods among different nodes in the supply network, and, hence, does not account for seasonal trends or cyclical trade. The CBI insurance market is still developing, and CBI insurance take-up rates are low. As a result, there are significant differences between economic and insured losses. Businesses may not publicly report supply chain disruptions to protect their market share and brand reputation. For these reasons, model calibration and validation studies relied on economic losses and not the insured losses.

Supply chain risk is calculated as the combination of hazard, exposure and vulnerability, and uncertainty can emanate from each of the modules in the modelling framework. The uncertainty associated with the proposed modelling framework can be categorised into epistemic and aleatoric components.

Epistemic uncertainty (i.e., uncertainty due to lack of data) comes from the lack of knowledge of the system being modelled and accounts for the uncertainty in model structure and parameters. Aleatoric uncertainty (i.e., inherent non-reducible randomness) represents data uncertainty and captures noise inherent in the observations.

To quantify the uncertainty, AIR employs probabilistic tools to estimate the impacts of both common and extremely rare events.

Typical model outputs from AIR's Touchstone® platform include mean estimates of BI and the associated standard deviations. In this study, however, only the mean values of BI are considered to calculate the resulting CBI losses. To obtain more accurate estimates of CBI and the associated uncertainty, the BI loss distribution can be sampled multiple times, and each BI sample could then be run in the supply chain model to create a loss distribution for CBI, along with uncertainty bounds.

8. Potential role for insurers and corporate risk managers using the risk modelling framework

As supply chains have continued to evolve, insuring interconnected BI and CBI risks has grown more challenging. Due to a scarcity of historical claims data and the emergence of unforeseen threats in value chains, there is no systematic method for an insurer or a corporate risk manager to quantify a supply chain's risk and project it for future scenarios. As a result, many insurers set relatively low limits, high deductibles and policy exclusions to constrain losses emerging from possible intangible aggregation scenarios in their portfolios.

The modelling framework proposed in this study offers a plausible solution to bridge these data gaps and knowledge limitations and to provide insurers and corporate risk managers with a rich set of quantitative metrics, which are more reflective of the actual risk to the businesses.

The supply chain modelling framework analyses millions of disruption scenarios against the exposure (supply chain network) and obtains losses for each event. From the loss results, the model calculates EP curves and AAL estimates.

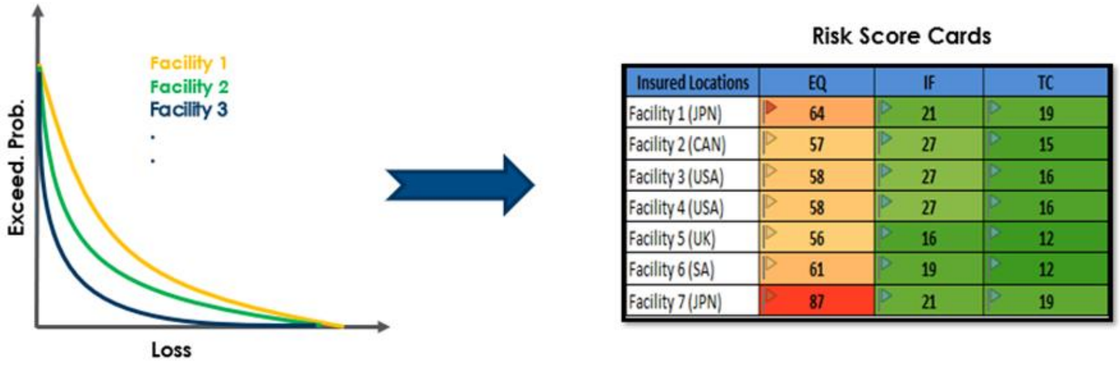
These metrics are more reflective of the risk to a business as they account for hidden vulnerabilities and future aggregation scenarios.

Standardisation can be done by transforming the risk metrics into equivalent risk scores, as illustrated in Figure 63. For example, the ratios between AAL and the 100-year return period (1% EP) losses could form the basis for individual supplier scores, which can then be scaled between 1 and 100 to arrive at an equivalent risk score. The indexed risk scores are easy to understand, enabling insurers and risk managers to identify nodes in their value chain needing the most attention.

Many other types of risk scoring platforms exist; however, these scoring platforms are based on looking back at what went wrong and cannot capture vulnerabilities in value chains before a disruption event happens.

The risk scores derived using the proposed framework are not just based on looking into the past (historical), but also looking forward to what could potentially go wrong in an insured's supply chain. This capability to prepare for many contingencies is key to ensuring sustainability for a business.

Figure 63: Transforming probabilistic modelling metrics to risk scores



Risk Score Cards

Insured Locations	EQ	IF	TC
Facility 1 (JPN)	64	21	19
Facility 2 (CAN)	57	27	15
Facility 3 (USA)	58	27	16
Facility 4 (USA)	58	27	16
Facility 5 (UK)	56	16	12
Facility 6 (SA)	61	19	12
Facility 7 (JPN)	87	21	19

Correlation of risks is another aspect that is often neglected by traditional scoring platforms and underwriters. Capturing correlation is central to understanding risk aggregations in interconnected risk.

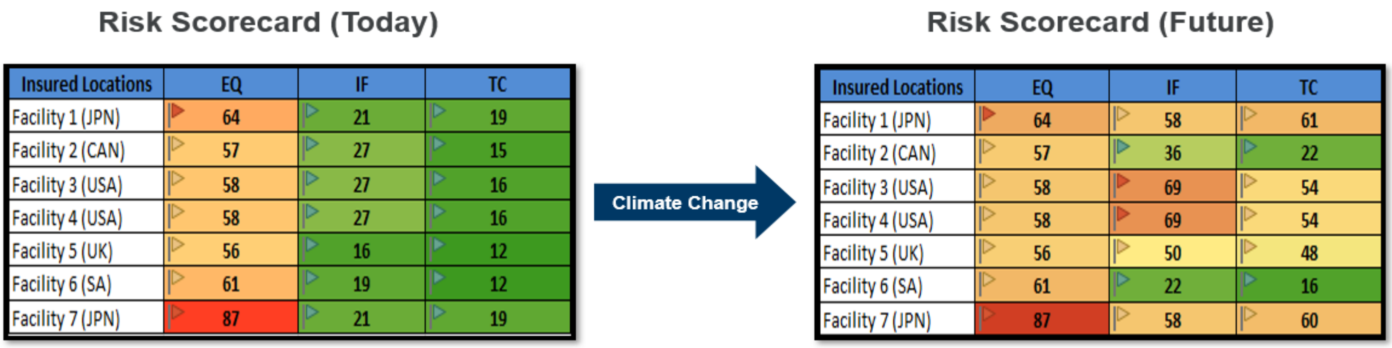
As outlined earlier in the report, the modelling framework proposed in the study accounts for spatial, product and supplier correlations, and the proposed risk scores reflect these interdependencies. The scores can be used by insurers to standardise and improve risk selection, make guidelines for automated underwriting, deploy capital and manage portfolio aggregations.

A compelling future concern, climate change presents further risk to insurers and corporate businesses. Climate change has been linked to an increase in extreme weather, which in turn may result in a rising risk of failures of critical infrastructure that manufacturing, and distribution networks rely upon.

Elevated sea levels are expected to displace populations and industries by permanently inundating coastal regions. Understanding the impact of climate change risks to interconnected systems can assist insurers and corporations in reshaping their portfolios and businesses.

Using the modelling framework discussed in the study, re(insurers) can future-proof their businesses by analysing different climate change scenarios on their exposures and develop risk mitigation strategies that include sustainability (Figure 64). Similarly, the risk scorecards can provide guidance to corporate risk managers on facilities under higher climate change risk that may require relocation and insurance placement.

Figure 64: Sustainability risk score cards



Risk Scorecard (Today)

Insured Locations	EQ	IF	TC
Facility 1 (JPN)	64	21	19
Facility 2 (CAN)	57	27	15
Facility 3 (USA)	58	27	16
Facility 4 (USA)	58	27	16
Facility 5 (UK)	56	16	12
Facility 6 (SA)	61	19	12
Facility 7 (JPN)	87	21	19

Risk Scorecard (Future)

Insured Locations	EQ	IF	TC
Facility 1 (JPN)	64	58	61
Facility 2 (CAN)	57	36	22
Facility 3 (USA)	58	69	54
Facility 4 (USA)	58	69	54
Facility 5 (UK)	56	50	48
Facility 6 (SA)	61	22	16
Facility 7 (JPN)	87	58	60

9. Call to action

To become resilient against vulnerabilities in value chains, insurers, corporations, and risk modelling companies may consider working together in developing data and analytics products for emerging interconnected risks. As part of the process, the risk management community should look to initiating and fostering dialogue, debate and research on the following topics.

Intangible aggregations

The globalisation of supply chains has exposed businesses to far-reaching consequences beyond the risks associated with their own manufacturing facilities and immediate suppliers. A systemic failure of critical infrastructure on one side of the world has the potential to cause catastrophic supply chain losses on the opposite side of the world.

Business interruption risks may be further exacerbated by climate change and the potential increase in the frequency of extreme weather events in many parts of the world. Increasing temperatures, along with precipitation-induced flooding and coastal flooding puts trillions of dollars of property at risk for chronic inundation due to rising sea levels.

Furthermore, ports, through which the majority of trade flows, are often located in low-lying areas and exposed to rising sea levels. Expected outcomes of climate change include industrial and population migration, which result in a shift of risk exposure.

In addition to natural hazards, the adoption of cloud technologies by companies has added a new threat vector for business interruption risk that stems from virtual value chains. As the physical and virtual value chains unify, the risk from interconnected systems may exceed the aggregation of risks from individual sectors.

To reinforce sustainability and future-proof businesses, both insurers and corporations should investigate intangible aggregation scenarios that their businesses may be exposed to and build resilience plans to address them.

Risk-adjusted supply chain optimisation

Typically, companies tend to look at supply chains only from quality and cost/spend perspectives. By focusing on high-spend products, risk managers fail to account for suppliers where total spend is low, but the financial impact of a disruption would be high. Integrating a risk dimension as part of supply chain planning has been commonly overlooked by businesses. Risk is a hidden cost that companies may not perceive until a disruption impacts them. To operate a sustainable business, companies should embrace risk management and explore ways to measure, monitor, mitigate and insure supply chain risks.

Developing data standards for underwriting supply chain risk

Supply chain data typically resides separately in a corporation’s disparate Enterprise Resource Planning (ERP) and Customer Relationship Management (CRM) systems. Integrating these systems to get a clear view of the business is challenging, and hence re(insurers) are often subjected to making data-constrained underwriting decisions.

By collecting and harmonising key attributes for CBI risk assessment, the re(insurance) community can help facilitate the development of a data standard for CBI risk underwriting. A data standard can help improve underwriting workflow by facilitating data transfer between different systems and vendors and build underwriting applications for a common data model in standardising risk selection and risk transfer across the industry.

Closing the protection gap

For businesses around the world, supply chain disruptions are costing billions of dollars in lost revenue each year. The take-up rate for CBI policies is fairly minimal, however, which may be attributed to the lack of insurance products that fulfils the needs of corporations. To close the existing protection gap, the (re)insurance community should partner with corporations to identify market demands and develop insurance products that fulfil market requirements.

Most big enterprises will have resilience measures, either in the form of inventory or insurance, to withstand supply chain disruptions. However, small and medium enterprises (SMEs), when impacted by prolonged downtimes, may fail without the essential protection that insurance affords.

To scale the underwriting process to cover SMEs, the insurance industry can explore the development of automated underwriting rules for CBI coverage and leverage economies of scale to offer coverage that is more affordable for SMEs. Similarly, parametric insurance products could be developed to increase market penetration and facilitate risk transfer to capital markets.

Advancing the science of supply chain risk modelling

Understanding supply chain risk is a Big Data problem that involves deriving actionable insights from large-scale multidimensional data sets. Applying qualitative methods to measure supply chain risk can lead to systemic oversimplification of the inherent complexities, thereby leading to underestimation of risk.

Advances in data mining and machine learning methods offer an alternative paradigm to develop predictive models that can identify patterns and complex interdependencies in supply chain data. Quantitative models, particularly the one discussed in this study, enable insurers and corporate risk managers to examine, analyse and measure supply chain risk from past, current and anticipated future events.

Quantitative metrics, such as AALs and EP curves, account for intangible aggregation scenarios. Adopting these metrics will empower businesses to transition from traditional to data-driven decision-making processes.

In summary, BI & CBI are two of the top risks for insurers and corporations. With increasing interconnectedness in both physical and virtual ecosystems, businesses are being exposed to higher BI risk than ever before. This white paper describes a novel approach to quantify interconnected risks. The scenarios discussed in this report just scratch the surface of potential applications of this framework for a diverse set of problems. The rich set of quantitative risk measures obtained from this modelling framework by running future aggregation scenarios enables businesses to transition from reacting to proactively managing supply chain risk.

While there has been a growing awareness of the potential threats posed by interconnected risk to businesses, the take-up rate of CBI policies remains minimal. Closing the protection gap before the next catastrophic supply chain disruption is pivotal for businesses and communities to stay resilient against emerging vulnerabilities and intangible aggregations.

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