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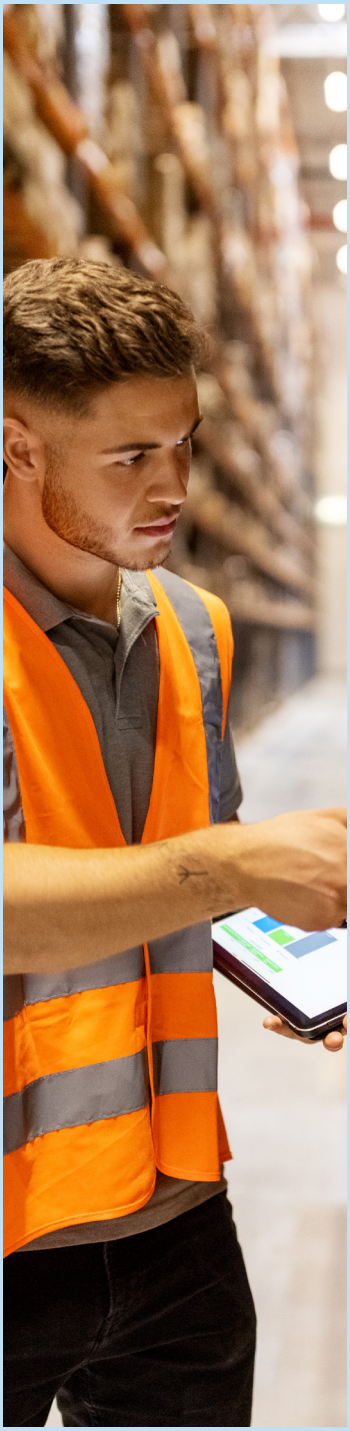

USING KNOWLEDGE GRAPHS FOR SMART SUPPLY CHAIN OPERATIONS

Abstract

The complexity of globalized supply chains due to global sourcing, dynamic consumer demand, and geopolitical shifts, presents significant operational challenges. Limited visibility, inefficient inventory management, and fragmented systems lead to supply chain disruptions. Knowledge graphs are emerging as a powerful tool to navigate this dynamic landscape and build resilience by connecting disparate entities across an enterprise supply chain ecosystem.

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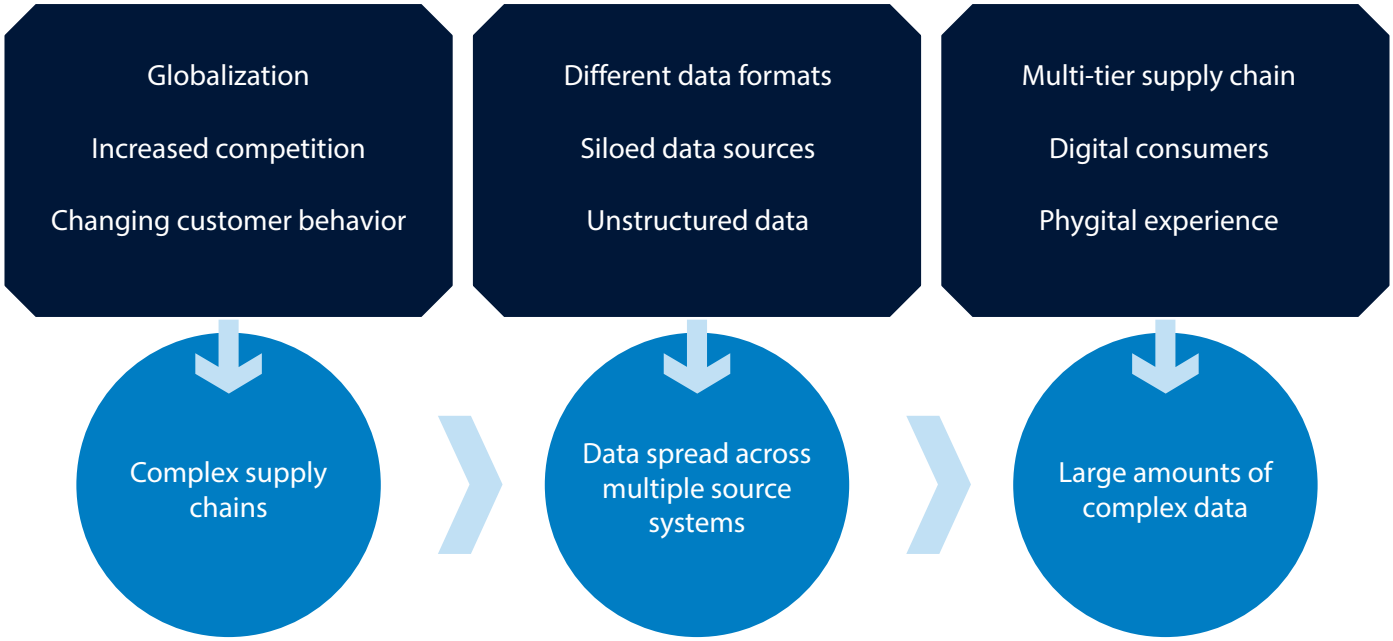
Global manufacturing bases, intense competition, and dynamic customer demand have transformed supply chains into intricate, non-linear networks, making supply chain planning a challenge. Inter-dependence among hundreds of constituents, including suppliers, contractors, logistics partners, and customers, compound the challenge. The lack of visibility into supplier performance, and the absence of transparency and agility are other significant constraints.

A fundamental prerequisite for achieving supply chain resilience is the construction of a digital representation of the end-to-end value chain. This ensures provisioning of pertinent data and knowledge at the requisite level of granularity and latency to support high-speed planning workflows. Unfortunately, the humongous volume and intricacy of data from disparate sources, including IoT devices, affect robust digital representation.

Conventional data storage methods, such as relational database management system (RDMS) and online analytical processing (OLAP) cubes, designed for granular data handling, cannot effectively address the complexity of modern supply chains. Data explosion hinders scalability and real-time analysis, often leading to oversimplified models that deliver performance at the expense of valuable insights. Consequently, organizations do not harness the available rich data for prompt, data-driven decision making.

Solution: Knowledge graphs

Knowledge graphs not only represent data, but also model relationships between multiple entities for various stakeholders. These graphs break down data silos, connect data at different levels, and provide a consistent, function-specific view for each department, thereby facilitating coordinated action. Knowledge graph-based planning is useful in cases where functional silos present a risk. Notably, it connects diverse functions, such as sales and manufacturing, to support data-driven decisions for realizing business objectives.



What is a knowledge graph?

A knowledge graph is a type of database that represents knowledge in a structured, comprehensive manner by establishing interrelationships between diverse elements of a given system. Such knowledge representation can be used to store and manage both structured and semantic information. Unlike traditional databases that store information in a rigid, hierarchical format, knowledge graphs are flexible and adaptable, allowing better connectivity and interoperability between data sources.

The basic building block of a knowledge graph is the 'node', which represents a piece of information or data point. Nodes are connected by 'edges' that represent relationships between the nodes (Figure 1). For example, in a knowledge graph for maintenance of a machine, the nodes may represent a spare part, its manufacturer, lifespan of that part, and its service history.

Knowledge graphs can be used for data integration and data discovery, and to represent virtual supply chains. This helps analysts and supply chain specialists to identify data issues and uncover insights that may not be apparent when a data source is analyzed in isolation.

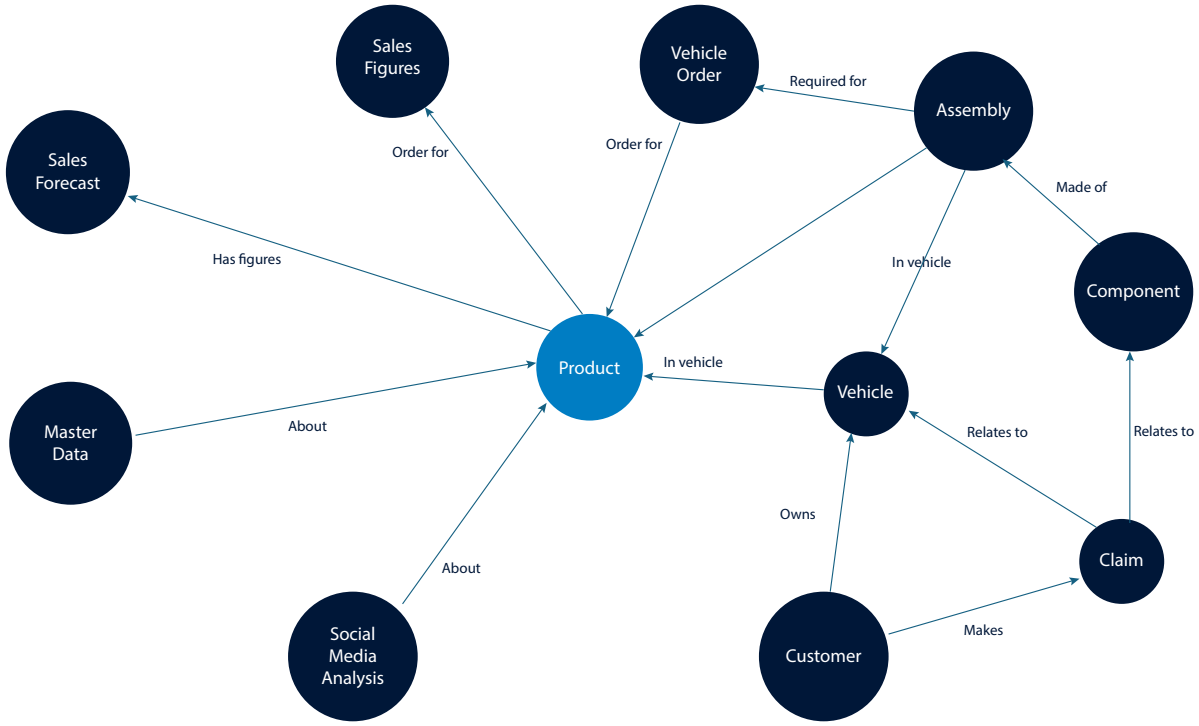


Figure 1: Knowledge graph and its components

Benefits of using knowledge graph in a supply chain

Knowledge graph is a powerful tool for streamlining supply chain management:

Visibility and transparency

- **Connecting data:** Integrates information from various sources (ERP, IoT sensors, logistics systems, news feeds, etc.) and offers a unified view of the supply chain network.
- **Mapping interrelationship:** Displays inter-connection between suppliers, materials, products, facilities, and transportation routes, and identifies potential bottlenecks, dependencies and business opportunities.
- **Real-time insights:** Provides an accurate view of supply chain operations by integrating real-time data.

Decision making

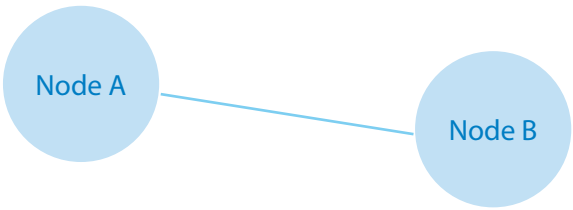
- **Predictive analytics:** Analyzes historical data and identifies patterns that are useful to predict disruptions, demand fluctuations, and other risks, which enables proactive measures to address issues.
- **Scenario planning:** Enables simulation of different scenarios, such as natural disasters or trade wars, which helps in assessing potential impact and developing contingency plans.
- **Resource allocation:** Identifies inefficiencies and hidden connections, and thereby optimizes resource allocation across a supply chain network.

Collaboration and agility

- **Knowledge sharing:** Provides a common source of truth for all stakeholders, enabling better communication and collaboration across supply chain functions / departments.
- **Supplier risk management:** Helps assess reliability, sustainability and other risk factors with respect to suppliers, which enables informed sourcing decisions.
- **Dynamic adjustment:** Analyzes real-time data to facilitate prompt response to dynamic market conditions.

Compliance

- **Traceability:** Tracks materials and products across a supply chain, ensuring compliance with regulations and facilitating product recall.
- **Sustainability tracking:** Monitors the environmental and social impact of supply chain operations, and identifies areas of improvement.



In its simplest form, a knowledge graph is a labeled graph comprising three elements:

- Nodes - Real-world entities that may be material objects or abstract concepts.
- Edges - Links that connect the nodes.
- Labels - Attributes that define the relationships between nodes and reasoning rules on the edges.

Use cases in supply chain operations

Predictive maintenance

Modern production lines rely on numerous sensors and interconnected machines. The breakdown of a single machinery can disrupt operations. Knowledge graphs act as digital twins, allowing companies to use virtual models of machines to identify potential issues and proactively address them before they halt production. A nuanced understanding of the interrelationship between parts of a system empowers teams to mitigate weaknesses and ensure smooth operations.

Siemens[1] uses a knowledge graph to track the performance of wind turbines and predict maintenance requirements. Result: Reduced downtime by up to 30%.

Ford[2] uses a TigerGraph graph database to track the performance of manufacturing equipment and predict parts failure. Result: Improved failure prediction by 90%.

Inbound logistics

A knowledge graph serves as the central nervous system for inbound logistics. It ingests data from disparate sources, including supplier portals, carrier tracking systems, and customs databases, to create a comprehensive repository spanning from shipment details (weight, dimensions and content) and supplier performance metrics (lead times and reliability) to customs delays for a specific product and its country of origin.

Infosys created a digital replica of a fashion retailer's inbound logistics operations using a knowledge graph. It improved visibility into shipments, and facilitated decisions to avoid disruptions.

Inventory management

The proliferation of contract manufacturing has created an ecosystem in which multi-level inventory management is unavoidable. Thousands of subparts, sourced from different locations, need to be tracked and accounted for, in addition to work-in-progress, finished goods and sales inventory.

By mapping the flow of products and relationships across materials in a knowledge graph, supply chain managers can make informed decisions on when to order, what to order, from which supplier, and when to inter-transfer products across facilities / suppliers.

Nokia Unified Inventory[3] is an innovative solution powered by Graph DB to enable AI/ML intervention in capacity management, network simulation, new service provision, and network failure impact simulation in the telecom industry.

Walmart[4] utilizes a knowledge graph known as 'Retail Graph' that captures connections between products and entities in the retail industry and helps customers with product discovery in Walmart's catalog.

Risk management

Supply chains often face risks due to the lack of visibility into operations across a multi-tier network, or due to uncertainties caused by natural factors or geopolitical issues, such as the Covid-19 outbreak and Russia-Ukraine conflict.

By representing the relationships between suppliers, products and customers in a visual form, a knowledge graph helps supply chain managers easily identify and mitigate risks, such as supply chain bottlenecks or suppliers adopting sub-par environmental or labor practices.

Sopra Steria[5] built the Intelligent Network Analysis (INA) explorer tool to help telecom companies simulate network changes and troubleshoot predicted failures in advance to proactively assess any risk related to network changes.

Jaguar Land Rover[6] uses TigerGraph knowledge graph to evaluate complex processes in the supplier network ecosystem, thereby improving decision making and reducing supplier risk by 35%.

Future outlook

The ability of knowledge graphs to drive seamless data integration, enhance search and recommendation systems, and boost data-driven processes helps enterprises across industries optimize supply chain operations. Knowledge graphs can also be applied to rationalize inventory and drive sustainable business growth. Advances in data recording and generative artificial intelligence-based use cases will further enhance the value of knowledge graphs. However, challenges such as data availability and quality, data security, costs, infrastructure agility, and user adoption need to be addressed prior to at-scale adoption.

- **Gartner:** The market for graph technologies, including graph database management systems (DBMSs), will grow to US$3.2 billion by 2025 with a CAGR of 28.1%.
- **IDC:** By 2027, the need to combine dual representation of enterprise knowledge will drive 50% of A2000 to combine vector embeddings stored in vector databases with graph databases for AI model training.
- **MarketsandMarkets:** Estimates global knowledge graph market to grow at a compound annual growth rate of 21.8% between 2023 and 2028, fueled by rising demand for data-driven decision-making.

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