Detect, Communicate, Collaborate:

An agile digital network to manage disruptions

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ABSTRACT

This project sought to address critical gaps in the extended supply chain network of the sponsor company by evaluating the efficacy of establishing a communication protocol with upstream suppliers to detect and mitigate supply chain disruptions. Leveraging an agent-based simulation model, the study examined what supply chain elements should be activated, and what internal and external stakeholders should be tracked to facilitate effective communication during disruption. The simulation results demonstrate the model's robustness in various scenarios, achieving a significant reduction in the detection lead time of disruptions ranging from 12% to 53%. By implementing the Supply Chain Digital Risk Console, Sponsor Company can benefit from early detection of disruption events and timely communication with appropriate stakeholders, resulting in faster responses to potential disruptions, a reduction in the Value at Risk, and an improvement in the supplier On Time In Full (OTIF) order fulfillment rate, thereby improving company’s overall supply chain performance and resilience.

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Prateek Tewari

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1. INTRODUCTION

The sponsor of this project is a multi-national enterprise (MNE) operating in the medical device industry. The annual sales of the company surpasses $25 Bn in 2019 (Sponsor Company, 2019). The medical device industry produces instruments, apparatuses, implants, machines, tools, etc., to diagnose, prevent, mitigate, treat, and cure disease or other conditions. This industry is a manufacturing success story that merges rapid innovation with precision product building and distribution.

As a global developer, manufacturer, and marketer of health care and medical products, our sponsor company has three business units:

- Pharmaceuticals: Produces pharmaceuticals, including prescription drugs
- Medical devices for health care providers: Produces high-tech devices for different complex medical procedures operated by health care providers
- Medical products for end consumers

Across our sponsor's medical devices business unit, they operate global supply chains to support the manufacture of products and their delivery to marketplaces and consumers. The company offers a range of products in interventional solutions, general surgery, orthopedics, and contact lenses. The operations of this business unit are divided into the following product verticals: Vision contact lenses, Trauma, Sutures, Spine, Electrophysiology, Knees, Hips, Endo cutters, Energy, Bio-surgical, and Vision surgical. Endo cutters, Energy, and Bio-surgical together form the medical devices department (Sponsor Company, 2022).

The project's scope with the sponsor is limited to the sourcing function within the medical devices department. Our sponsor's medical devices department is one of the leading providers of advanced medical devices for minimally invasive and open surgical procedures, focusing on procedure-enabling devices for the interventional diagnosis and treatment of conditions in general bariatric surgery and gastrointestinal health, genecology, and surgical oncology (Sponsor Company, 2022). The customers of the business unit are healthcare providers globally.

1.1 Motivation for the Study

Our sponsor has very high levels of complexity in their supply chain. It has more than 100 suppliers across multiple tiers of the supplier network and more than 2,500 raw materials/molds/tools used to manufacture finished goods. Regarding transportation networks, multimodal upstream and downstream transportation networks operate across sea, land, and air. Manufacturing-wise, there are more than 450 different work centers for suppliers and more than 50 work centers in owned manufacturing locations across four assembly/ packaging locations and four sterilization sites. Thus our sponsor company supplies more than 50 product families comprising 400+ products to the market (Sponsor Company, 2022).

A supply chain of innovation-driven high-tech products with such a high level of complexity globally is prone to risks and disruptions. These risks and disorders can be anticipated or unanticipated. Their source can be internal, external, or market-driven. Their severity and duration of impact can be of varying degrees.

To enhance the risk management of the supply chain, the sourcing function of our sponsor organization has several initiatives underway including project STAR-37, project SPRA, and project Hyperloop. These initiatives broadly align along the following dimensions:

- Macroscopic leading indicators of risk — An initiative of tracking leading indicators on a connected dashboard tool was proposed by the Sensing Testing Assessing Responding (STAR) class, a leadership development program. This dashboard model, which tracks global disruption events and their impact at a supplier level, is in a concept phase. It includes mapping the Bill of Materials (BOM) to the n-tier of suppliers, which enhances the risk assessment capability beyond just the 1st tier of suppliers (Sponsor Company STAR-37 Project Report, 2022).

- Supplier-specific risks - This is done through the Source Product Risk Assessment (SPRA) initiative. This initiative aims to identify risks associated with suppliers based on five scoring dimensions (Single/ Multisource, Quality, Reliability, Financial, Macroeconomics/ geopolitical). This tool can assess risk at a product, delivery node, and supplier location levels. This tool is in the pilot phase (Sponsor Company SPRA Initiative Report, 2022).
- Enhanced visibility with Tier 1 suppliers - This is done via the "hyperloop project," which entails implementing a digital tool. This tool will be embedded within the supplier portal, which is currently used by all vendors working with Vendor Managed Inventory (VMI) to understand raw materials/ component requirements and commit to shipment. This tool will allow our sponsors to have visibility into the capacity, inventory, and performance of their first-tier vendors. Our sponsor will be able to launch an event within the tool to inform the supplier of any changes in demand for finished goods. This tool is in the concept phase (Sponsor Company Hyperloop Project Report, 2022).

With the above initiatives in the concept or pilot phase, there is a rich landscape in risk identification and visibility with the 1st tier of suppliers. However, a gap exists in the following areas:

- There needs to be more visibility in the extended supply chain network, particularly the upstream suppliers (2nd tier onwards).

- There needs to be more proactive communication between internal and external stakeholders along the risk management process, especially when a disruption signal is identified.

Even though the sponsor company has made efforts to build supply chain resilience, there are still gaps in visibility across the extended SC network and proactive-timely communication. The motivation is to bridge the gaps so that the sponsor company can detect disruptions early to take proactive actions and minimize the effect brought by the disruptions.

1.2 Research Problem or Question

Once a supply chain risk is actualized, it may cause disruptions in the regular workflows. Therefore, it becomes essential to proactively manage complications arising from such events to mitigate or reduce their adverse effects. For instance, a disruption in the upstream supply chain can impact the supply of essential raw materials, necessitating the procurement team to swiftly shift their focus to alternative sources. Failure to act promptly may lead to a slowdown in production. To address such issues, active communication, collaboration, and accountability among all stakeholders become imperative. Currently, such event management efforts are being carried out by our sponsor through traditional communication channels such as emails. Such channels are designed to facilitate information exchange rather than provide a platform for collaboration. If such channels are used for collaboration efforts, problems like the volume of emails, unmanaged emails, or email phishing and hacking may arise.

In the context of collaborative efforts toward risk management and handling supply chain disruptions, these traditional email-based channels have the following shortcomings:

- They are designed for passive communication.

- They do not support fact-based, real-time, and semi-automated decision-making.
- They lack monitoring capabilities.
- They do not facilitate collaboration and prioritization of action items.
- They lack event management capabilities.

As a result, these communication channels are not designed for proactive and collaborative risk mitigation. Critical communications over these channels are often delayed or overlooked as they are mixed in with other non-critical emails. Thus, an effective tool that supports real-time event management is required.

Additionally, there needs to be clearer visibility of the risk associated with the upstream suppliers. For example, a disruption with the Tier 2 supplier can eventually affect the operations of our sponsor. Still, there is minimal visibility into such risks, as there is no information sharing or collaboration beyond the 1st tier of suppliers. If such risks can be identified in time, appropriate actions can be initiated to salvage the expected losses.

With those shortcomings in mind, the critical questions that are posed in this project are:

- Q1: What supply chain elements can our sponsor activate, and what internal and external stakeholders can our sponsor engage in tracking, triaging, and communicating supply chain disruptions effectively?
- Q2: How can our sponsor set up a protocol to ensure that a disruption event is detected early, that the correct information is communicated to the right stakeholders at the right time, and that the right actions can be taken promptly?

1.3 Project Goals and Outcomes

As part of this project, the team will leverage existing tools/platforms used by our sponsor and work with the sponsor’s digital team to create a Supply Chain Digital Risk Console. The aim is that this console will act as an integrated solution that can be used in conjunction with other digital platforms, such as mobile apps, for easy adoption by multiple stakeholders in the tracking and reporting of disruptions and events.

The team intends to illustrate the practical application of the tool by selecting critical scenarios that require the input of various data, including a bill of materials, supplier information, finished goods and component inventory, estimated sales, multi-node and sub-tier relationships, as well as market data for external risk analysis such as geopolitical risks. Furthermore, the team will leverage data from past supply chain disruptions and their effects to evaluate the efficacy of the new console. The sponsor team will also offer supply chain leading risk indicators and determine key performance indicators (KPIs) for comparing model performance and identifying suitable alternatives.

To streamline the communication on disruption signals, the team designed an information request form on labor, inventory, and other signals to gain insights into the suppliers' practices and identify any potential risks or opportunities for improvement. The information request will be conducted via a mobile app. The team also explored the possibility of cascading the information request form down to Tier 2 or Tier 3 suppliers to ensure that all levels of the supply chain are aware of potential risks and disruptions.

The following are within the scope of this project:

- Diagnosis of existing risk management processes and initiatives along the sponsor company's upstream and internal supply chain.
- Conceptual framework that helps the sponsor company bridge the gaps in supply chain disruption management and communication.
- Protocol to ensure early detection of a disruption event and that the correct information goes to the right decision-makers at the right time.
- Agent-Based Simulation Model for scenario analysis and dynamics understanding.
- Prototype of the mobile app, which should enable the following functions:
    - Enquire suppliers on labor, inventory, and any other signals with the possibility of allowing our Tier 1 supplier to cascade the information request form down to a Tier 2 or Tier 3 supplier.
    - Define a grid of clear roles and responsibilities to manage the disruption. This Grid may include: who can get access to the leading indicators, who leads the reaction activities, who support the event lead, what tasks are active, what the due date is for each task, and what is the current status of these events.
    - Share critical disruptions information with specific stakeholders based on profile and ask for feedback to summarize the new information request form.
    - Monitor global events, conduct supplier risk assessments, estimate impacts, and evaluate trade-off opportunities through a KPI dashboard.

The following is considered out of the scope of the project:

- Defining the supply chain leading indicators (the sponsor team already proposes these)
- Development of the Mobile App/Software
- Implementation of the protocol

- Anything not explicitly mentioned in the In-scope part of the document

This tool will be able to sense disruptions using macro-level event monitoring and micro level supplier information request forms. It will also be able to triage, communicate effectively, and take actions to mitigate them.

2. STATE OF THE ART

To address the central problems of our capstone — Q1: What supply chain elements can our sponsor activate, and what internal and external stakeholders can our sponsor engage in tracking, triaging, and communicating supply chain disruptions effectively? Q2: How can our sponsor set up a protocol to ensure that a disruption event is detected early, that the correct information is communicated to the right stakeholders at the right time, and that the right actions can be taken promptly? — We reviewed literature in several areas: (1) supply chain resilience and risk management, (2) supply chain digital transformation, (3) supply chain event management, and (4) Agent-Based Simulation and Modelling.

2.1 Supply Chain Resilience and Risk Management

In the context of business and management, risk can be defined as the potential for loss, damage, or negative impact on an organization's goals or objectives. It is the uncertainty that exists in any situation or decision that may result in either a positive or negative outcome(Giannakis & Louis, 2011). Disruption is defined as an event or circumstance that interrupts or interferes with the normal functioning of a process, system, or organization. In the context of a supply chain, disruption can refer to any unexpected event that causes a delay or interruption in the flow of goods or services. This can include natural disasters, labor strikes, supplier bankruptcy, transportation disruptions, and other unforeseen events that can impact the availability, quality, or cost of goods and services in the supply chain (Sáenz & Revilla, 2014).

Supply chain risk management (SCRM) is the process of identifying, evaluating, treating, and monitoring supply chain risks through the use of internal tools, techniques, and strategies, as well as external coordination and collaboration with supply chain partners, to reduce vulnerability and ensure the stability while increasing performance and competitive advantage (Fan & Stevenson, 2018). Risk identification, risk assessment, implementation of risk management actions, and optimization comprise the four steps of the risk management process (Giannakis & Louis, 2011). The extensive spectrum of supply chain risks (from both the supply and demand sides) may have detrimental effects on supply chain performance. This means companies need to enhance their supply chain resilience to ensure the continuity of their operations. For example, Cisco put mitigation measures in place to strengthen the resilience of its supply chain and discovered how to mix more reactive measures with proactive risk management measures, such as adding alternative supplier options (Sáenz & Revilla, 2014). Thus, to attain the required level of resiliency for their supply chain, companies must have effective strategies to manage these risks and disruptions (Giannakis & Louis, 2011).

In this capstone, we will simulate various disruption events for the sponsor company under multiple risk reaction scenarios and measure the detection lead time and cost impact to understand the dynamics. The detection lead time measures the amount of time it takes for the sponsor company to detect a disruption event in their supply chain or logistics operations. The shorter the detection lead time, the faster the company can respond to the disruption and minimize its impact. The cost impact measures the financial impact of the disruption event on the sponsor company. This could include direct costs such as lost revenue or increased expenses, as well as indirect costs such as damage to the company's reputation or customer loyalty. We aim to propose effective frameworks and protocols to help the sponsor company better manage its supply chain risks.

2.2 Supply Chain Digital Transformation

Digital supply chain transformation is the process of leveraging digital technologies to optimize and automate supply chain management activities, from sourcing raw materials to delivering finished products to customers (Saenz & Cottrill, 2019). Digital solutions can help with some challenges facing today’s supply chain. For example, supply chain communication can be improved by integrating different suppliers, clients, and processes through data gathering and information exchange (Preindl et al., 2020). Sharing information among supply chain components is one of the most important factors for lowering supply chain costs (McKinsey & Company, 2019). Literature has documented the benefits of information sharing on supply chain performance. As for today’s business world, there are still obstacles to information sharing among various supply chain actors. For example, some businesses are reluctant to provide comprehensive information to their partners. Different metrics standards, lack of mechanisms, and lack of guidelines are also regarded as the main challenges in information-sharing (Preindl et al., 2020).

During a roundtable discussion at MIT Center for Transportation and Logistics, the participants agreed that enabling digital transformation in both top-down and bottom-up manners with the appropriate skills and talent is essential. "Top-down" refers to changes and decisions made by leaders or management, while "bottom-up" refers to changes and ideas generated by employees or individuals at lower levels of an organization. In addition, deeply rooted behaviors and processes may be better understood along the journey of a digital transformation (Saenz & Cottrill, 2019).

To gain a competitive edge for a company, business strategy and IT strategy must be integrated to design and implement digital technologies. A digital technology roadmap can help achieve this goal. However, digital transformation roadmaps bear the risk of concentrating too much on the technology rather than the best way to achieve the supply chain objectives (Hartley & Sawaya, 2019). One risk associated with focusing too much on technology is the Frankenstein effect (Saenz et al., 2022). The Frankenstein effect refers to the unintended consequences or negative impacts of technological innovations. In the context of supply chain digital transformation, the Frankenstein effect can manifest in several ways. For example, implementing new technology without considering the impact on employees' work processes and job roles can lead to resistance and inefficiencies. Similarly, automating supply chain processes without considering the impact on customer experience can lead to reduced customer satisfaction.

Achieving supply chain resilience with end-to-end visibility and digital supply chain transformation involves leveraging digital technologies and tools to improve the visibility and agility of the supply chain. End-to-end visibility enables companies to gain real-time insights into their entire supply chain, from raw material suppliers to end customers, and to identify potential disruptions and risks before they occur (Saenz et al., 2022). Digital supply chain transformation provide companies with the ability to quickly respond to disruptions and make informed decisions to mitigate risks, thereby increasing their resilience (Saenz et al., 2022).

Derived from research work carried out with more than 40 companies, a Supply Chain Digital Transformation framework was presented in the Supply Chain Management Review (Saenz et al., 2022). This framework can be used to put companies on the right track and significantly increase the likelihood of success in their digital supply chain transformation efforts. The framework does this by enabling the companies to avoid common pitfalls of digital supply chain transformation. These common pitfalls were identified in this research as – A. The Frankenstein effect (digital efforts that are scattered and disconnected rather than holistic and based on a long-term vision of the company's entire value chain); B. Technocentrism (the tendency of most companies to become overly focused on technology when starting their digital journey); C. Unscalability (tech projects prove successful at the pilot stage, but falter when they are scaled up to capture economies of scale). This framework will be leveraged for this capstone project at section 4.2.1.

In this capstone, we will help the sponsor company optimize its risk management process by leveraging digital solutions. We will begin by conducting a comprehensive assessment of the current risk management process to identify pain points and areas for improvement. Then, we will design and develop a custom application that streamlines the process and enables real-time data collection and analysis. We will also work closely with the sponsor company's team to ensure that the new application and associated business processes are fully integrated with their existing systems and workflows. By doing so, we aim to help the sponsor company achieve greater visibility into its supply chain risks and enable faster and more informed decision-making. Ultimately, our goal is to help the sponsor company become more resilient and agile in the face of disruptions and uncertainties in the supply chain.

2.3 Supply Chain Event Management

Supply Chain Event Management (SCEM) is a process that involves monitoring and responding to events and disruptions that occur within a supply chain (Stölzle, 2004). It is the practice of tracking events, such as shipment delays or inventory shortages, in real-time and taking proactive measures to mitigate their impact on the supply chain. SCEM involves the use of software and other technologies to monitor the supply chain and provide visibility into the movement of goods and services. The goal of SCEM is to improve supply chain efficiency, reduce costs, and enhance customer satisfaction by identifying and addressing potential problems before they become major issues.

SCEM processes are typically broken down into two categories – Detection and Execution. The detection category includes monitoring the supply chain for patterns and signals of abnormality, and the execution category includes active management of such an abnormality (risk or disruption). These SCEM processes shift from traditional static risk assessment methods like supplier scorecards to a more dynamic-response-based approach depending on the nature, magnitude, and impact of disruption events. Such a dynamic-response-based approach is better suited to manage disruptions in the contemporary complex global supply chains (Sáenz & Revilla, 2014).

An essential precursor to Detection processes under SCEM is supply chain visibility. Supply Chain visibility is the ability to track the flow of goods/services, finance, and information across the nodes of the Supply Chain. Such an ability to accurately track the flow across the supply chain promptly enables early detection of abnormality within the system. Companies with the most complex and top-performing Supply Chains, like Cisco, have leveraged supply chain visibility to continuously monitor disruptive events that may impact their value chain (Sáenz & Revilla, 2014).

Monitoring tools are an essential antecedent to effective supply chain disruption management. However, they must also be closely paired with an efficient disruption response management system. Consequently, leading companies like Cisco have developed robust, tried, and tested crisis playbooks for response management. These crisis playbooks, based on the type of event and the expected magnitude of impact, can allow for the deployment of cross-functional response teams that can then actively manage the risk/ disruption (Sáenz & Revilla, 2014).

Such cross-functional teams must effectively collaborate and communicate throughout the lifecycle of disruption. It is, therefore, important to carefully understand the elements of collaboration quality to provide cross-functional teams with efficient tools and processes to execute disruption response efforts. These elements of collaboration quality include (1) Communication (Sufficient, open, and efficient information exchange between collaborative actors); (2) Coordination (Shared mutual understanding of roles, responsibilities, and goals); (3) Mutual support (willingness to collaborate actors to help each other in achieving commonly agreed goals); (4) Aligned efforts (Alignment of contributions provided by collaborating actors with the expectations of the contributions); and (5) Cohesion (Existence of the collaborative spirit between actors) (Dietrich et al., 2010). These elements of collaboration quality must act as guiding pillars for designing an efficient and effective SCEM tool.

Due to the limitations previously described, email is not the right tool for SCEM. Therefore, there is a need to design a tool that facilitates visibility and collaboration across the supply chain.

2.4 Agent-Based Modelling and Simulation (ABMS)

Agent-based modeling and simulation (ABMS) is a powerful tool for studying and understanding complex supply chain systems, especially in the context of risk management. ABMS allows for the modeling of both events and agents simultaneously, which is crucial for understanding the impact of different behaviors on the system's outcomes(Giannakis & Louis, 2011). Our methodology will incorporate ABMS to assess different disruption levels and response scenarios in our sponsor's supply chain network, helping us to identify potential risks and opportunities for improvement. By leveraging ABMS, we hope to gain a deeper understanding of the complex dynamics within the supply chain and make more informed decisions to mitigate risks and enhance resilience.

This computational approach models and simulates an interconnected system of agents. An agent can be an individual or a collective entity, such as an organization or group. This modeling method allows the agents to act and interact with each other within the system. The resulting outcomes of such actions allow for a better understanding of the system's behavior and what governs its consequences(Drogoul et al., 2003). For example, in the context of SCEM, the actors could be a Tier 1 supplier and the manufacturer. The behavior we can model under the SCEM context could be an information sharing – i.e., does the tier 1 supplier share information with the manufacturer? Based on this simulation of behavior, we can understand the outcomes within the system (Supply chain) – whether the manufacturer was able to manage disruption or not based on the information provided by the tier 1 supplier.

ABSM represents a recent development in supply chain planning that has been regarded as highly appropriate for studying risk management (Chen et al., 2013). Traditional risk management methods in Supply Chain Management included static supplier scorecards or event simulation using techniques like Monte-Carlo simulation. These models could also incorporate the probabilistic nature of events using stochastic programming (Chen et al., 2013). However, Supply chains are spatially and temporally dispersed, which adds much complexity to such modeling techniques. Moreover, the supply chains are impacted by events and the behaviors of different agents within the system. There is, therefore, a need to model such behaviors in conjunction with event-based simulation. This paves the way for ABMS, which can model both events and agents at the same time. In its basic form, ABMS merges discrete event simulation (which provides a simulation framework that models discrete events within an interconnected system) with object-oriented programming (which provides a structural framework that manages agent behaviors) (Chen et al., 2013). Using this technique, one can study the outcomes within a system (supply chain), incorporating event and agent-based dynamics.

Agent-based modeling and simulation (ABMS or ABM) are recognized as among the most promising paradigms for detailed investigations and reliable problem-solving of complex real-world supply chains. They assess, evaluate, and respond to supply chain risks by exploring possibilities, diagnosing problems, and finding flexible yet robust optimal solutions in SCM (BANKS, 1999). This is possible due to several abilities in this modeling technique:

- Ability to model with high fidelity/ accuracy the intrinsic complexity of real-world supply chains and complexity of interactions among agents
- Ability to compare alternative risk mitigation solutions under several constraints
- Ability to model and observe multiple performance measures at the same time

There have been many studies in the Supply Chain Risk management domain using ABMS. Chen et al. (2013) focus on the influence of information sharing on supply chain inventory levels. The study uses a 4-level multi-agent-based system (retailer, wholesaler, distributor, and manufacturer) with a decision-making model for every enterprise agent in the supply chain. The results from the research confirmed that the information-sharing strategy effectively decreases the variation amplitudes of inventory of each enterprise in the supply chain; i.e., the bullwhip effect is diminished when enterprises in the supply chain share information. Using a similar approach as described above, we will be modeling the agents (Tier 1 suppliers, Tier 2 suppliers and our sponsor) within our sponsor's supply chain network and use simulations to assess effectiveness of information sharing.

3. METHODOLOGY

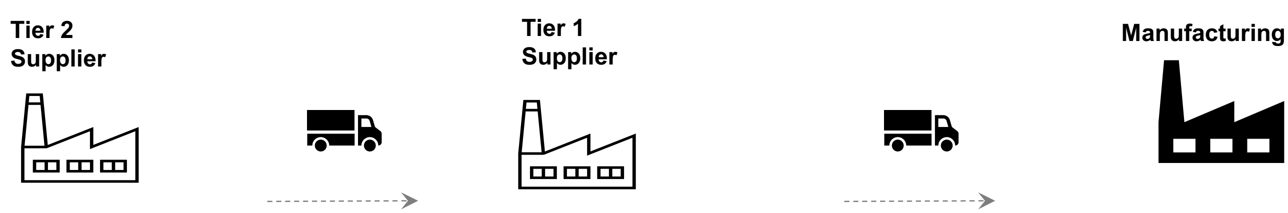
To address the key research questions, we explored an agent-based simulation model designed to detect and manage disruptive events in the upstream supply chain of our sponsor company. The model focuses on individual disruption events and considers each node in the supply chain as an agent. To provide a comprehensive understanding of the model, the section provides an overview of its architecture, including network configurations, criteria for creating different scenarios, and simulation logic. The model is evaluated based on the Detection Lead Time of a disruption, a metric that determines how well information is synchronized across supply chain nodes. It is calculated as the time difference between the occurrence of a disruption event and the time when the event is detected and communicated across the supply chain nodes (Sheffi, 2015). A shorter Detection Lead Time indicates that the supply chain nodes are quickly able to detect and communicate disruption events, allowing for faster response times and minimizing the impact of the disruption. Conversely, a longer Detection Lead Time suggests that there are delays in detecting and communicating disruptions, potentially leading to longer periods of supply chain disruption and increased costs. In examining the base model, we explored various supply chain parameters such as manufacturing lead time and inventory levels to determine how long it takes for a disruption to impact a downstream node. Overall, We aim to demonstrate the effectiveness of the proposed communication protocol in detecting and managing supply chain disruptions.

3.1 Configuration of the Agent-Based Simulation Model

An agent-based simulation is a unique simulation used to model complex systems with autonomous interacting agents. In its capacity to model complex and dynamic systems, it has the edge over other modeling approaches (including simple simulation models). The developing behavior of a complex system can be discovered by simulating the actions and interactions of autonomous agents. Because the agents (supply chain entities) can communicate, negotiate, and coordinate with one another, the application of agent-based simulation in this context seems promising (Giannakis & Louis, 2011). In our study, each node of the supply chain is an agent.

We create an agent-based simulation model to keep track of disruptive occurrences in the upstream supply chain of our sponsor company. The unit of analysis with this modeling and simulation exercise is individual disruption event, for example, a strike at a Tier 2 supplier. After discussions with the project stakeholders, we simulate a three-echelon supply chain as illustrated in Figure 1.

Figure 1: *Network configurations for the 3-tier supply chain model used in the simulation*



Note: This figure demonstrates a three-tiered supply chain that was used in the agent-based modeling and simulation to determine the value of establishing disruption detection communication protocol. The different frequencies of disruption simulation resemble naturally occurring characteristics of several types of disruptions, such as labor shortages, capacity bottlenecks, and shipment restrictions. This was done to check the robustness of the communication protocol while working with different naturally occurring disruptions. In the following sections, we will discuss the logic of simulation by explaining the base case of the model.

3.2 Setup of the Baseline Model

As shown in Figure 1, the simulation model has 3 tiers of supply chain nodes. At the upstream end is the Tier-2 supplier, followed by Tier-1 supplier and finally, the manufacturer. At each tier multiple supply chain nodes can be created to simulate the complexity of real-world, 3-tiered supply chains. Each node at each tier is an agent and has the following behaviors:

- Each node having any number of upstream nodes can seek periodic information from upstream nodes
- Each node having downstream nodes can provide periodic information to downstream nodes
- Manufacturing node has the additional capability of seeking ad-hoc information (to simulate the effects of communication protocol using internal and external signals of disruption)
- Each node connected directly with the manufacturing node can provide ad-hoc information when it is requested by the manufacturing node

The model incorporates the flexibility to set the periodicity of feedback independently at each tier/ node. The model also provides flexibility in setting appropriate cycle times for ad-hoc communication. This cycle time in this case denotes time taken across the complete lifecycle of ad-hoc communication, i.e., time taken to identify the disruption signal, determine the criticality of disruption, trigger ad-hoc upstream information request, and receive information request response. It is worth examining two separate scenarios with the ad-hoc information request cycle – System integrated (communication via an app) and non-system-integrated (manual communication via email) scenario. This will be helpful in understanding if there will be any value added derived from adopting a system-integrated approach to communication versus the non-system-integrated approach. The average cycle time will be lower for a system-integrated approach using an app vs the manual information request form release and responses in a non-system-integrated approach.

The model incorporates SC parameters like manufacturing lead time, replenishment lead time, and inventory levels at each upstream node to determine when the disruption reaches the downstream node through a reactive AS-IS communication scenario. In the TO-BE scenario, where the disruption communication protocol is established, the information passes from an upstream node to a downstream node through information request responses (periodic and ad-hoc) and reactive AS-IS communication, whichever happens, earlier. In theory, the disruption detection using communication protocol in the TO-BE scenario, should detect disruption earlier than the AS-IS scenario of reactive communication. The best-case scenario is the maximum improvement that can be reached with same-day information exchange about disruption occurrences.

This KPI of time elapsed from the occurrence of disruption at an upstream node until the detection of the same disruption at a downstream node is termed as Detection Lead Time of the distuption for the downstream node (Sheffi, 2015). This is the output KPI that needs to be measured to establish value from proactive communication protocol vs. reactive communication protocol in case of supply chain disruptions.

3.3 Disruption Scenarios

In our simulation model, the disruption events are happening at Tier 2 supplier level. Disruption events can happen with various causes, such as labor shortages, natural disasters, and shipment restrictions. The disruption events can happen stochastically based on the disruption frequency set in the model – monthly, quarterly, semi-annual, and annual.

To evaluate the proposed communication protocol's robustness, we developed and tested several "what-if" scenarios. These scenarios were constructed based on specific criteria, including deterministic supply chain (SC) parameters and stochastic SC parameters with low and high dispersion. Additionally, we varied the frequency of disruptions, testing scenarios with high frequency (monthly), moderate frequency (quarterly), medium frequency (semi-annual), and low frequency (annual) disruptions.

By examining these scenarios, we were able to test the protocol's ability to effectively communicate disruption events to the appropriate stakeholders and facilitate prompt action. The use of deterministic and stochastic parameters allowed us to explore the protocol's performance in both stable and volatile SC environments. The different disruption frequencies enabled us to evaluate the protocol's effectiveness in responding to disruptions of varying magnitudes and durations.

Overall, the development and testing of these scenarios allowed us to thoroughly evaluate the proposed communication protocol's resilience and suitability for managing disruptions in complex supply chain environments.

3.4 Evaluation Metrics (KPIs)

The objective of our study is to evaluate the efficacy of the proposed communication protocol, which includes periodic and ad-hoc information requests, in managing disruptions in a complex supply chain with multiple tiers. To measure the performance of the protocol, we have selected the Detection Lead Time for the disruption event as the key performance indicator, which measures the synchronization of information (i.e., disruption occurrence) across supply chain nodes. A lower value of this indicator indicates a higher level of synchronization among the nodes, whereas a higher value indicates lower synchronization.

The information asymmetry regarding the knowledge of existing disruptions among supply chain nodes results in downstream nodes being adversely affected due to late detection of the disruption. This can cause production shutdowns or lost sales. Conversely, proactive communication reduces information asymmetry and synchronizes all nodes, thereby enabling early detection of disruptions. Early detection allows each node to react and mitigate disruption before operations are impacted.

Thus, we aim to demonstrate the importance of synchronized information flow in reducing disruption lead time and enhancing supply chain resilience through the proposed communication protocol.

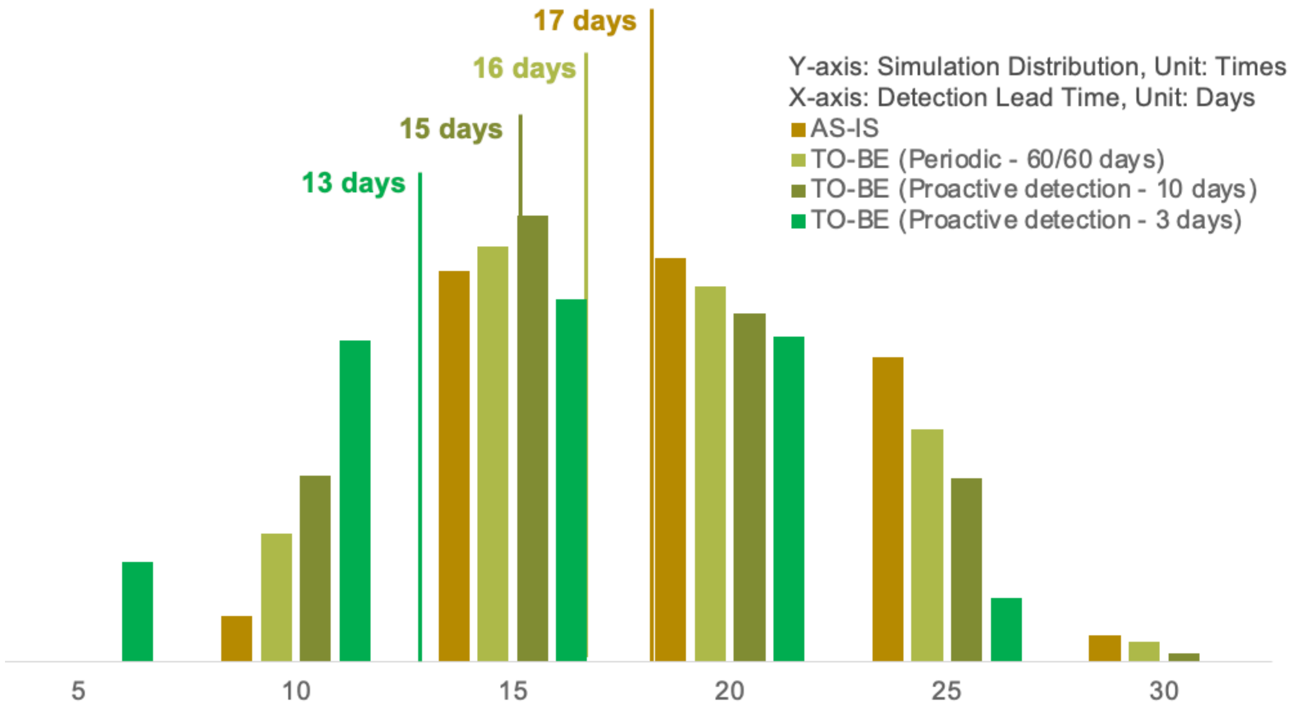
4. RESULTS AND DISCUSSION

In this section we will first review the results from the agent-based modeling and simulation. Next, we will discuss the implications of these results on designing the communication protocol. Finally, we will discuss the insights from the state of the art and stakeholder interviews in a digital supply chain transformation framework which has implications for designing the application and associated processes.

4.1 Simulation Results

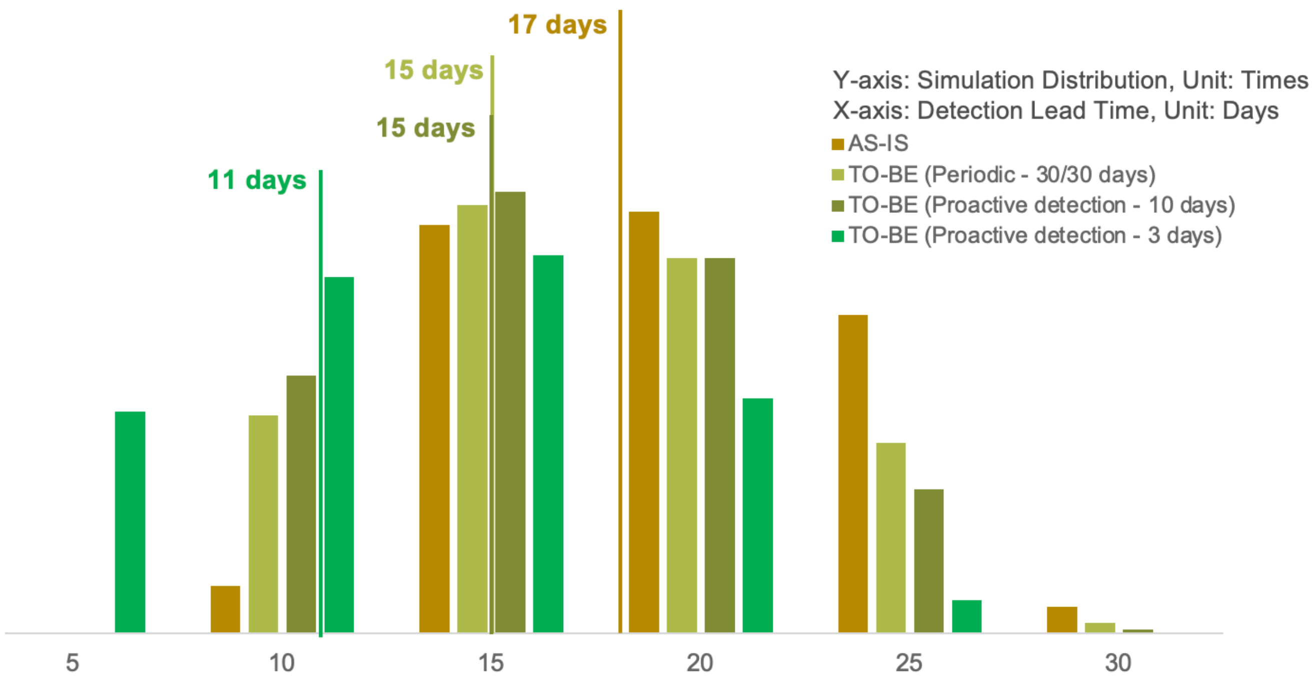
The results from the simulation with deterministic supply chain parameters can be summarized with below sets of figures:

Figure 2: *Results for a 60-day periodic cycle*



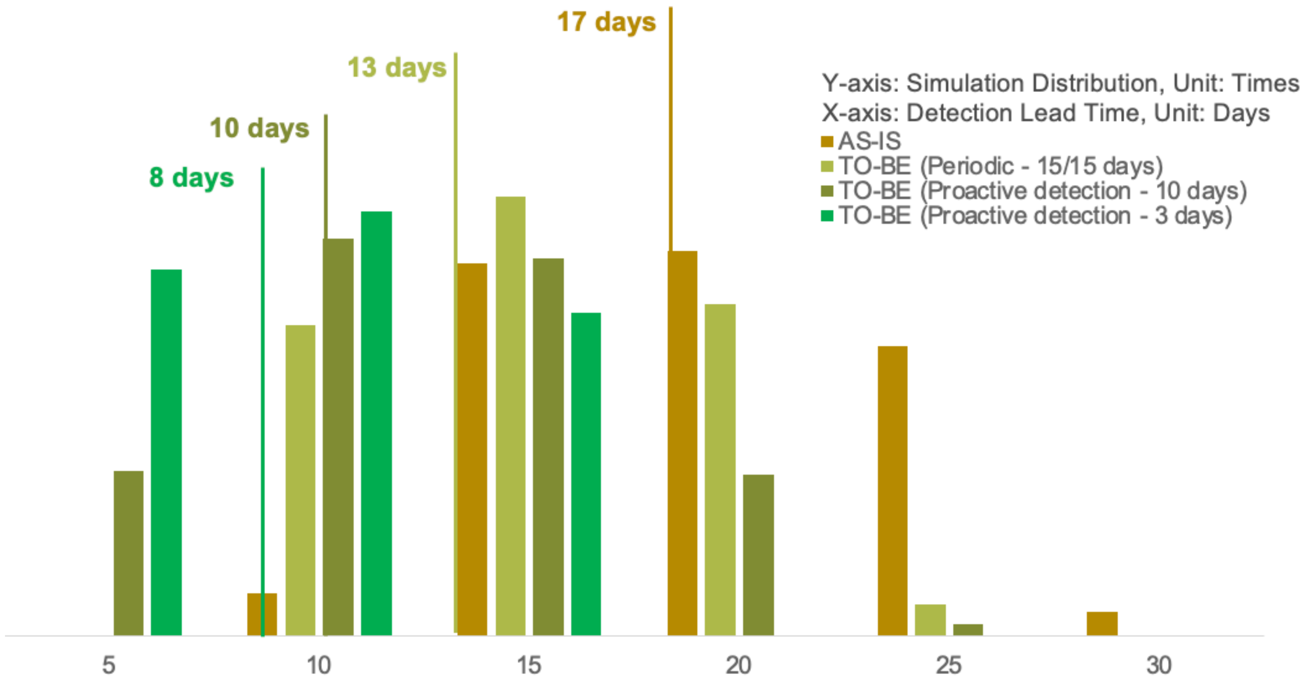
Note: This figure illustrates results from simulation on a 60-day periodic cycle. Each series represented by a different color denotes an independent Monte-Carlo simulation batch of 1000 runs. It can be seen from the graph that the mean disruption detection lead time in the AS-IS scenario is 17 days, which can be reduced to 16 days by a 60-day periodic feedback cadence provided by Tier-2 to Tier-1 and Tier-1 to the Manufacturing node. If the ad-hoc information request cycle with non-integrated systems (10 days) is introduced between Tier-1 and Manufacturing node, the mean disruption detection lead time decreases to 15 days, which further decreases to 13 days with a system-integrated (app-based) approach to the ad-hoc information request cycle (3 days).

Figure 3: *Results for a 30-day periodic cycle*



Note: This figure illustrates results from simulation on a 30-day periodic cycle. Each series represented by a different color denotes an independent Monte-Carlo simulation batch of 1000 runs. It can be seen from the graph that the mean disruption detection lead time in the AS-IS scenario is 17 days which can be reduced to 15 days by a 30-day periodic feedback cadence provided by Tier-2 to Tier-1 and Tier-1 to the Manufacturing node. If the ad-hoc information request cycle with non-integrated systems (10 days) is introduced between Tier-1 and Manufacturing node the mean disruption detection lead time remains same (i.e., 15 days) but reduces dramatically to 11 days with a system-integrated (app-based) approach to ad-hoc information request cycle (3 days).

Figure 4: *Results for a 15-day periodic cycle*



Note: This figure illustrates results from simulation on a 30-day periodic cycle. Each series represented by a different color denotes an independent Monte-Carlo simulation batch of 1000 runs. It can be seen from the graph that the mean disruption detection lead time in the AS-IS scenario is 17 days which can be reduced to 13 days by a 15-day periodic feedback cadence provided by Tier-2 to Tier-1 and Tier-1 to Manufacturing node. If the ad-hoc information request cycle with non-integrated systems (10 days) is introduced between Tier-1 and Manufacturing node, the mean disruption detection lead time decrease to 10 days which further decreases to 8 days with system-integrated (app-based) approach to the ad-hoc information request cycle (3 days).

Figures 2 – 4 summarize the proof of value in establishing a communication protocol with upstream suppliers. This can be seen by a decline in the primary target KPI – detection lead time for the disruption event with introduction of communication protocol. By establishing a periodic communication protocol with upstream suppliers, the information sharing across the supply chain network increases. This increase in information sharing is the main reason for reduction in disruption detection lead time as the information of disruption trickles down the network faster than the scenario without any communication protocol. Figures 2 – 4 highlight the results from the simulation with deterministic supply chain parameters. These figures clearly demonstrate an improvement in the primary target KPI (disruption detection lead time) by establishing a proactive communication protocol with upstream suppliers as compared to the AS-IS ways of reactive communications.

The simulation was also run with stochasticity in supply chain parameters like lead time and inventory levels. This was done to ensure that there is value from communication protocol under real world settings where such supply chain parameters are non-deterministic in nature, i.e. they can't be predicted with certainty. This means that these parameters vary a lot under real life conditions. To test the value of communication protocol under such a setting stochasticity was introduced in modelling of supply chain parameters. We get the results showing that the communication protocol adds value by lowering the disruption detection time under stochastic supply chain conditions of real world. Two scenarios were evaluated – A. Low degree of variation (+/- 10% deviation of supply chain parameters around their deterministic value); B. High degree of variation (+/- 30% deviation of supply chain parameters around their deterministic value). In both scenarios, there was a consistent improvement in the primary target KPI (disruption detection lead time) by establishing a proactive communication protocol with upstream suppliers as compared to the AS-IS ways of reactive communications via email. This means that establishing a communication protocol with upstream suppliers will help reduce the disruption detection lead time even if there is high variability in the system regarding unpredictable supply chain paramaters like lead times and inventory levels.

In addition, the simulation was run for different types of disruptions differing in their intensity of impact. This was done to ensure there is value in establishing a communication protocol with upstream suppliers for different types of disruption scenarios. The consistent improvement in the target KPI – detection lead time of disruptions indicates that there is value in information sharing by communication across the supply chain network in different types of disruption scenarios. Five different frequencies of disruption occurrence were used in this simulation – Monthly, Quarterly, Semi-annual, Annual and Rare disruption occurrence (greater than 1 year). We get results from the simulation showing that there is consistent improvement in the target KPI in all types of disruptions by establishing a proactive communication protocol with upstream suppliers as compared to the AS-IS ways of reactive communications via email. This means that establishing a communication protocol with upstream suppliers will help in reducing detection lead time of disruptions for high impact low frequency disruptions like natural disasters to low impact high frequency disruptions like labor related issues.

4.2 Discussion

In this section we will discuss the key findings from the simulation and their management implications. We will also discuss the insights gathered from the state of the art and stakeholder interviews into a digital supply chain transformation framework which has implications in designing Supply Chain Digital Risk Console and associated processes.

4.2.1 Supply Chain Digital Transformation Framework

Digital supply chain transformation (DSCT) requires the application of digital technology and data to transition toward a value-driven supply chain. Hence, the key question for companies embarking on this journey is how will they embrace the end-to-end opportunities yielded by a digital supply chain? Also, how do they dynamically create the right digital capabilities to retain the flexibility to change with the evolution of markets? Once these questions are addressed, technology solutions can be brought into play as an enabler of these capabilities—not earlier in the process (Saenz et al., 2022).

As mentioned in section 2.2, the Supply Chain Digital Transformation framework is leveraged for this capstone project. This framework consists of three main steps:

- **STEP 1: Create the VISION –** Because DSCT enables the transition to a value-driven supply chain, the first step is to clarify how the company envisions the supply chain's contribution to its strategic goals and the deficiencies that hinder the achievement of these goals. This vision will serve as a long-term guide for the DSCT process and will help the company to set specific goals that may evolve over time as digitalization progresses and matures. In case of this DSCT for the sponsor company, the vision is "**enabling a SYNCHRONIZED NETWORK**". This translates into a supply chain network that is more synchronized through improved information sharing at each supply chain node. Such synchronization of the network harmonizes the network-wide efforts toward risk identification and management, which is extremely pertinent in disruption management
- **STEP 2: Integrate the STRUCTURAL LEVERS –** There are three structural levers that companies should pull in order to start this transformation:
    - **Processes –** Processes that support the supply chain vision must be identified, mapped and analyzed in order to pinpoint the problem areas, ascertain which technologies are in use, the availability of data, and identify the actors involved. Often, these processes must be reconfigured to enable digital transformation and make the most of the new digital tools. It may be necessary to design new supply chain processes because digitalization does not simply

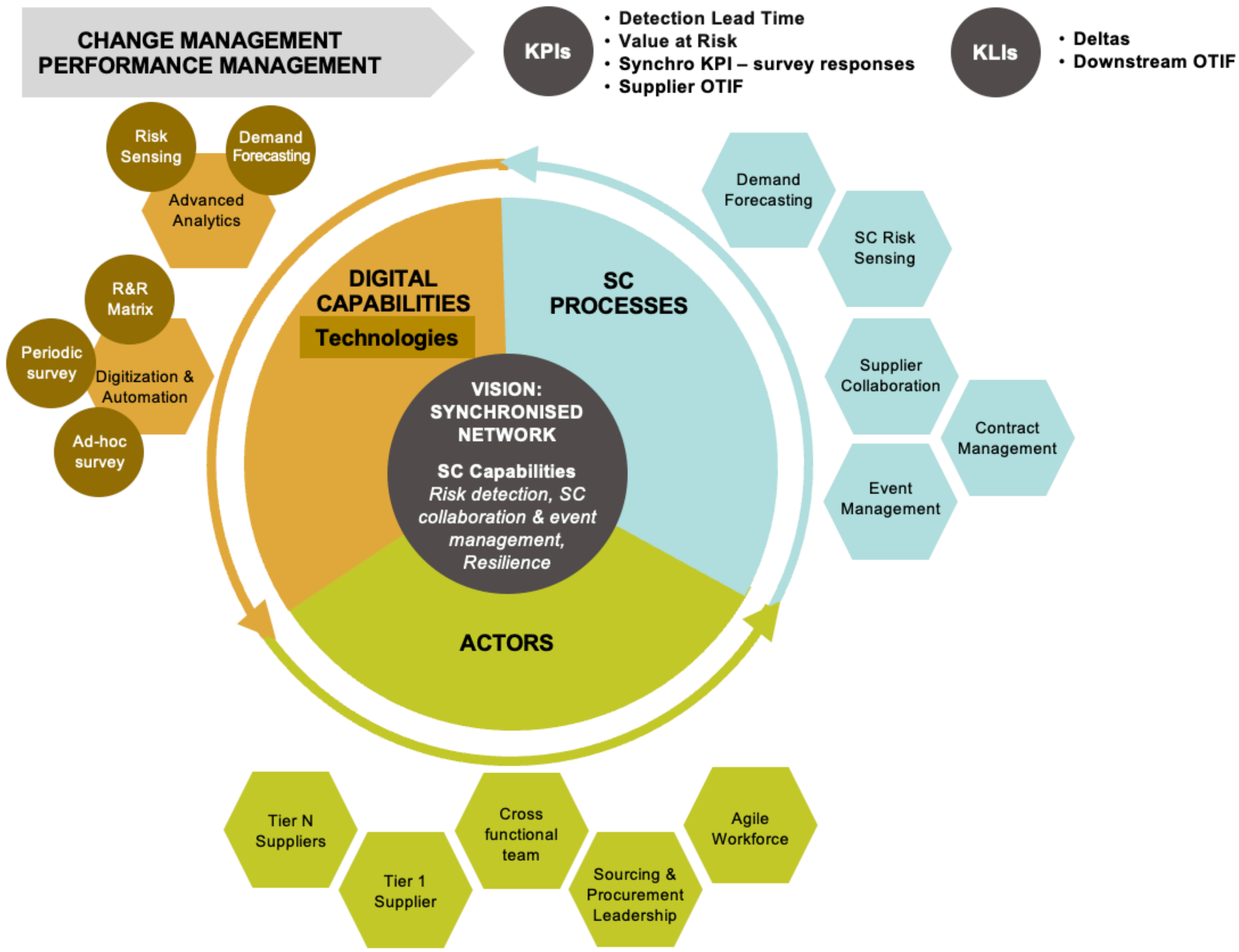
involve the implementation of new technology but a new digital mindset for running operations. In case of this DSCT for the sponsor company, the processes involved are Demand Forecasting, Supply Chain Risk Sensing, Supplier Collaboration, Contract Management, and Event/ Project Management

- **Digital capabilities –** These are the key competencies that a company requires to achieve its supply chain vision through the application of digital technologies. Each company needs to develop a different set of digital capabilities to realize its vision. Also, developing each digital capability requires certain digital technologies to be deployed and the right kind of data. However, it is important to be technology agnostic when evaluating the necessary capabilities and to bring in technologies and data as enablers of the vision. In the case of this DSCT for the sponsor company, the digital capabilities are Advanced Analytics, Digitization & Automation. The associated technology elements include Risk Analytics, Machine Learning and Natural Language Processing.
- **Ecosystem of Actors –** DSCT programs are implemented and influenced by people and departments. To succeed, a digital transformation project teams need to consider the ever-changing ecosystem of actors involved. A combination of top-down and bottom-up approaches is usually the most successful path for DSCT teams to follow. In all likelihood, senior managers trained in digital transformation will lead the strategy's deployment. These leaders need to inspire and promote a new agile culture of working and remove any boundaries and silos that impede progress. Meanwhile, achieving buy-in from the operational actors whose work and processes will be affected by the transformation is essential. In case of this DSCT for the sponsor company, the actors involved are Tier N Suppliers (n denotes the distance from sponsor nodes – e.g., Tier 1 suppliers are direct suppliers to the sponsor

company, Tier 2 suppliers are direct suppliers of Tier suppliers, and so on), cross-functional teams to manage disruption projects, agile workforce, Sourcing & Procurement Leadership and third-party partners.

- **STEP 3: Activate the DRIVERS OF CHANGE –** The digital transformation should be envisioned as a lifelong journey. A journey of continuous discovery and reconfiguration. Companies may transition from early adopters to mature digital entities through a series of loops that reinforce and improve their digital capabilities. These feedback loops are represented in the framework by the circle in which the structural levers are integrated along consecutive rounds, enabling the company to become proficient in the "digital language" enabled by the data. Having acquired a digital language, the company can select KPIs to measure the progress of its DSCT efforts and develop KLIs to refine the set of KPIs as needed. This combination helps the company maximize the benefits derived from digitalization. Each feedback loop may require different Key Performance Indicators (KPIs) and Key Learning Indicators (KLIs), and these measures might have to be modified as the DSCT program evolves. Project teams should also keep in mind that KPIs are intended to measure their progress toward realizing the supply chain vision (enabling a synchronized network)— not the level of implementation of digital technologies. Some companies are inclined to take the latter path to justify their ROIs, which must be avoided. In case of this DSCT for the sponsor company, the KPIs are Detection Lead Time of disruptions, Value at Risk, Synchro KPI – timeliness and accuracy of information request responses, supplier On Time In Full order fulfillment (OTIF), risk prediction accuracy, and risk recording accuracy. While the KLIs are deltas in the KPIs and downstream OTIF (On Time In Full order fulfillment by the sponsor to their downstream nodes). These deltas in KPIs and the downstream OTIF forms a governing set of Indicators to monitor to evaluate performance on the vision of enabling a synchronized network. Figure 5 highlights the framework in a pictographic manner:

Figure 5: *Digital SC Transformation Framework for an agile digital network to manage disruptions*



Note: This figure demonstrates the digital supply chain transformation framework for the sponsor company.

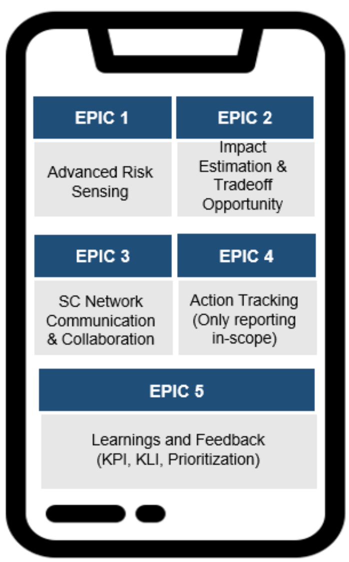
4.2.2 The Supply Chain Digital Risk Console

The Supply Chain Digital Risk Console is a mobile application designed to assist the sponsor company and its suppliers in identifying, assessing, and managing risks that could impact their operations. The software has several features:

- Advanced risk-sensing capabilities
- Risk Impact Analysis and Decision Tradeoff features
- Supply chain network communication and collaboration tools
- Action management functions
- Learning and feedback mechanisms

All of these features work together to help users manage risks, estimate the potential impact of different decisions, communicate and collaborate with their supply chain partners, take action based on their insights, and learn from their experiences.

Figure 6: *The design of the Supply Chain Digital Risk Console for the sponsor company*



Note: This figure demonstrates the design of the Supply Chain Digital Risk Console for the sponsor company.

The following sections of this report discuss the advanced risk sensing and impact-estimation, and tradeoff features based on multiple stakeholder interviews conducted with subject matter experts from sponsor organization.

4.2.2.1 Advanced Risk Sensing

This section identifies different signal sources of risk and highlights the requisite analytical element associated with each signal to process them further. The source signals for risk can be broadly classified into five categories:

A. **Internal** – The signal for this category primarily comprises downstream demand patterns. A sudden spike in downstream demand can potentially cause a disruption in the sponsor's ability to fulfill orders. This can be sensed and acted upon by deploying rules based on advanced analytics conducted on demand forecasts, inventory positions and shipment receipts

B. **Extended Supply Chain Network** – The category signals a potential disruption in the upstream extended supply chain network. The disruptions could be further sub-classified as disruption due to installed capacity shortage, labor shortage, transportation disruption and raw material shortage. The signals for these types of disruptions could be received via rules based on analytics (e.g. monitoring production backlog vs installed capacity for tier 1 suppliers for issues related to capacity, monitoring supplier OTIFs for issues related to labor shortages, monitoring transportation reports for issues related to logistics and 3PL providers, proactive sourcing material category monitoring for issues related to raw materials), global event monitoring and periodic information request based communication with upstream suppliers

C. **Natural Hazards –** These signals pertain to extreme natural events like fire, storm, earthquakes etc. While these are rare (low frequency) and extremely difficult to predict events, they cause sudden and high impacts on the supply chain network. Under the Supply Chain Digital Risk Console, the sponsor will aim to detect these types of disruptions as soon as possible from the timeframe of their occurrence so that the downstream effect can be minimized. This can be done effectively by mapping the extended supply chain (to record the geographical spread and quantify the dependence on extended suppliers) and global event watch (to stay current with respect to the state of functioning of the extended supply chain network)

D. **Economic/ geopolitical events –** With global supply chains, economic and geopolitical events like wars, embargos/treaties, new rules and legislations, taxation policies etc. pose an additional layer of risk which can be monitored by mapping the extended supply chain (to record the geographical spread and quantify the dependence on extended suppliers) and global event watch (monitoring the newsfeed for any potential signal of such economic/ geopolitical events)

E. **Market dynamics –** Another source of potential disruption are the market forces, including the competitor's strategy on their products and services. These can be actively monitored via global event watch (monitoring newsfeeds for potentially impactful events triggered by market dynamics). Figure 4 highlights these sources of signals and the approach to capture them at a nascent stage to minimize the effects of disruption

Figure 7: *Classification of Signal Sources of Risk*

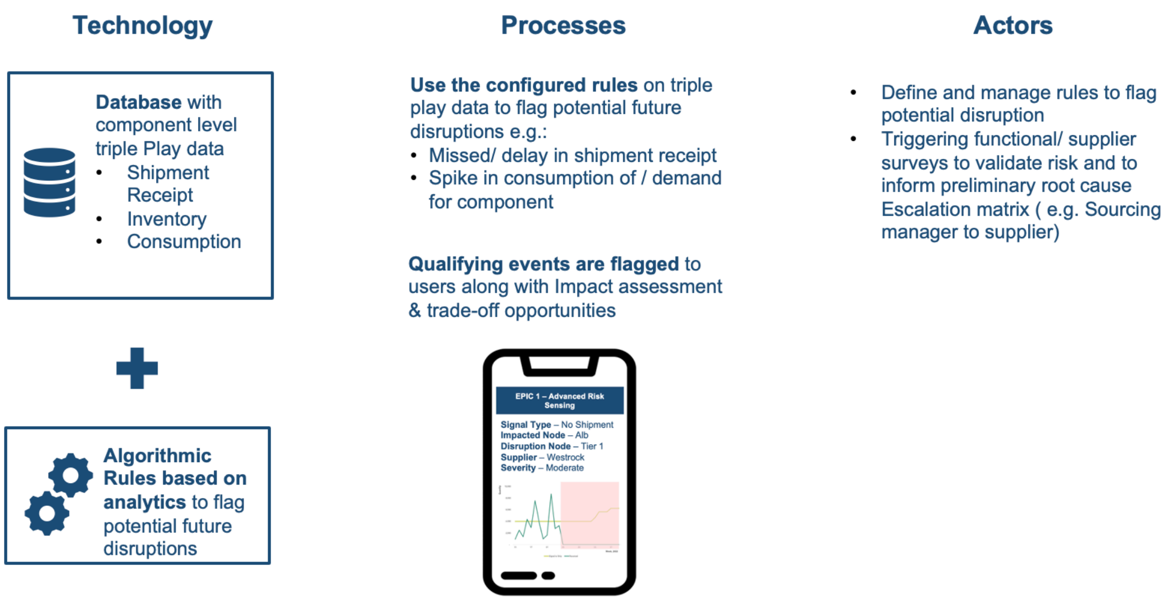
Signal Source level 1	Signal Source level 2	Signal	Mode
Internal	Demand	• FG/ Component demand	Analytics on • Inventory position & shipment receipt • Regression based algorithm implemented at Sponsor Company
Extended SC Network	Installed capacity	• Reduction in OTIF • Shipment delay • Partial order fulfilment • Increase in quality rejects	• Periodic survey • Analytics on Production Backlog vs installed capacity algorithm
	Labour	• Reduction in OTIF • Shipment delay • Partial order fulfilment • Increase in quality rejects • Newsfeed	• Periodic survey • Global Event Monitoring
	Transportation	• Reduction in OTIF • Shipment delay • Newsfeed	• Periodic survey • Global Event Monitoring • Sponsor Company Transportation report (on risk assessment)
	Raw Material	• Inventory health of Tier 1 supplier • RM supplier OTIF	• Periodic survey • Global Event Monitoring • Sponsor Company Source Category monitoring (weekly/ monthly report of risk)
Natural Hazards	Extreme natural events (Fire, Storm, earthquake)	• Newsfeed	• Global Event Monitoring
Economic/ Geopolitical	War, embargo/ treaty	• Newsfeed	• Global Event Monitoring
Market	Competitor product	• Newsfeed	• Global Event Monitoring

Note: This figure demonstrates the classification of sources of risk signals and highlights the approach to capture them at a nascent stage to minimize the effects of disruption.

The above signal sources classification helps in understanding what approach is to be deployed to actively monitor and manage risks arising from these different sources. The approach to monitor and manage these signal sources can be further classified into the following three categories:

A. **Advanced Analytics of Signal Sources** – This type of action can be carried out on signals sources that present an active relational dataset, e.g., each company maintains data on demand forecasts, inventory positions, and shipment receipts. Analytics can be implemented on this relational dataset to uncover patterns that can signal potential disruption. This approach can be summarized in Figure 5. The technology involved in this approach is the creation of a relational database of shipment receipts, inventory positions, consumption data, as well as demand forecasts. Analytics can be used to uncover patterns in this data, and rules can be established on the relevant metrics in a way that triggers some downstream action (e.g., trigger validation information request with the supplier to confirm the risk identified in the patterns from the dataset)

Figure 8: *Use case for Analytics-driven approach for early disruption signal detection*



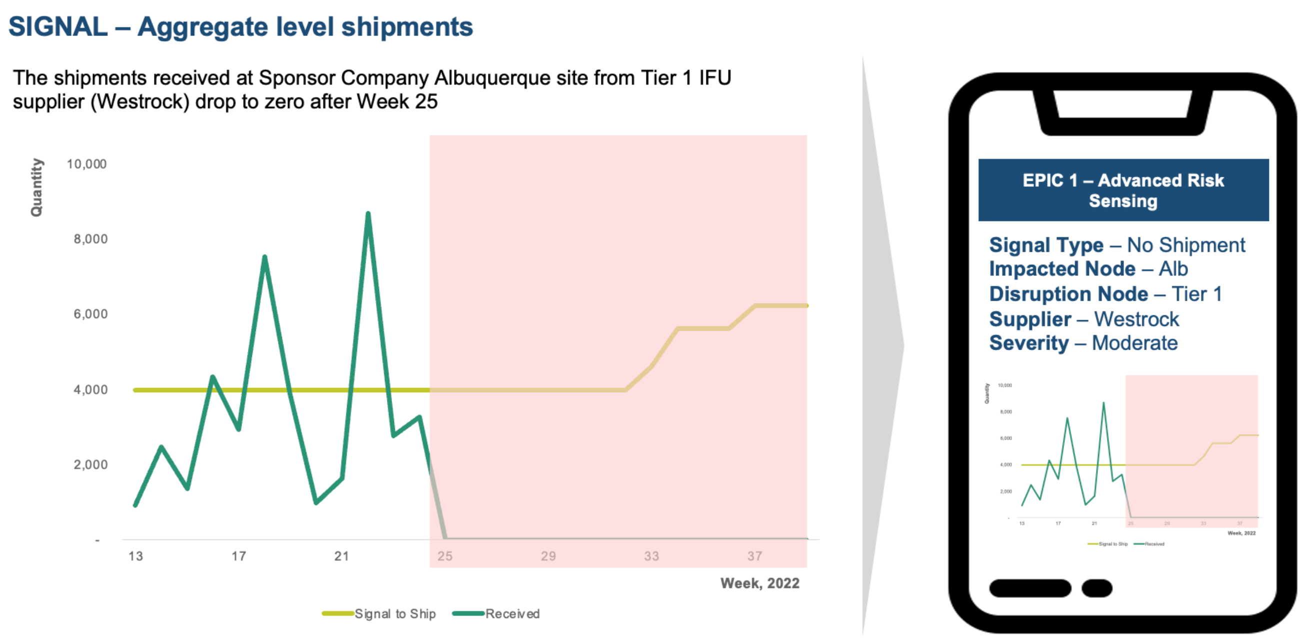
Note: This figure demonstrates the use case for Analytics driven approach to defining rules for early disruption signal detection.

A couple of examples are presented below for illustrative purposes to demonstrate the application of the analytics-based approach to signal identification:

Example 1 – Signal based on Aggregate shipment levels

The shipments received can be monitored with respect to the orders generated for the same time period to understand if the supplier is meeting the agreed-upon shipment schedule. Any major deviation in the shipments schedule is potentially a signal for disruption and must be carefully examined by validation information requests with the upstream supplier to understand if the instance of missed/ delayed/ partial fulfillment of shipment is systemic or just a one-off outlier due to uncontrollable factors that will not repeat itself. If the source is identified as systemic, this is a signal for disruption and must be actively managed to dampen the downstream effects.

Figure 9: *Use case to trigger a downstream workflow on aggregate shipment levels*

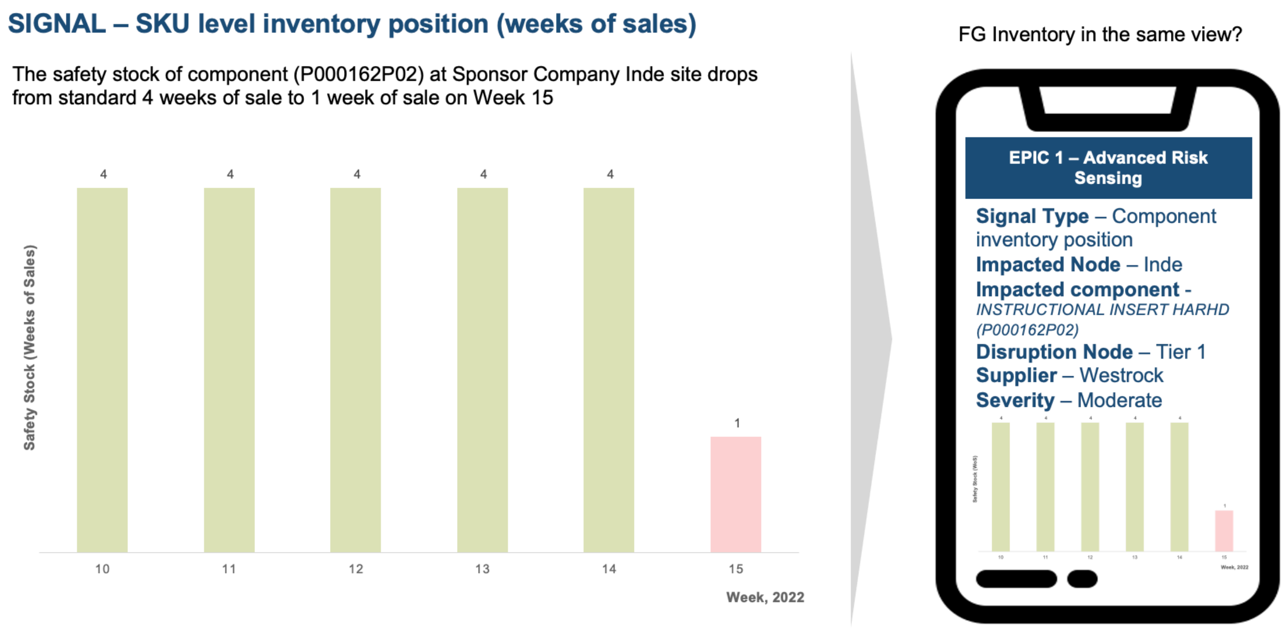


Note: This figure demonstrates the potential use case to trigger a downstream workflow based on analytics on aggregate shipment levels. The signal data source from the supplier through information request form and here this data is for demonstration purpose only.

Example 2 – Signal based on inventory positions

The inventory at the Finished Goods SKU or component level can be monitored, and any substantial deviation from the target value could potentially be a signal of disruption. This signal could be further examined by triggering a validation information request with the upstream supplier if the source of this declining inventory was assessed to be the supplier side, or an internal workflow can be triggered to readjust inventory levels by further estimating short-term demand and consumption patterns and revising the order volume in a timely manner.

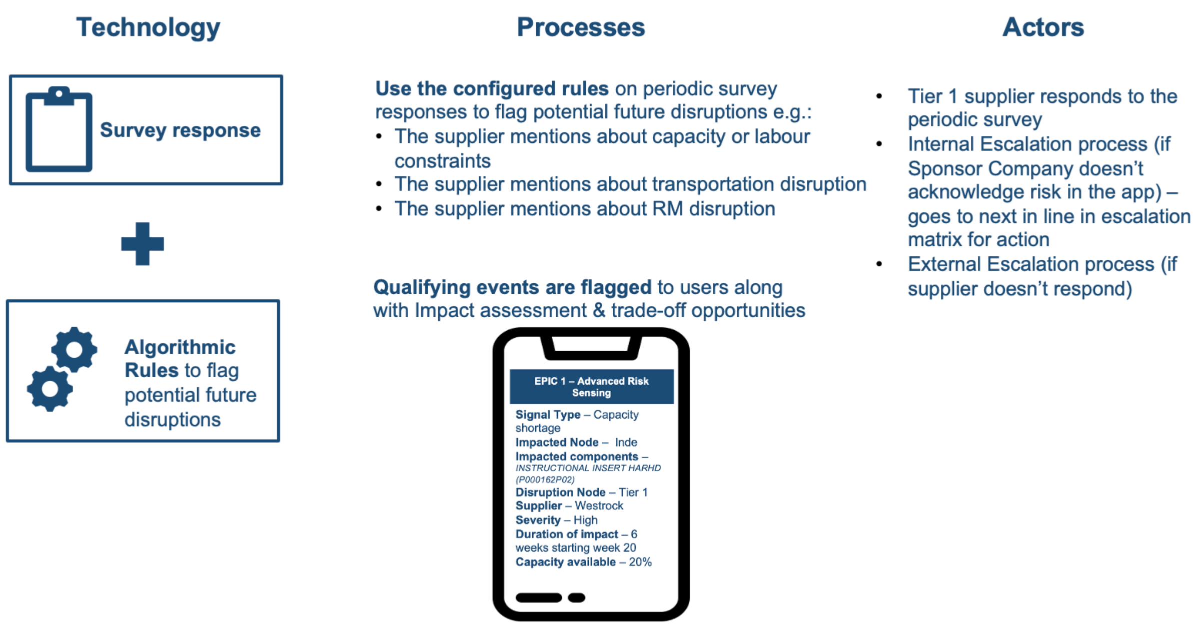
Figure 10: *Use case to trigger a downstream workflow on inventory positions*



Note: This figure demonstrates the potential use case to trigger a downstream workflow based on analytics on inventory positions.

B. **Proactive communication using periodic upstream information request forms –** While the previous approach utilized lagging indicators of risk to identify signals of potential disruptions, this approach is more proactive in nature and requires a certain degree of trust and collaboration among the supply chain partners. In this approach, the sponsor will use the supply chain digital risk console to trigger periodic information requests to assess the operational health of their upstream suppliers. The supply chain digital risk console will have the ability to allow the tier 1 suppliers to extend this feature further upstream, which will magnify the tool's power to proactively communicate and propagate information to all the nodes of the supply chain network. Automation rules can be created based on the responses received from suppliers to trigger downstream workflows for disruption management, e.g., the tradeoff can be assessed if the supplier mentions capacity or labor shortages, and existing orders can be modified to support such shortages. This approach is summarized in Figure 11.

Figure 11: *Use case for periodic information request approach for disruption signal detection*



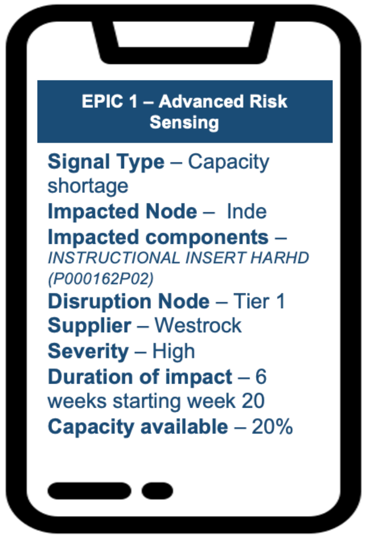
Note: This figure demonstrates the use case for a periodic information request driven approach for early disruption signal detection.

A few examples are presented below for illustrative purposes to demonstrate the application of a periodic information request driven approach for early disruption signal detection:

Example 1 – Capacity Shortage

Any shortage in capacity captured during the periodic information requests with the upstream supplier can be used to trigger a downstream workflow for disruption management

Figure 12: *Use case to trigger a downstream workflow on the capacity dimension*

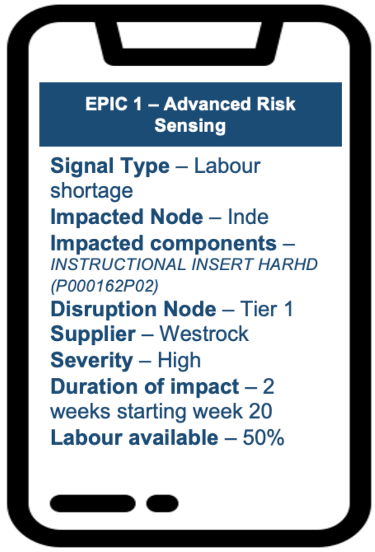


Note: This figure demonstrates the potential use case to trigger a downstream workflow based on supplier responses on the capacity dimension.

Example 2 – Labor Shortage

Any shortage in labor captured during the periodic information request with the upstream supplier can be used to trigger a downstream workflow for disruption management.

Figure 13: *Use case to trigger a downstream workflow on labor dimension*

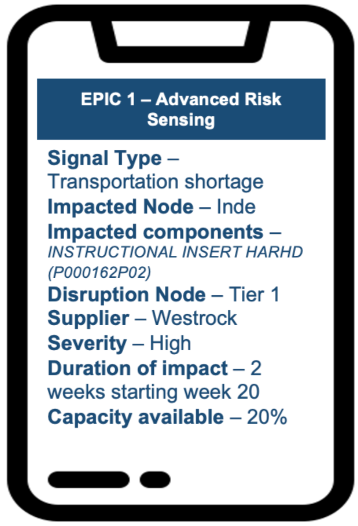


Note: This figure demonstrates the potential use case to trigger a downstream workflow based on supplier responses on the labor dimension.

Example 3 – Transportation disruption

Any transportation disruption captured during the periodic information request with the upstream supplier can be used to trigger a downstream workflow for disruption management.

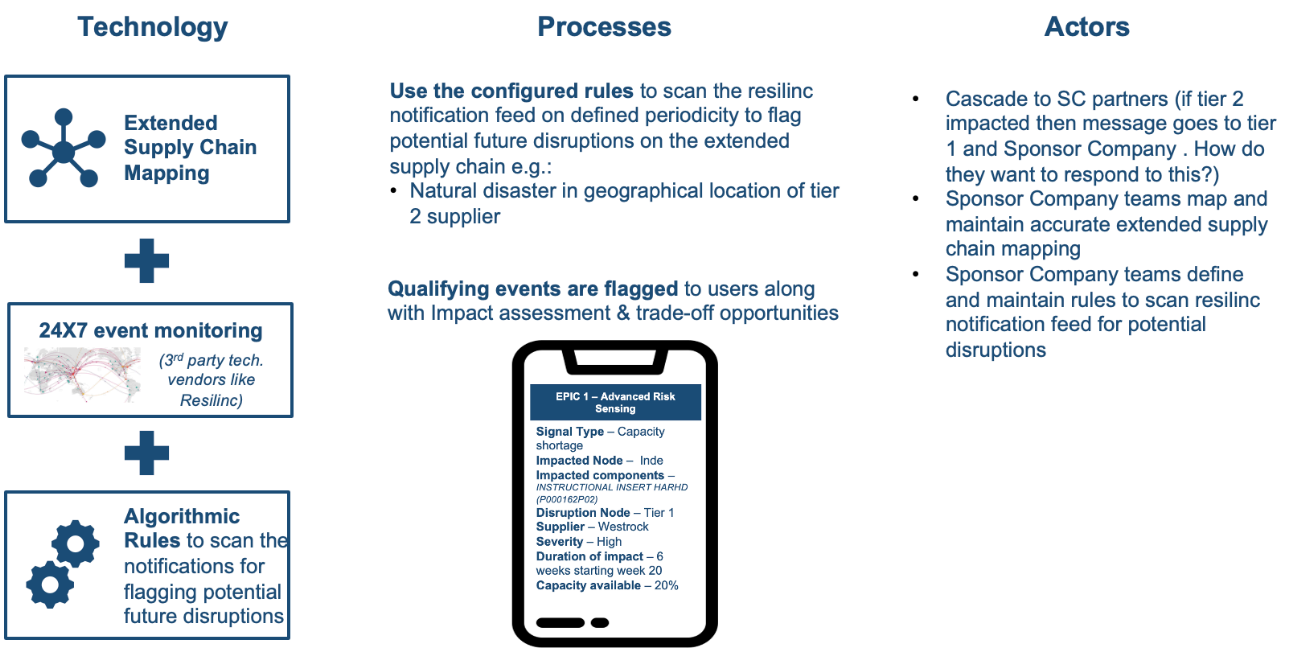
Figure 14: *Use case to trigger a downstream workflow on transportation dimension*



Note: This figure demonstrates the potential use case to trigger a downstream workflow based on supplier responses on the capacity dimension.

C. **Global Event Monitoring –** This approach can be utilized to identify low-frequency and high-impact signals arising in the extended supply chain network. This approach requires mapping the external supply chain network to improve signal detection. The sponsor company needs to actively map its Bill of Material with tier 2 and beyond suppliers. In this effort, geographic concentrations of the supplier base will be revealed, and any such geographic concentration in an extended supply chain is a potential source of risk. Therefore all newsfeeds concerning such a concentration must be actively monitored for signals of disruption. E.g. If the extended supply chain mapping reveals a certain region/ province in China to be a geographical concentration for the sponsor company, all newsfeeds concerning supply chains in that geographical concentration must be reviewed for sources of disruption. While the extended supply chain mapping has to be performed by the sponsor company and must be taken up as a separate long-term program, where the mapping is continuously updated for changes and extended beyond the existing tiers. Global event monitoring can be performed using the services of a number of providers in this domain. Automation rules can also be created on these newsfeeds to trigger the downstream workflow of validation information requests. Figure 12 highlights the use case for this approach

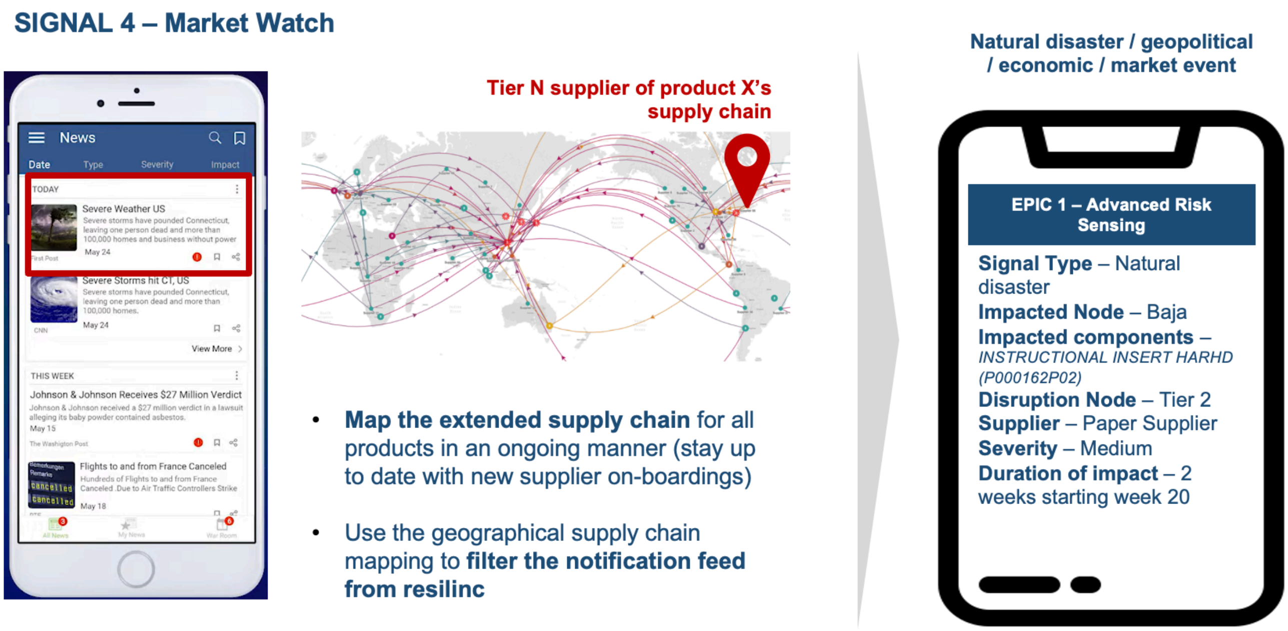
Figure 15: *Use case for global event monitoring driven approach for disruption signal detection*



Note: This figure demonstrates the use case for a global event monitoring-driven approach for early disruption signal detection.

The following example demonstrates a potential use case scenario to detect a signal for potential disruption. In the scenario highlighted in the following example, extended supply chain mapping is performed to uncover geographic concentration and subsequently, a severe weather event in the same geographic concentration is flagged as a potential source of disruption, which must be further evaluated. Downstream workflows of impact estimation and validation information requests are triggered based on this newsfeed from global event watch

Figure 16: *Use case to trigger a downstream workflow based on global event monitoring*



Note: This figure demonstrates the potential use case to trigger a downstream workflow based on global event monitoring.

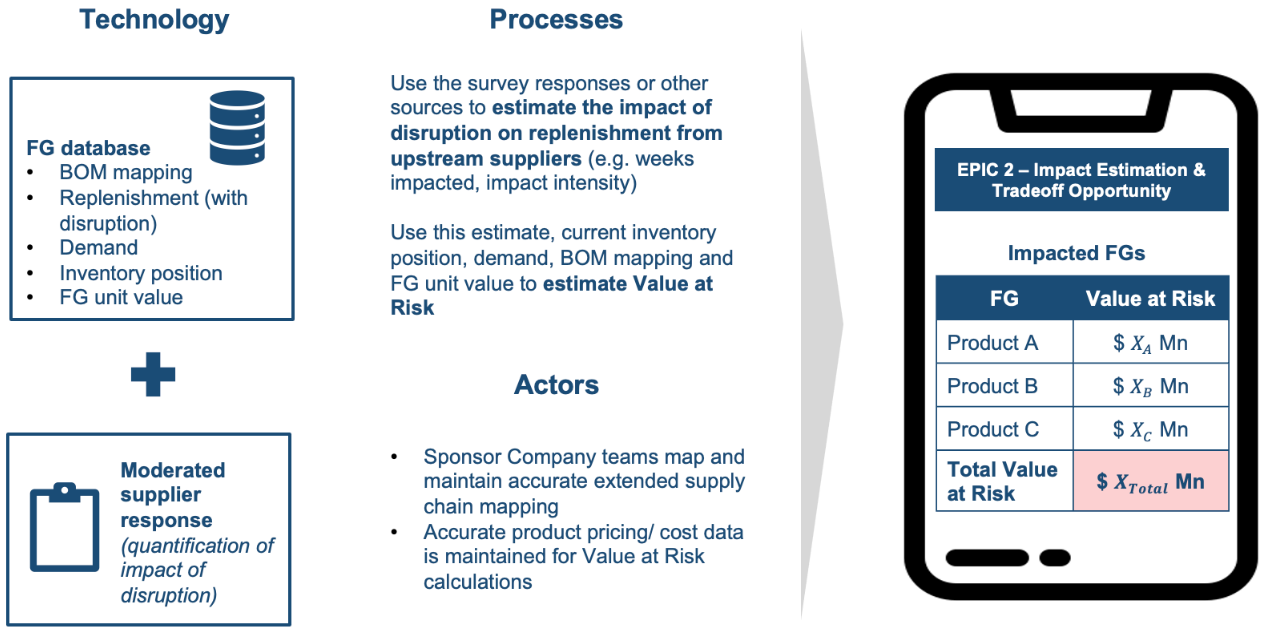
4.2.2.2 Risk Impact Analysis and Decision Tradeoffs

This section highlights the analytical element involved in the process of impact estimation and finding tradeoff opportunities.

Impact Estimation

Information request responses could be used to establish an estimate of the impact of disruptions on replenishment from the upstream suppliers (e.g., in weeks impacted, impact intensity, etc.). Using this estimated impact and associated data elements like current inventory positions, demand forecasts, BOM mapping and FG unit value, Value at Risk can be calculated. This will quantify the impact estimation for potential disruption.

Figure 17: *Approach to Impact Estimation of a potential future disruption*

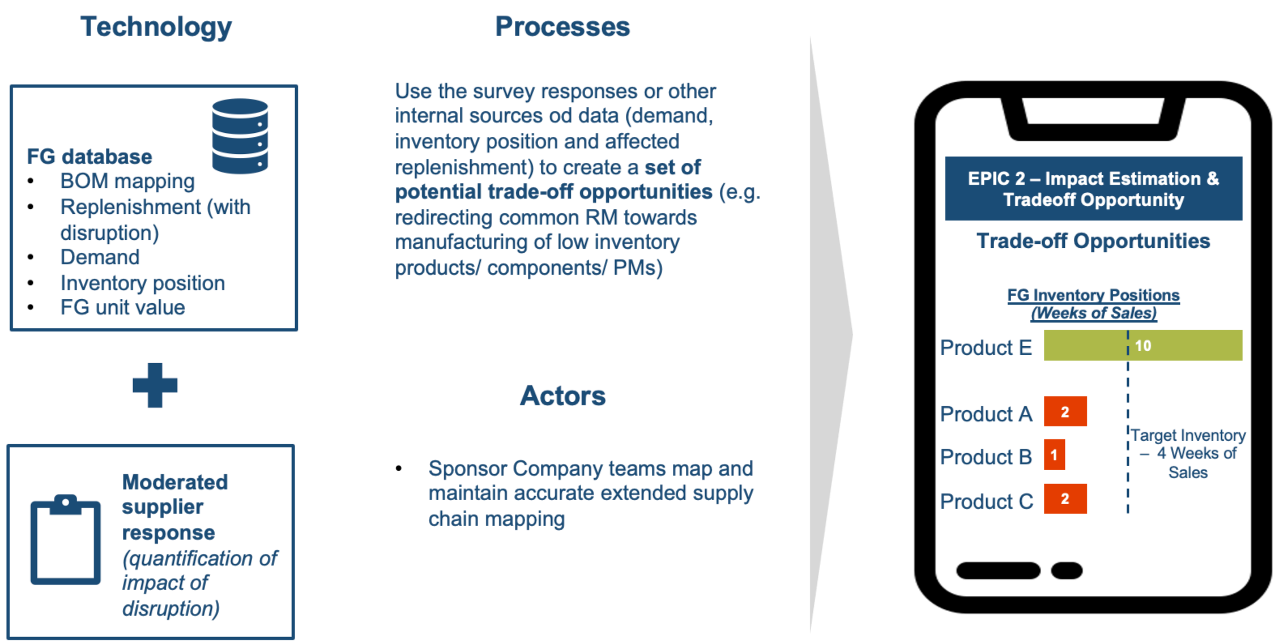


Note: This figure demonstrates the workflow to estimate the impact of potential future disruption. The Value at Risk is to estimate the potential loss that our sponsor company may experience over a specific time horizon, with a given level of confidence. Here the Value at Risk table is for demonstration purpose only.

Tradeoff Opportunity

All the inputs and the Output from impact estimation can be used for rules-based tradeoff opportunity assessment. E.g. a rule can be created to assess the impact of redirecting common Raw materials from the impacted supply chain towards manufacturing for low inventory products/ component/packaging materials in place of manufacturing for high inventory products/ component/packaging materials. The effects of this tradeoff can simply be achieved through an order modification process from the sponsor's end.

Figure 18: *Approach to identify potential tradeoff opportunities for a potential future disruption*



Note: This figure demonstrates the approach to identify potential tradeoff opportunities for a potential future disruption.

4.2.3 Information Request Form Design

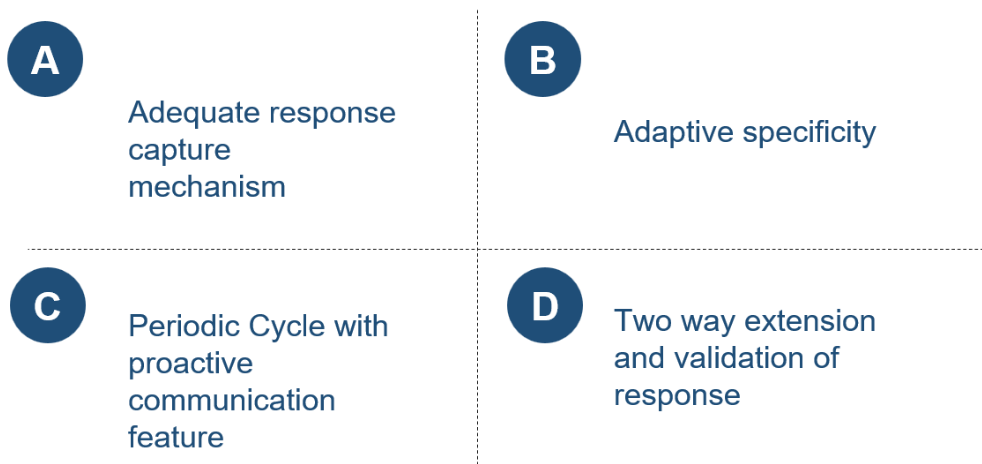
The simulation results from section 4.2 prove that establishing effective communication with the upstream suppliers improves the disruption detection lead time, which can potentially provide more time to proactively manage disruption leading to a reduction in the impacted value. This can be achieved by establishing a communication protocol with the upstream suppliers. This section details the design aspects of this upstream communication protocol. The communication protocol will be established via a information request form and response mechanism with upstream information requests, which will be used as an information sharing medium across different tiers of sponsor supply chain network.

The information request and response mechanism should be designed in such a way that it is:

- Flexible based on the requirement of the supply chain partner
- Establishes a cadence of regular information sharing
- Provides opportunities to collaborate across the supply chain rather than just with the immediate supplier/ customer

With these basic principles forming the core of the communication protocol, the information request response mechanism for Supply Chain Digital Risk Console was designed.

Figure 19: *Design Elements of Information Request Response Mechanism*



Note: This figure highlights the design elements of information request response mechanism for Supply Chain Digital Risk Console.

The design elements are described in detail as follows:

A. **Adequate response capturing mechanism** – This means that the information request form will provide the respondants with adequate mechanism to record their responses. Each question in the information request form will provide the respondents with an opportunity to respond with a guided response as well as free-flow text response. The guided response consists of the following elements:

a. **Rating response** – This captures the risk level the supplier is currently facing in fulfilling the business requirement. The question is reverse coded to assess the confidence of the supplier to fulfill the business requirement. Therefore, the low and medium level rating response for any question signals risk for the downstream supply chain partner
b. **Category of risk** – This captures the category of risk that the supplier is facing which is the reason for low/ medium confidence in fulfillment of business requirement. Therefore, this field becomes mandatory to complete once a low or medium confidence is selected in the rating response. This field provides suppliers to choose from one of the pre-configured choices (Raw Material, Labor, Supplier, Transportation and Capacity) or choose Others and fill in their risk category which is not available in the provided options
c. **Plan of action/ support needed** – This captures the plan of action or downstream support required to mitigate the risk. This is a semi-structured response field, which will become mandatory if a low or medium rating response is received on any question. This field allows the supplier to either capture in text, the plan of action or the support required to mitigate risk or allows them to connect with a point of contact with the downstream partner to discuss in detail
d. **Additional comments** – This is an optional text response where the supplier can capture anything that didn't get captured in the other response capturing mechanisms. This will also allow the supplier the option to upload files of certain types (e.g. powerpoint and excel)

Figure 20: *Response capturing mechanisms for information requests in SC Digital Risk Console*

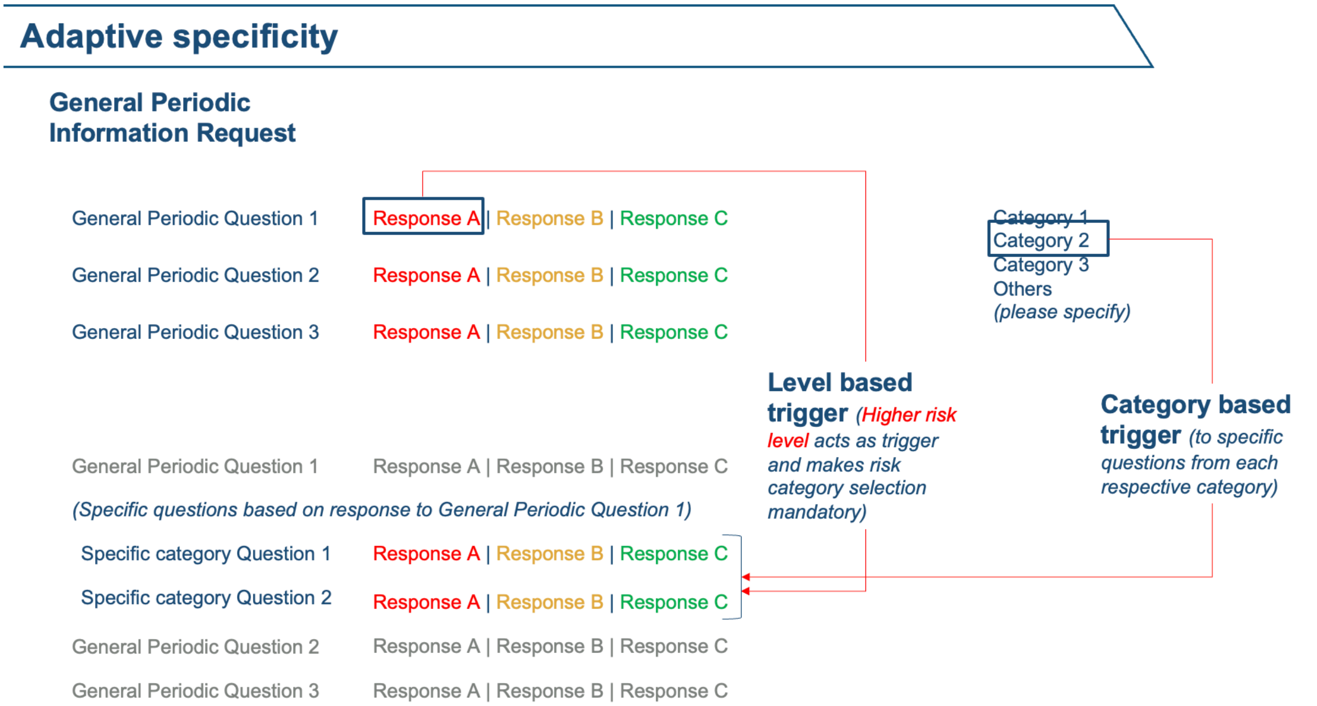
Adequate response capture mechanism

General Periodic Information Request	1 Rating Response	2 Category of Risk	3 Plan of Action/ Support Needed	4 Additional Comments
	Ordinal response	Categorical response	Semi structured response	Text response
	Mandatory field	Mandatory if risk is highlighted	Mandatory if risk is highlighted	Optional response
	Captures **Risk Level,** which acts as a trigger to further specific questions in case of high risk level	Captures **Risk Category** to trigger further relevant risk category specific questions	Allows to **connect with Point of contact** OR **capture brief plan of action or support needed**	Captures additional details
General Periodic Survey Question 1	Response A Response B Response C	Category 1 Category 2 Category 3 Others (please specify)	Connect with SPOC (Point of Contact) **OR** Text response	Free flow text

Note: This figure highlights the response capturing mechanisms for information requests in Supply Chain Digital Risk Console.

B. **Adaptive Specificity** – This gives the information requests a mechanism to adapt to more specific inquiries based on the response recorded by suppliers. This mechanism is driven by responses entered in rating response and category of risk fields. The follow-up specific questions are generated if the rating response is entered in low or medium categories. The question generated in this mechanism will be specific to the category of risk selected by the supplier to further understand in detail the problem, the supplier is facing

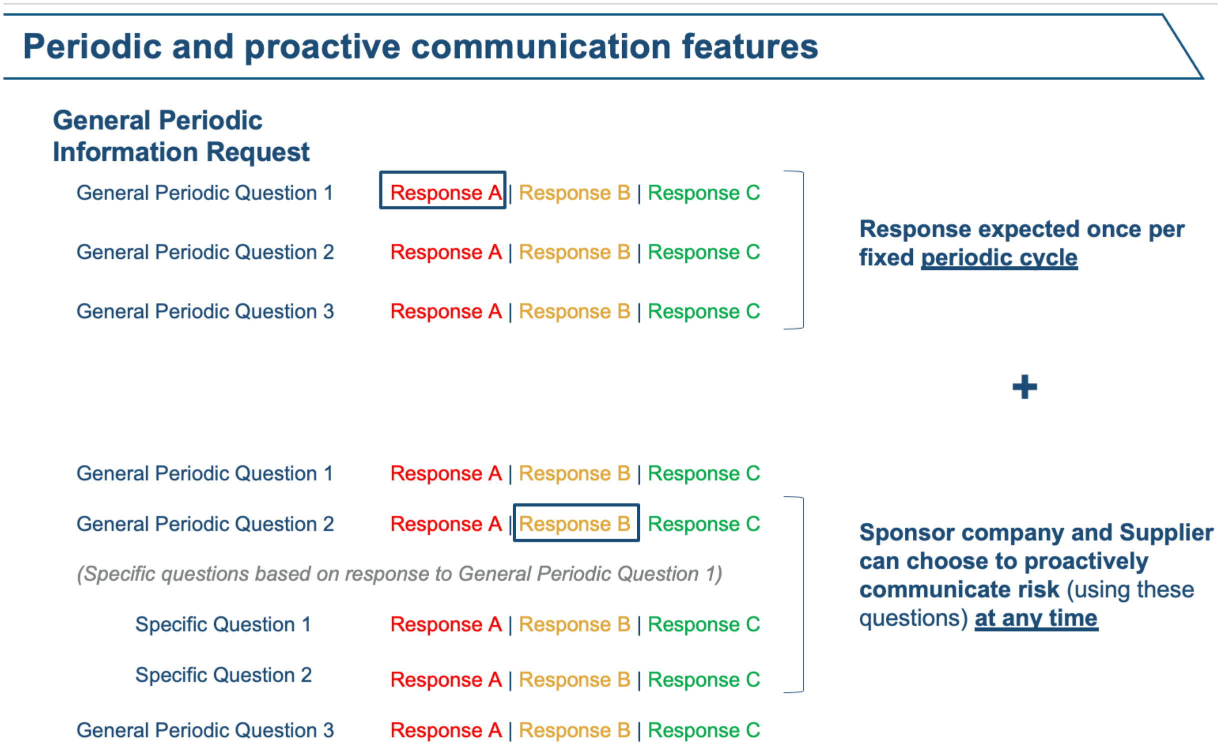
Figure 21: *Mechanism for adaptive specificity in information requests for SC Digital Risk Console*



Note: This figure highlights the mechanism for adaptive specificity in information requests for Supply Chain Digital Risk Console.

C. **Periodic cycle with proactive communication feature** – This features ensures to establish a cadence of information request response mechanism between the supplier and the their downstream customer. The periodicity of this regular cadence can be decided mutually by both the involved parties. This will ensure that once in each period a information request is triggered and responses are sought out. If the information request form is not responded to with then period, it will lead to standard escalations, which can be agreed upon in the supplier contract. Moreover, there is an additional feature which allows the upstream supplier to proactively respond to the standard and specific information request form questions outside the periodic cadence cycle. This will allow the supplier to proactively communicate any immediate risk to downstream partners without having to wait a complete cycle when the periodic information request gets triggered. This saves time and also improves information sharing across supply chain nodes

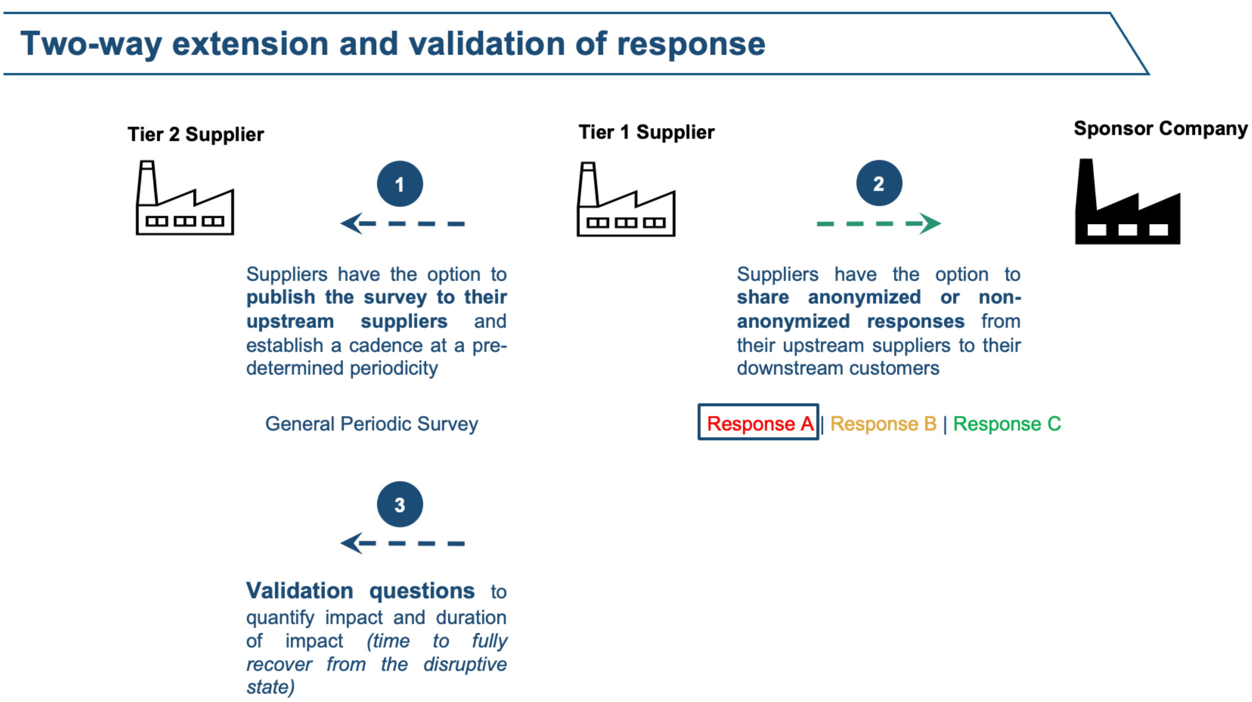
Figure 22: *Periodic cycle with proactive communication feature for SC Digital Risk Console*



Note: This figure highlights the Periodic cycle with a proactive communication feature for Supply Chain Digital Risk Console.

D. **Two way extension and validation of response** – Any supply chain partner who is on the Supply Chain Digital Risk Console app, have an opportunity to connect their upstream supplier to the app. This will enable a wider network on the app and will create a network effect for information sharing with any critical information spreading downstream faster. With this in mind, the suppliers will have the facility to onboard their upstream suppliers to the app. Once this is done, they can extend the information request form to their upstream supplier and seek response from them. These responses will stay confidential with the supply chain partners and their upstream suppliers and will not be shared downstream. The supply chain partner will have an option to share the information request responses from their upstream suppliers to their downstream nodes. They can do this by sharing either anonymized responses or non-anonymized responses, sharing the details of identity of their upstream supplier. Additionally, the supply chain partners can use the validation feature of the app to seek more detailed information from their upstream suppliers to quantify the impact of disruption – duration of impact and severity of impact

Figure 23: *Two way extension and validation of response feature for SC Digital Risk Console*



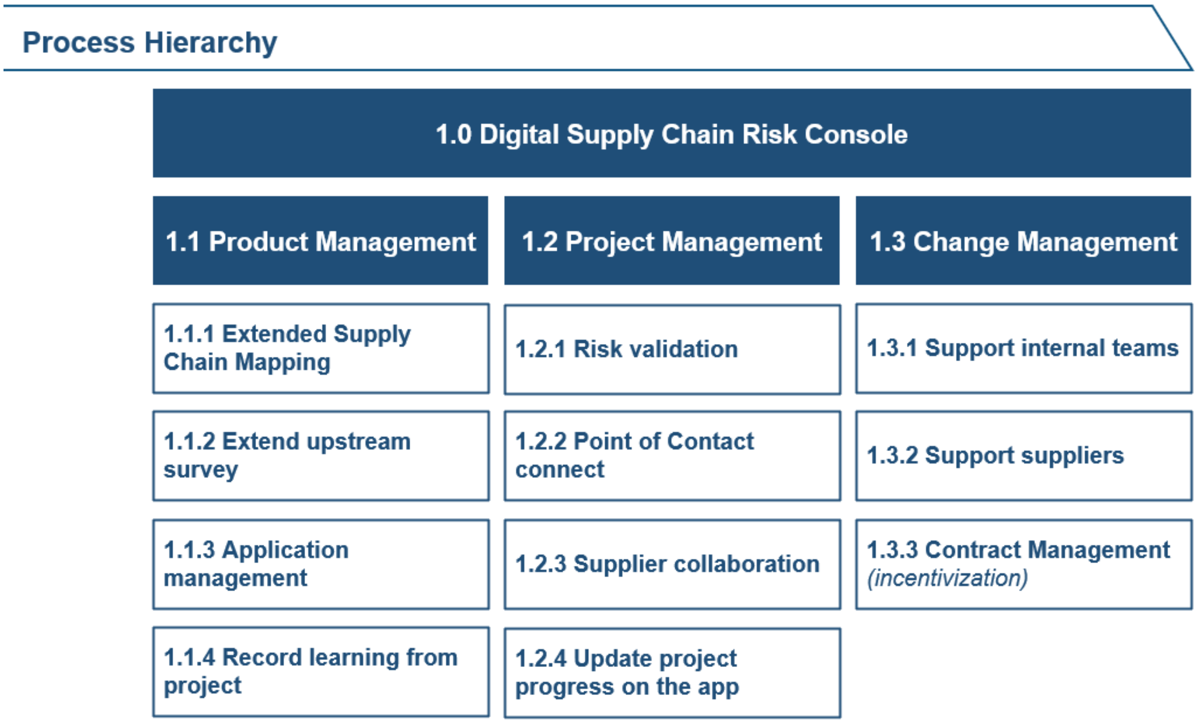
Note: This figure highlights the Two way extension and validation of response feature for Supply Chain Digital Risk Console.

4.2.4 Process Mapping

The Digital Supply Chain Risk console is a technology based app but must be accompanied by associated process to completely implement the early disruption detection program discussed in section 4.2.1. The related processes fall under the following categories:

- **Application Management**: This process group relates to the tasks/ activities required to manage the Digital Supply Chain Risk Console app. The program will start at the base case with just the mapping of sponsor company's immediate supply chain. This supply chain mapping has to be extended vertically to the upstream suppliers. The sponsor company must actively invest in the process of extending this supply chain mapping on the app. Additionally the sponsor company must manage the application for potential IT and strategic improvement.
- **Project Management** – This process group related to the tasks/ activities required to manage any typical early disruption detection and management projects. The process group covers the tasks required for validation of risk, establishing a point of contact with the upstream suppliers, managing supplier collaborations and updating the progress of the project over the app.
- **Change Management** – This process group relates to guiding organizational change to fruition, from the earliest stages of conception and preparation, through implementation and, finally, to resolution in context of the Digital Supply Chain Risk console app. The process group includes taks to support both internal teams and upstream supplier teams throughout the lifecycle. It also contains taks required to contractually incentivize the adoption of the app

Figure 24: *Process hierarchy for Digital Supply Chain Risk Console App*



Note: This figure highlights the process hierarchy for Digital Supply Chain Risk Console app.

The detailed process steps of each process described in this section are mapped in standard process mapping swimlane in the Appendix E.

4.2.5 Roles and Responsibilities

This section discusses the roles and responsibilities to implement and operationalize the app. The digital supply chain risk console app requires such roles that achieve boundary spanning. This is a term used to describe any situation where an individual crosses the boundaries of a social group to enable knowledge exchange, translate language, or share values among various groups that are external to the current group that the individual is associated with.

The app ensures that there is both internal boundary spanning where a cross functional team can be formed with representatives from different supply chain teams. This team can then facilitate internal boundary spanning where they promote gains from feedback and learnings from the project leading to process improvements. They can also discuss trade-off opportunities with other members of the cross functional teams and identify the right opportunity to mitigate the impacts of disruption. These teams can also fulfill external boundary spanning roles when they collaborate with their supply chain partners over the app to plan for mitigating disruption.

Additionally, a dedicated application manager role is required to facilitate the product roadmap, extend the supply chain mapping like a long running program and other application management tasks. This role can facilitate internal boundary spanning by understanding and delivering to the product specific requirements from cross functional teams and training them on the application itself. This role can also facilitate external boundary spanning by extending the supply chain mapping.

Figure 25: *Internal and external boundary spanning roles for Digital Supply Chain Risk Console App*

Key Roles and Responsibilities – Internal and external boundary spanning

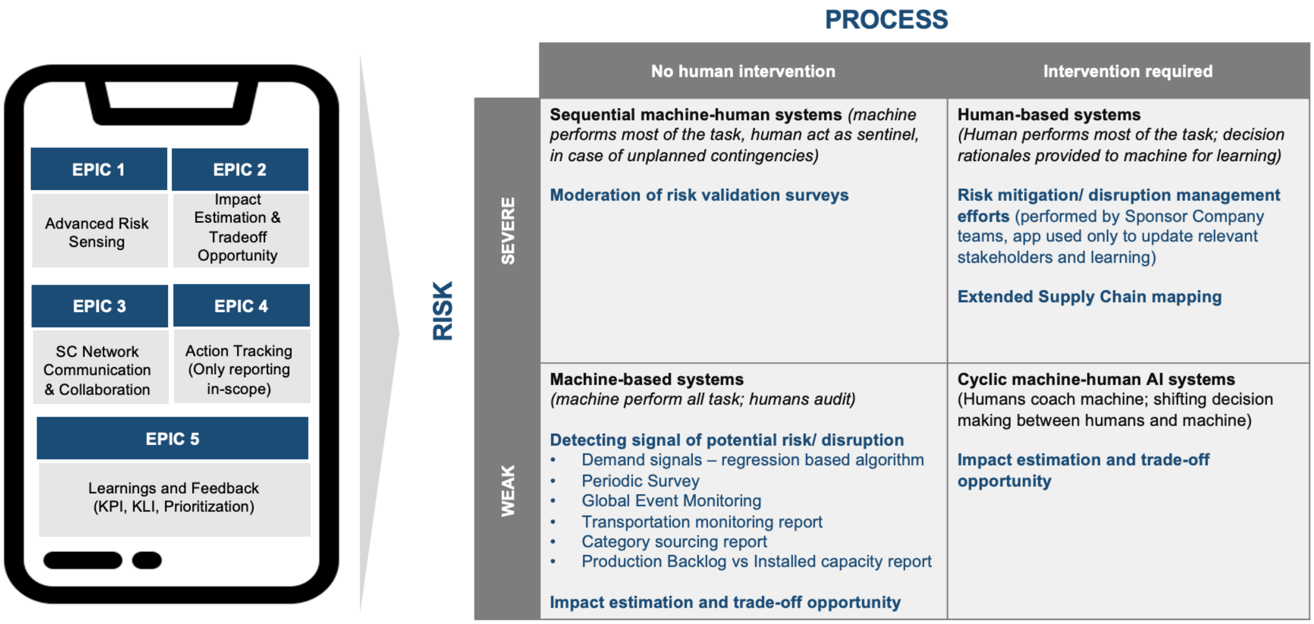
	Digital Risk Console App Program/ Product manager	***Sponsor Company* Cross Functional Teams**
Internal Boundary Spanning	• **Promote gains from Feedback and Learning** – Socialize KPIs and KLIs • **Product Management** o Understands functional requirement from cross functional teams *(on product improvement)* o Prioritize functional requirements on product roadmap	• **Promote gains from Feedback and Learning** o Identify areas for improvement in product/ process using KLIs – deltas • **Identify Trade-Off Opportunities** o Cross functional teams collaborate internally to identify the right opportunity for trade-off to manage disruption o Progress update on portal
External Boundary Spanning	• **Promote gains from Feedback and Learning** – Socialize KPIs and KLIs • **Extended Supply Chain Mapping** – Enable incrementally more and more supply chains on the digital risk console app by mapping the extended supply chain and enabling partner access to platform (app)	• **Execute the optimal Trade-Off Opportunity** o Cross functional teams collaborate with external SC partners to execute the optimal opportunity for trade-off to manage disruption o Progress update on portal

**Each supplier can potentially act in the similar role as Sponsor Company Cross Functional Teams with their upstream supplier*

Note: This figure illustrates the Internal and external boundary spanning roles for the Digital Supply Chain Risk Console app.

The digital supply chain risk console can also drive partnership between human and machine by enabling automation and artificial intelligence driven algorithms

Figure 26: *Human-machine partnership for Digital Supply Chain Risk Console App*



Note: This figure illustrates the human-machine partnership for the Digital Supply Chain Risk Console app.

The detailed roles and responsibilities have been mapped on the process hierarchy discussed in section 4.2.5 and appendix E.

4.2.6 KPI Dashboard

The digital supply chain risk console app includes KPI dashboard thet can be used both by the sponsor company and its upstream suppliers, for global event monitoring, supplier risk information requests and VaR/ Impact estimation and assessing Trade-off opportunities.

- **Global Event Monitoring Dashboard**

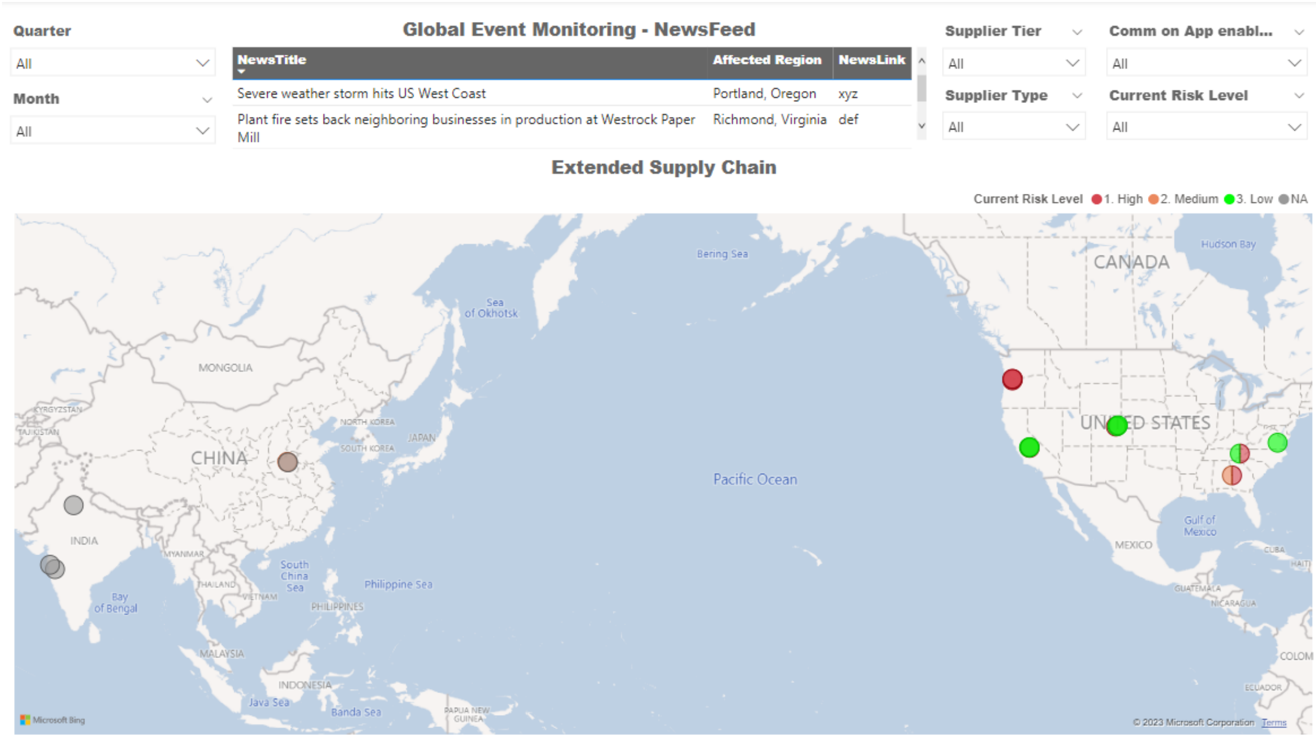
This dashboard can be used for monitoring the global events that affect extended supply chain. The bottom section of the dashboard visualizes the extended supply chain on map. The top section of the dashboard comprises of filters that can be used to zero in on the relevant event. The filters selections include:

a. **Time period** – The user of dashboard can filter the global events by the time period that they want to investigate (quarter and month selection).

b. **Supplier characteristics** – The user can filter on supplier characteristics based on the the tier of the supplier and the type (e.g. raw material, component, packaging material etc.). They can also filter down the suppliers by choosing if the supplier communication is enable of the app as well as the current risk levels the supplier is experiencing.

c. **The newsfeed** – The user can also use the running newsfeed of global events and the affected region associated with each news as a filter to understand the affected nodes in their supply chain due to that particular event.

Figure 27: *Global Event Monitoring dashboard for Digital Supply Chain Risk Console App*



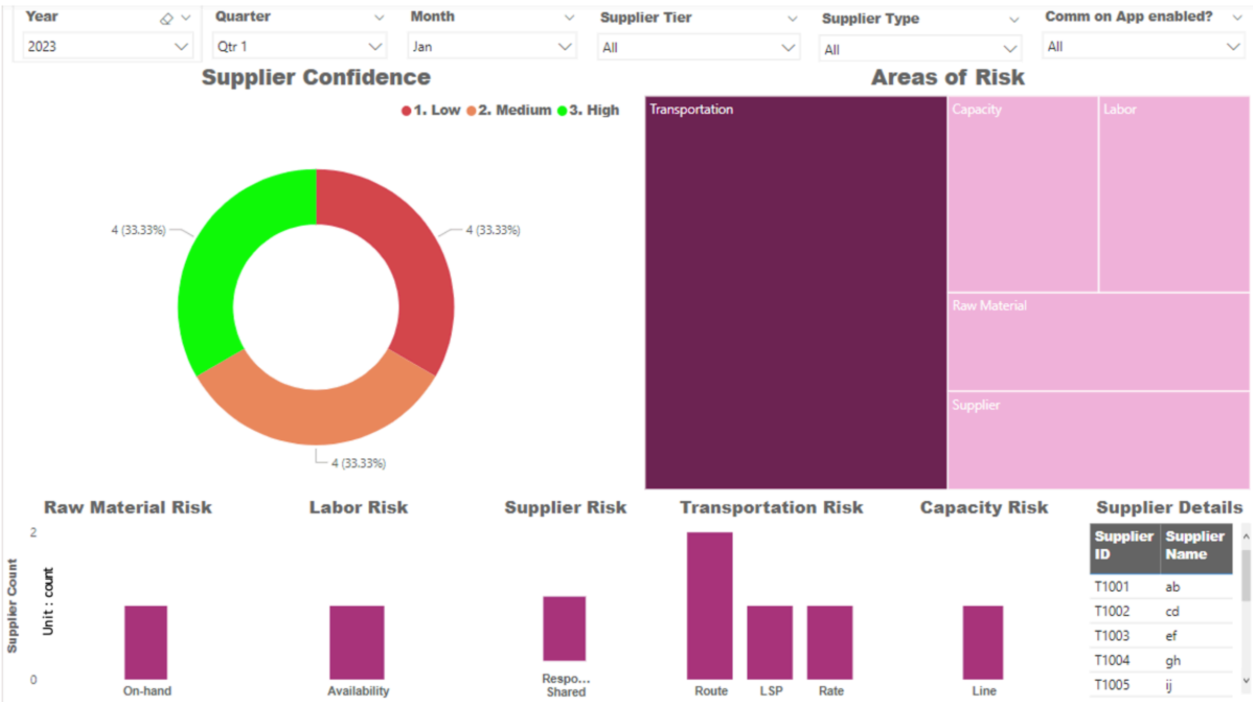
Note: This figure illustrates the Global Event Monitoring dashboard for Digital Supply Chain Risk Console app.

- **Supplier Risk Dashboard**

This dashboard can be used to monitor supplier responses from the communication protocol of the app. The top section of the dashboard contains filters that can be used to zero in on the relevant datapoint from supplier responses to the upstream information request forms. The filter selection includes Time period (year, quarter and month) and supplier characteristics (supplier tier and type and whether communication is enabled on the app).

The bottom portion of the dashboard includes graphics to demonstrate the current risk levels based on the responses from upstream suppliers to the periodic or proactive information requests. The donut chart on the left denotes the current supplier confidence in fulfilling the business requirement. This is based on the responses from suppliers on the first overall assessment question from the information request form. The low and medium confidence suppliers are required to mandatorily fill in the category of risk they are experiencing in the information request form. This is visualized on the box plot labelled as “Areas of Risk”. In the example illustration presented by Figure 28, transportation is identified as the highest risk area according to supplier responses. In the last row there is a subclassification of each risk category (Raw Material, Labor, Supplier, transportation, capacity), based on responses from suppliers on specific adaptive questions from the information request form. This is followed by the supplier details in a table at bottom right portion of the dashboard.

Figure 28: *Supplier Risk Dashboard for Digital Supply Chain Risk Console App*



Note: This figure illustrates the Supplier Risk Information request Dashboard for Digital Supply Chain Risk Console app.

- **VAR and Trade-Off Opportunities Dashboard**

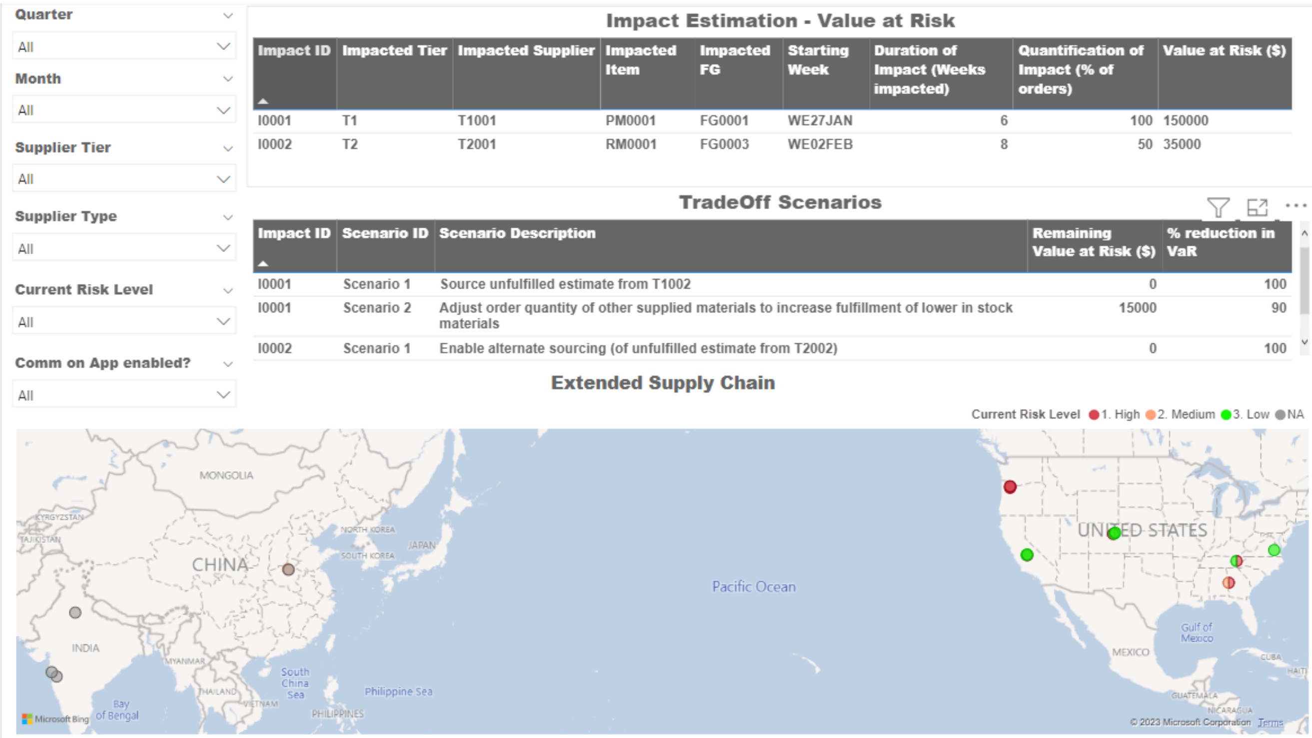
This dashboard can be used to estimate the impact of a disruption in terms of value at risk (VaR) based on the supplier responses. It can also be used to assess trade-off opportunities to mitigate the impact of disruption. The left panel of the dashboard contains filters on time period (year, quarter and month) and supplier characteristics (supplier tier, type, current risk level and whether the communication is enabled on the app for the supplier).

The right portion of the dashboard contains two tables:

a. **Impact estimation (Value at Risk)** – This table uniquely highlights all the disruptive events currently in progress or future disruptive events flagged by the supplier in advance. The VaR associated with each disruption event has been quantified by using supplier responses to validation questions (intensity and duration of the impact). This table can be used as a filter to filter down the trade-off opportunities relevant to the disruption the user wants to investigate.

b. **Tradeoff Scenarios** – This table highlights the trade-off scenarios that can be adopted by supply chain teams to mitigate the impact of disruption. The table highlights each scenario along with the remaining Value at Risk post the scenario has been executed. Additionally, it displays the % reduction in VaR which is an important Key Learning Indicator (KLI) for the app.

Figure 29: *VAR and Trade-Off Opportunities dashboard for Digital Supply Chain Risk Console App*



Note: This figure illustrates the VAR and Trade-Off Opportunities dashboard for Digital Supply Chain Risk Console app.

4.3 Key Findings and Management Implications

Effective communication protocol with suppliers can bring significant value to supply chain management. By simulating a dummy supply chain, we tested the sensitivity of the communication protocol to various disruptions and stochasticity of supply chain parameters. The results, as presented in figures 2 to 4, showed consistent improvement in the detection lead time for disruptions with the implementation of a communication protocol with upstream suppliers. This proof of concept suggests that effective communication with upstream suppliers can improve the detection lead time, providing more time to proactively manage disruption and ultimately reducing value impact.

Extending the communication protocol beyond immediate suppliers can enhance the value gained through network effects. By enabling immediate suppliers to establish a similar protocol with their upstream suppliers, there was a reduction in disruption detection lead time when using the communication protocol within a three-tiered supply chain network. The simulation runs (figures 2 to 4) showed that the primary target KPI, disruption detection lead time, decreased not only for the supply chain node that implements the communication protocol but for all downstream nodes as well. This implies that information sharing across any two nodes has the potential to improve the quality and near-timeliness of information at all downstream nodes. Therefore, the sponsor should facilitate vertical integration by enabling their immediate suppliers to establish a similar protocol with further upstream suppliers, enhancing the network effect, and improving the speed of disruption communication across all SC nodes.

An increase in communication frequency (or reduction of periodicity) enhances the value gained from establishing a communication protocol with suppliers. The results of simulation show that the value gained from effective communication with the supplier increased with an increase in communication frequency. The difference in the detection lead times across AS-IS and TO-BE scenarios increased with an increase in the frequency of communication with upstream suppliers, as presented in figures 2 to 4. This means the more frequent the communication, the better the information sharing and the better the disruption detection lead times. Therefore, the sponsor can work collaboratively with their immediate suppliers to operationalize the communication protocol through periodic information requests at an agreed-upon frequency. While they may set a high periodicity for communication protocol initially, they must strive to lower it further as the process matures to enhance the value gained.

5.CONCLUSION

In conclusion, this capstone aims to evaluate the value of establishing a communication protocol with upstream suppliers to improve the detection of supply chain disruptions. The simulation results presented in this study provide strong evidence that establishing a periodic communication protocol with upstream suppliers can lead to a 12% - 53% reduction in the detection lead time of disruptions. This reduction in lead time can help supply chain managers proactively manage supply chain disruptions, thereby reducing the overall impact of the disruption on the supply chain. The simulation results also demonstrate that there is value in extending the communication protocol beyond immediate suppliers to include all tiers of the supply chain network. This is because the network effect enhances the value gained from the communication protocol.

The Supply Chain Digital Risk Console presented in this document is a comprehensive solution designed to help organizations proactively manage and mitigate supply chain risks. By providing real-time visibility into supply chain vulnerabilities, the console enables companies to identify potential risks, take preventive measures, and minimize the impact of disruptions. The console's capabilities include signal assessment, information request form design, process mapping, and a KPI dashboard, among others. These modules work together seamlessly, providing end-to-end disruption management support and helping organizations make data-driven decisions.

Implementing the Supply Chain Digital Risk Console can be done through a phased approach, starting with a pilot implementation in a specific area of the supply chain. The pilot can then be expanded to cover other areas and tiers of the supply chain network. The implementation requires a collaborative effort between different stakeholders, including supply chain managers, IT teams, and disruption management professionals. By working together, organizations can enhance their supply chain resilience and ensure business continuity in the face of disruptions. To scale up the solution, organizations can collaborate with technology partners to integrate the console with their existing IT systems and supply chain management processes. The customized digital supply chain transformation framework in 4.2.1 can help companies scale the solution up and make it more extensive. Incorporating feedback loops with supply chain management performance can be achieved by regularly monitoring and analyzing the console's KPI dashboard and making necessary adjustments to the communication protocol and disruption management strategies. Supply chain managers can also engage in continuous improvement efforts by conducting regular assessments of the console's effectiveness in managing supply chain disruptions and identifying areas for improvement.

While this study provides valuable insights into the benefits of establishing a communication protocol with upstream suppliers, there are some limitations to consider. One limitation is that the simulation was conducted using a simplified supply chain network with a limited number of nodes and suppliers. The results may not be generalizable to more complex supply chain networks. Additionally, the study assumed that all suppliers would be willing and able to participate in the communication protocol, which may not always be the case. Finally, the study did not consider the potential costs and resources required to implement and maintain the communication protocol.

Future research and development could enhance the effectiveness of the Supply Chain Digital Risk Console and the communication protocol by exploring various areas. One area is the integration of emerging technologies like artificial intelligence and machine learning, which possess capabilities such as proactivity, adaptability, scalability, agility, and explainability that could improve the assessment and prediction of disruptions signals. Another area is the expansion of the communication protocol to include downstream customers, which could provide additional insights and reduce lead times further.

Additionally, incorporating real-time data from IoT sensors and other sources could enable more accurate and timely detection of disruptions. Finally, the development of a decision support system that utilizes the console's data and insights could help supply chain managers make more informed and effective decisions in response to disruptions.

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APPENDIX

Appendix A: Supply Chain Digital Risk Console Epics

Supply Chain Digital Risk Console is a mobile application designed to assist the sponsor company and its suppliers in identifying, assessing, and managing risks that could impact their operations. The software is equipped with advanced risk-sensing capabilities, impact-estimation features, supply chain network communication and collaboration tools, action management functions, and learning and feedback mechanisms. Following are the 5 epics, or collections of user requirements, designed for the Supply Chain Digital Risk Console:

1. Advanced Risk Sensing:

The Supply Chain Digital Risk Console will provide advanced risk-sensing capabilities to detect and analyze potential risks. The system will be able to scan various sources, such as news articles, social media, and internal and external data sources, to identify possible threats to the organization's operations. The system will have the capability to prioritize risks based on their probability and impact.

2. Risk Impact Analysis and Decision Tradeoff:

The Supply Chain Digital Risk Console will have the capability to estimate the potential impact of identified risks on the organization's operations. The system will consider the likelihood and severity of the risks and provide an estimate of the potential impact on the organization's financial, operational, and reputational aspects.

3. Supply Chain Network Communication and Collaboration:

The Supply Chain Digital Risk Console will provide supply chain network communication and collaboration tools to facilitate effective communication between all parties involved in the supply chain. The system will provide real-time visibility of the supply chain and enable communication and collaboration among all parties to ensure timely identification and mitigation of risks.

4. Action:

The Supply Chain Digital Risk Console will provide action management functions to enable organizations to take appropriate actions to mitigate identified risks. The system will allow organizations to assign responsibilities, set timelines, and track the progress of the actions taken to mitigate the identified risks.

5. Learnings and Feedback:

The Supply Chain Digital Risk Console will provide learning and feedback mechanisms to enable organizations to learn from past incidents and continuously improve their risk management strategies. The system will enable organizations to track and analyze incidents, identify root causes, and provide feedback to stakeholders to improve their risk management practices.

Appendix B: Supply Chain Digital Risk Console Features

Advanced Risk Sensing

- Real-time monitoring of potential risks and threats to the organization
- Automatic identification and categorization of risks based on severity, likelihood, and impact
- Integration with external data sources (e.g., news feeds, social media) to detect emerging risks
- Customizable risk scoring and prioritization based on business objectives and risk appetite
- Notification and alerting capabilities for identified risks

Impact Estimation

- Automated assessment of the potential impact of identified risks on the organization's operations, finances, and reputation
- Visualization of impact scenarios and probabilistic analysis of outcomes
- Integration with existing risk management frameworks and methodologies
- Collaboration and feedback tools for cross-functional risk assessment and evaluation
- Support for scenario planning and sensitivity analysis

SC Network Communication & Collaboration

- Secure communication channels for sharing risk-related information and insights with supply chain partners
- Real-time collaboration and coordination capabilities for joint risk mitigation and contingency planning
- Integration with supply chain management systems and tools for seamless data exchange
- Support for privacy and data protection regulations (e.g. GDPR, CCPA)
- Role-based access control and permissions for different user groups and partners

Action

- Automated and manual risk response options based on identified risks and impact assessments
- Integration with incident management and business continuity systems for rapid response and recovery
- Audit trail and reporting capabilities for tracking risk response actions and outcomes
- Collaboration tools for cross-functional risk response teams
- Risk treatment options including transfer, mitigate, accept, or avoid

Learnings and Feedback

- Analytics and reporting capabilities for tracking risk-related metrics and trends over time
- Feedback and review tools for continuous improvement of risk management processes and strategies
- Integration with training and awareness programs for enhancing risk culture and awareness
- Knowledge management and sharing capabilities for capturing and disseminating best practices and lessons learned
- Support for compliance and regulatory reporting requirements.

Appendix C – User Stories and Testing Criteria

Advanced Risk Sensing

- User Story: As a risk manager, I want to be able to monitor and detect potential risks in real-time so that I can proactively mitigate them before they become a problem.
- Testing Criteria: The system should be able to scan multiple data sources (such as news feeds, social media, and internal data) to identify potential risks and generate alerts for the risk manager to investigate.
- User Story: As a risk analyst, I want to be able to assess the likelihood and impact of identified risks so that I can prioritize my mitigation efforts.
- Testing Criteria: The system should provide a risk-scoring model that takes into account factors such as probability, severity, and impact to help the analyst determine which risks to focus on.

Impact Estimation

- User Story: As a project manager, I want to be able to simulate the potential impact of risks on my project schedule and budget, so that I can make informed decisions about risk mitigation strategies.
- Testing Criteria: The system should be able to generate "what-if" scenarios that show the potential impact of various risk events on the project timeline and budget based on historical data and assumptions.
- User Story: As a risk manager, I want to be able to estimate the financial impact of identified risks so that I can communicate the potential cost of inaction to stakeholders.
- Testing Criteria: The system should provide a financial impact model that takes into account factors such as loss of revenue, cost of recovery, and reputation damage and provides a clear estimate of the potential cost of the risk event.

SC Network Communication & Collaboration

- User Story: As a supply chain manager, I want to be able to collaborate with my partners to share information about potential risks and coordinate risk mitigation efforts.
- Testing Criteria: The system should provide a secure communication platform that allows supply chain partners to share risk information, collaborate on risk mitigation strategies, and track progress.
- User Story: As a logistics provider, I want to be able to track the status of my shipments and identify potential disruptions in real-time so that I can take proactive action to mitigate risks.
- Testing Criteria: The system should provide a tracking and monitoring feature that allows logistics providers to receive real-time updates on the status of their shipments and alert them to potential disruptions (such as weather events or customs delays).
- User Story: As a supply chain manager, I want to schedule and send regular information request forms to my tier 1 and tier 2 suppliers to obtain real-time updates on their supply capacity, labor status, inventory levels, shipment status, and other relevant information.
- Testing Criteria: The user should be able to select the frequency of the information request form (weekly, bi-weekly, monthly, bi-monthly).The information request form contents should be customizable and cover relevant information required by THE SPONSOR COMPANY. The information request form should be sent automatically based on the frequency set by the user. The user should be able to view the response rate and response quality of the information request forms. The user should be able to filter and sort the responses based on various criteria (e.g., supplier, information request form frequency, response quality). The system should send automated reminders to suppliers who have not responded to the information request form

after a certain period of time. The user should be able to export the information request responses to various formats (e.g., Excel, CSV).

- User Story: As a supplier, I want to receive regular information request forms from THE SPONSOR COMPANY to share my supply capacity, labor status, inventory levels, shipment status, and other relevant information with THE SPONSOR COMPANY.
- Testing Criteria: The supplier should receive a notification when a information request form is sent by THE SPONSOR COMPANY. The information request form should be easy to access and complete, with clear instructions and understandable questions. The information request form should not take an excessive amount of time to complete. The supplier should be able to save the information request form and come back to it later if necessary. The supplier should be able to submit the information request form without encountering any errors or technical issues. The supplier should be able to view their own responses to the information request form. The supplier should be able to receive automated reminders to complete the information request form if they have not done so after a certain period of time. The supplier should be able to contact THE SPONSOR COMPANY for any questions or concerns related to the information request form.

Emergent Information Request Forms

- User Story: As a supply chain manager, I want to send out emergent information request forms to my tier 1 and tier 2 suppliers when an alert is detected externally or internally to obtain immediate updates on the situation.
- Testing Criteria: The system should be able to detect alerts both externally and internally and trigger the emergent information request form. The information request form contents should be customizable and cover the relevant information required by THE SPONSOR COMPANY. The

information request form should be sent automatically to the related tier 1 and tier 2 suppliers. The supplier should be able to respond to the information request form easily.

- User Story: As a supplier, I want to receive emergent information request forms from THE SPONSOR COMPANY when an alert is detected externally or internally to share my situation and status with THE SPONSOR COMPANY.
- Testing Criteria: The system should be able to detect alerts both externally and internally and trigger the emergent information request form. The information request form contents should be customizable and cover the relevant information required by THE SPONSOR COMPANY. The information request form should be sent automatically to the supplier. The supplier should be able to respond to the information request form easily.

Ad-Hoc Communication

- User Story: As a supply chain manager, I want to use the ad-hoc communication channel to communicate with my tier 1 and tier 2 suppliers, share important updates, and resolve any issues or conflicts in a timely manner.
- Testing Criteria: The communication channel should allow the supply chain manager to initiate conversations with specific suppliers and communicate with multiple suppliers at once. The communication channel should support various types of information exchange, such as text, files, photos, and video calls. The communication should be secure and encrypted to protect the confidentiality of the information exchanged. The communication history should be logged and easily accessible for future reference. The user should be able to search for previous communication history with a specific supplier.

- As a supplier, I want to use the ad-hoc communication channel to communicate with THE SPONSOR COMPANY, share important updates, and resolve any issues or conflicts in a timely manner.
- Testing Criteria: The communication channel should allow the supplier to receive messages from THE SPONSOR COMPANY and respond in a timely manner. The communication channel should support various types of information exchange, such as text, files, photos, and video calls. The communication should be secure and encrypted to protect the confidentiality of the information exchanged. The communication history should be logged and easily accessible for future reference. The user should be able to search for previous communication history with THE SPONSOR COMPANY.

Action

- As a risk manager, I want to be able to create and assign risk mitigation tasks to team members, so that we can take coordinated action to address identified risks.
- Testing Criteria: The system should allow the risk manager to create and assign tasks related to risk mitigation, set deadlines and priorities, and track progress.
- As a team member, I want to be able to access and update my assigned risk mitigation tasks so that I can collaborate with my team and keep track of progress.
- Testing Criteria: The system should provide a task management feature that allows team members to view their assigned tasks, update their progress, and communicate with other team members.

Disruption Committee

- User Story: As a disruption committee member, I want to be able to quickly identify and assemble a reaction team to address the disruption.
- Testing Criteria: The system should have a clear process for identifying and assembling a reaction team. The system should allow for easy communication and collaboration between committee members and the extended supply chain. The system should track and report on the effectiveness of the reaction team's response to the disruption.
- User Story: As a member of the reaction team, I want to be able to track and monitor the progress of agreed-upon actions.
- Testing Criteria: The system should have a clear process for logging and tracking agreed-upon actions. The system should assign clear actors and timelines for each action. The system should provide notifications and alerts when actions are overdue or incomplete. The system should allow for easy review and reporting on the progress of actions and outputs.

Learnings and Feedback

- User Story: As a risk manager, I want to be able to review and analyze past risk events, so that I can identify patterns and improve our risk management strategies.
- Testing Criteria: The system should provide a historical analysis feature that allows the risk manager to review past risk events, analyze the root causes and consequences, and identify opportunities for improvement.
- User Story: As a user of the system, I want to be able to provide feedback on the usability and effectiveness of the Supply Chain Digital Risk Console so that the developers can make improvements over time.

- Testing Criteria: The system should provide a feedback mechanism (such as a information request form or feedback form) that allows users to provide input on their experience with the system and allows developers to track and analyze user feedback.
- User Story: As a supply chain manager, I want to be able to monitor and track disruption detection lead time, time to recovery (TTR), total loss estimation, and actual loss from disruption so that I can identify areas of improvement and optimize our supply chain performance.
- Testing Criteria: The system should be able to automatically detect disruptions and calculate the lead time between the detection and notification to the relevant stakeholders. The system should track the time taken to recover from the disruption, from the initial detection to the full recovery of the supply chain. The system should accurately estimate the total loss caused by the disruption. The system should provide accurate information about the actual loss incurred due to the disruption, such as the amount of inventory lost, the number of orders canceled, etc. The metrics provided by the system should be verified and validated against real-world data to ensure their accuracy and relevance. The system should provide clear and concise reports that highlight the performance of the supply chain in terms of the identified metrics.
- User Story: As a supply chain manager, I want to be able to evaluate my suppliers' performance and collect feedback from them through information request forms so that I can make data-driven decisions regarding our partnerships.
- Testing criteria: The system should provide a way to evaluate supplier performance based on predefined metrics, such as on-time delivery, quality, and cost. The system should allow the creation and customization of information request forms to collect feedback from suppliers. The system should track the response time of information request forms to evaluate the

effectiveness of communication channels. The system should provide analytics and reporting capabilities to display supplier evaluation results. The system should ensure data accuracy and prevent duplicate or incomplete responses.

Overall System Integration:

- User Story: As a user of the risk management system, I want it to seamlessly integrate with other systems and tools we use in our organization so that we can maximize efficiency and reduce errors.
- Testing Criteria: The system should have a well-defined integration process, with clear documentation on how to integrate with other systems and tools, and provide seamless data transfer between systems to eliminate manual data entry and reduce errors.

Reporting and Analytics:

- User Story: As a risk manager, I want to be able to generate reports and analytics on identified risks and mitigation efforts so that I can communicate effectively with stakeholders and continuously improve our risk management processes.
- Testing Criteria: The system should provide a range of reporting and analytics tools that allow risk managers to generate reports and dashboards on identified risks, mitigation efforts, and overall risk management performance, with the ability to customize the level of detail and format of the reports.

Usability and Accessibility:

- User Story: As a user of the risk management system, I want it to be easy to use and accessible from anywhere so that I can quickly access the information I need to perform my job effectively.

- Testing Criteria: The system should have a user-friendly interface that is intuitive and easy to navigate, with clear and concise instructions and helpful resources. The system should also be accessible from any device with an internet connection and support multiple languages for international users.

Security:

- User Story: As a user of the risk management system, I want to be confident that my data is secure and protected from unauthorized access or breaches.
- Testing Criteria: The system should have strong security measures, including encryption, access controls, and monitoring to prevent unauthorized access and protect against data breaches. The system should also comply with relevant industry standards and regulations, such as GDPR and HIPAA, to ensure data privacy and protection.

Appendix D – Sample Questions for Information Request Forms in Risk Console App

Figure D1: *Sample questions for general periodic information request form*

General Periodic Information Request

Question	Response	Key areas of risk	Plan of Action/ Support needed	Additional Comments
Overall ability to supply/ fulfill business needs per quarterly forecast	Low or Med or High	Choose when Low or Med RM or Labor or Supplier or Transportation or Capacity or Others (please specify)	Choose One Connect with SPOC or Other (free flow text)	<Optional Text Response>
Confidence on availability of Raw Material to support business requirement	Low or Med or High	Choose when Low or Med On-hand position or Quality rejections/ holds or New shipment delivery or Others (please specify)	Choose One Connect with SPOC or Other (free flow text)	<Optional Text Response>
Confidence on ability to maintain/ enhance staff to support business requirement	Low or Med or High	Choose when Low or Med Labor shortage (on-role/ contract) or Health and Safety concern or Labor Union related or Others (please specify)	Choose One Connect with SPOC or Other (free flow text)	<Optional Text Response>
Confidence on Sub-tier or Outsource Supplier's ability to support business requirement (if applicable)	Low or Med or High	Choose when Low or Med RM or Labor or Supplier or Transportation or Capacity or Others (please specify)	Choose one Connect with SPOC or Other (free flow text)	<Optional Text Response>
Confidence on transportation/shipment capability to the destination location	Low or Med or High	Choose when Low or Med Route related or LSP related or Rate related or Others (please specify)	Choose One Connect with SPOC or Other (free flow text)	<Optional Text Response>
Confidence on ability to meet capacity required to support business requirement (additional volume/surge if needed)	Low or Med or High	Choose when Low or Med Plantwide issue or Production line related issue or Others (please specify)	Choose One Connect with SPOC or Other (free flow text)	<Optional Text Response>

Note: This figure illustrates sample questions for general periodic information request form.

Figure D2: *Sample adaptive questions for specific information request form – Raw material, Labor, Supplier categories*

Periodic Survey – Category Specific Adaptive Questions

Question	Response	Key areas of risk	Plan of Action/ Support needed	Additional Comments
Raw Materials				
Raw Material on-hand position	Low or Med or High	<Optional Text Response>	<Optional Text Response>	<Optional Text Response>
Raw Material meeting quality standards	Low or Med or High	<Optional Text Response>	<Optional Text Response>	<Optional Text Response>
Confidence on new shipment delivery of Raw Material	Low or Med or High	<Optional Text Response>	<Optional Text Response>	<Optional Text Response>
Labor				
On-role or contract labor availability for the quarter	Low or Med or High	<Optional Text Response>	<Optional Text Response>	<Optional Text Response>
Ability to contain/ manage health and safety concern	Low or Med or High	<Optional Text Response>	<Optional Text Response>	<Optional Text Response>
Ability to manage labor union related issue	Low or Med or High	<Optional Text Response>	<Optional Text Response>	<Optional Text Response>
Supplier				
Share upstream supplier response (if applicable)	Choose one Share (Anonymized) Share (non-anonymized) Do not share	<Optional Text Response>	<Optional Text Response>	<Optional Text Response>

Note: This figure illustrates sample adaptive questions for specific information request form for Raw material, Labor, Supplier categories.

Figure D3: *Sample adaptive questions for specific information request form – Transportation and Capacity*

Periodic Information Request – Category Specific Adaptive Questions

Question	Response	Key areas of risk	Plan of Action/ Support needed	Additional Comments
Transportation				
How do you rate the availability of route in near term	Low or Med or High	<Optional Text Response>	<Optional Text Response>	<Optional Text Response>
Confidence on LSP ability to support business requirement (if applicable)	Low or Med or High	<Optional Text Response>	<Optional Text Response>	<Optional Text Response>
Effects of transportation rate volatility to business	Low or Med or High	<Optional Text Response>	<Optional Text Response>	<Optional Text Response>
Capacity				
Confidence on restoring plant wide operations to normalcy in short term	Low or Med or High	<Optional Text Response>	<Optional Text Response>	<Optional Text Response>
Confidence on restoring production line operations to normalcy in short term	Low or Med or High	<Optional Text Response>	<Optional Text Response>	<Optional Text Response>

Note: This figure illustrates sample adaptive questions for specific information request form for Transportation and Capacity categories.

Figure D4: *Sample validation questions to quantify the impact of disruption – duration and intensity*

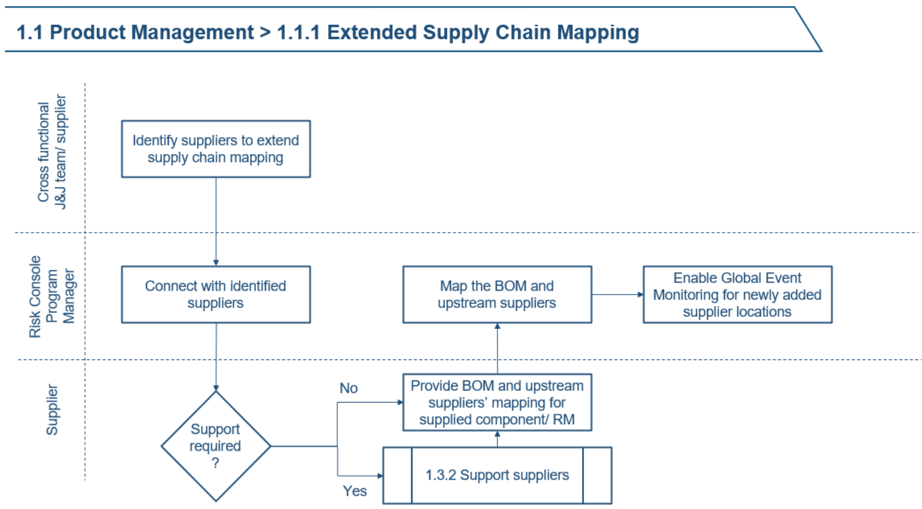
Validation / Quantification Questions

Quantify the Impact of disruption	Total Impact (% Orders for the period)	<Optional Text Response>	<Optional Text Response>	<Optional Text Response>
Quantify duration of impact/ time to recover	Period (Weeks)	<Optional Text Response>	<Optional Text Response>	<Optional Text Response>

Note: This figure illustrates sample validation questions to quantify the impact of disruption in terms of duration and intensity.

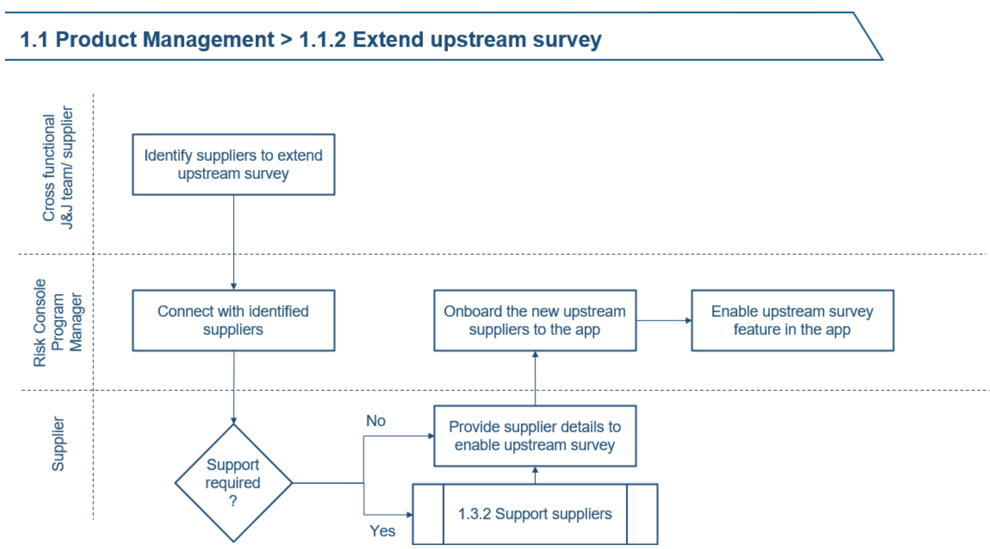
Appendix E – Detailed TO-BE Process Maps for the Digital Supply Chain Risk Console App

Figure E1: *TO-BE process for extended supply chain mapping*



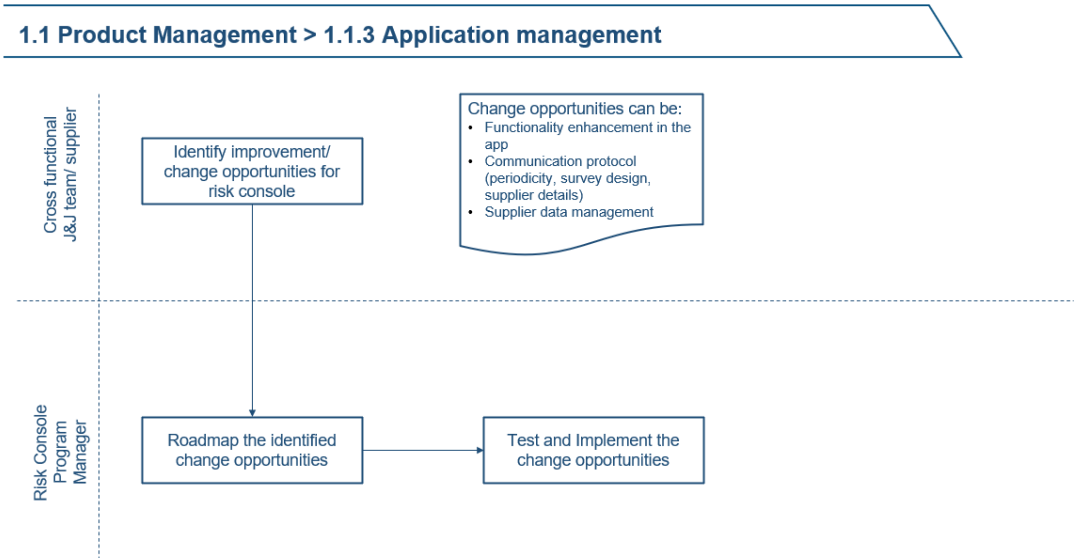
Note: This figure illustrates the TO-BE process for extended supply chain mapping for Digital Supply Chain Risk Console app.

Figure E2: *TO-BE process for extended upstream information request form*



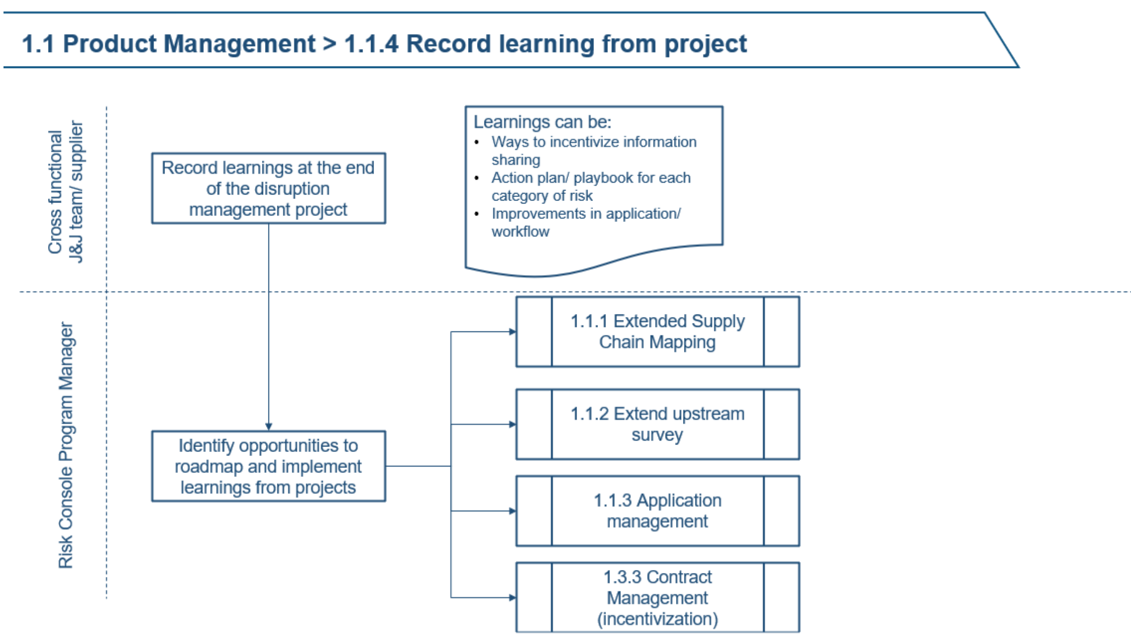
Note: This figure illustrates the TO-BE process for extended upstream information request form for Digital Supply Chain Risk Console app.

Figure E3: *TO-BE process for application change management*



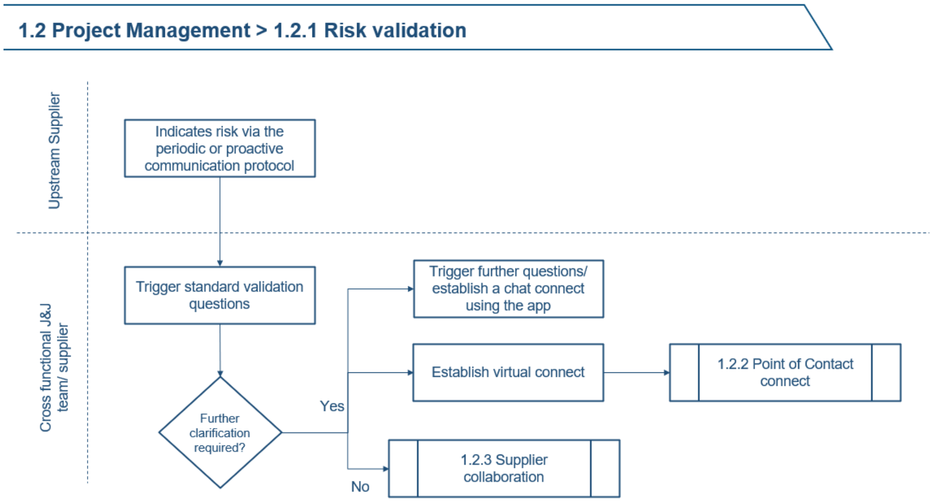
Note: This figure illustrates the TO-BE process for application change management for Digital Supply Chain Risk Console app.

Figure E4: *TO-BE process for recording learning from the project*



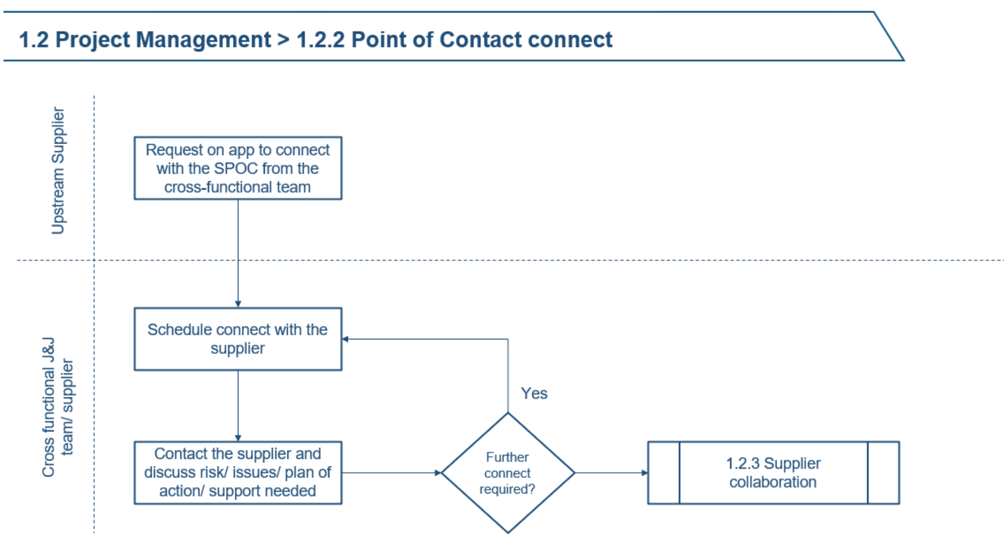
Note: This figure illustrates the TO-BE process for recording learning from the project for Digital Supply Chain Risk Console app.

Figure E5: *TO-BE process for risk validation in the app*



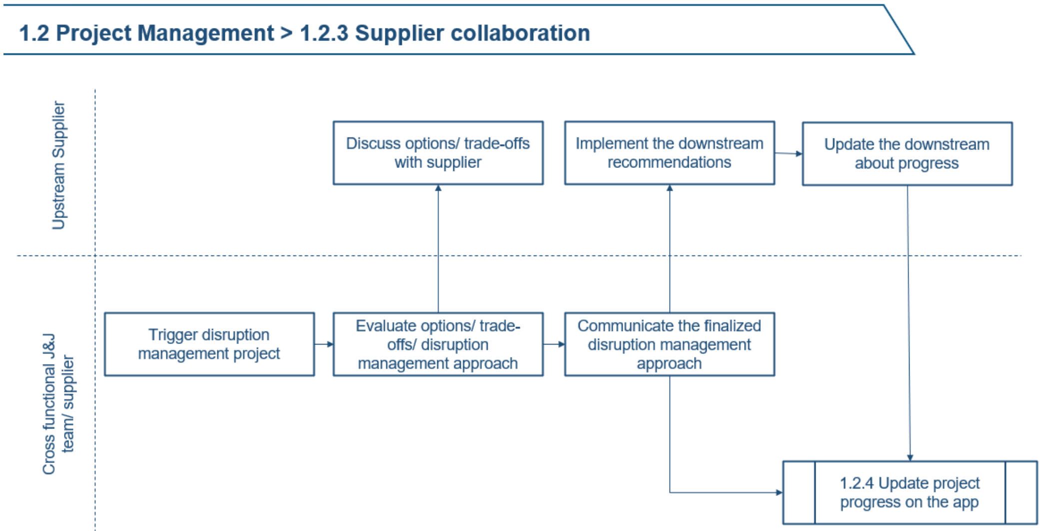
Note: This figure illustrates the TO-BE process for risk validation in the Digital Supply Chain Risk Console app.

Figure E6: *TO-BE process for point of contact connect in the app*



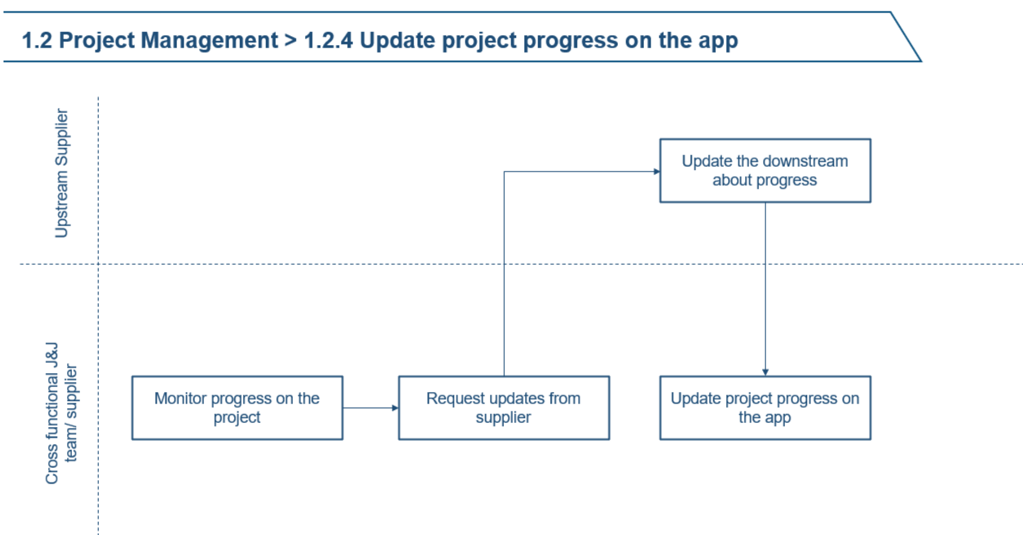
Note: This figure illustrates the TO-BE process for point of contact connect in the Digital Supply Chain Risk Console app.

Figure E7: *TO-BE process for supplier collaboration in the app*



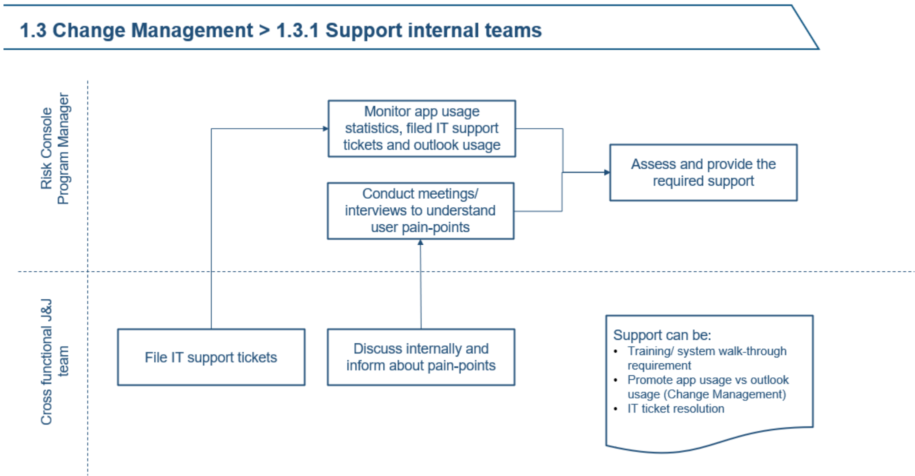
Note: This figure illustrates the TO-BE process for supplier collaboration in the Digital Supply Chain Risk Console app.

Figure E8: *TO-BE process for updating project progress in the app*



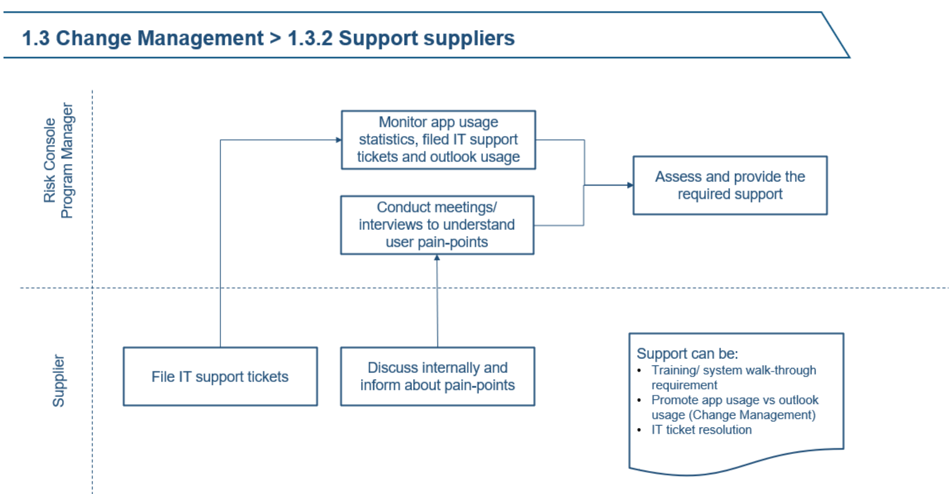
Note: This figure illustrates the TO-BE process for updating project progress in the Digital Supply Chain Risk Console app.

Figure E9: *TO-BE process to support internal teams in the app*



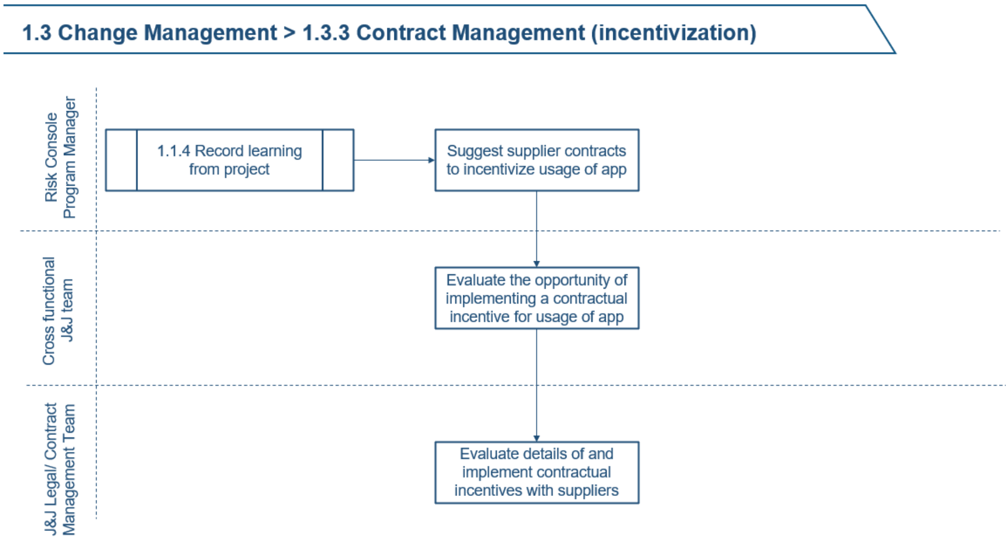
Note: This figure illustrates the TO-BE process for supporting internal teams in the Digital Supply Chain Risk Console app.

Figure E10: *TO-BE process to support suppliers in the app*



Note: This figure illustrates the TO-BE process for supporting upstream suppliers in the Digital Supply Chain Risk Console app.

Figure E11: *TO-BE process for contract management in the app*



Note: This figure illustrates the TO-BE process for contract management in the Digital Supply Chain Risk Console app.