SEEING IT ALL - VISIBILITY & DIGITAL TWINS IN SUPPLY CHAIN MANAGEMENT

Ms. Reyya Pawani
Assistant Professor, School of Management Studies,
Sathyabama Institute of Science and Technology, Chennai
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Abstract

In a rapidly globalizing and technology-driven business environment, supply chain visibility has emerged as a critical determinant of operational efficiency, resilience, and sustainability. This paper explores the transformative role of visibility and digital twin technologies in modern supply chain management. Supply chain visibility (SCV) enables organizations to track, monitor, and analyze every movement of goods, information, and resources across the value network, thereby ensuring transparency, agility, and responsiveness. However, many global supply chains still suffer from fragmented data systems and poor coordination among partners.

The study highlights how digital twin technology—virtual replicas of real-world supply chain systems powered by IoT, analytics, and AI—enables real-time synchronization, predictive simulation, and proactive decision-making. Through integrated data, modelling, and analytics layers, digital twins enhance predictive planning, operational optimization, and cost efficiency. The incorporation of IoT-based real-time tracking and smart sensors further strengthens end-to-end visibility by providing continuous, actionable insights. The article emphasizes managerial imperatives such as investing in data governance, fostering cross-functional collaboration, promoting proactive management, and building digital literacy. Ultimately, visibility and digital twins transform supply chains from reactive frameworks into intelligent, predictive ecosystems that drive competitive advantage, sustainability, and resilience in the face of global uncertainty.

Introduction:

Something you cannot see is something you can not have control over. -- Peter Drucker

In the contemporary globalized society, efficiency is being changed in place of visibility. Global supply chain has been transformed into a complex web of suppliers, distributors, and other logistics partners and digital platforms that are under great pressure to work faster, cheaper, and more sustainably. Nevertheless, there is one thing even about the most advanced system, they can lack visibility.

The miss of a shipment in one side of the world can halt the production in the other side; the failure of one supplier can ruin an entire network. Managers no longer compete in terms of cost or speed they are competing on their vision, insight and responsiveness. In this chapter, the authors explain how emerging technologies, including the Internet of Things (IoT), real-time tracking and models based on digital twin are transforming supply chains into a responsive system into a predictive ecosystem.

Supply Chain Visibility Insights.

1.1 Supply Chain Visibility: What Is It?

Supply chain visibility (SCV) is the ability to track all the links, deliveries and the portion of the supply chain both on the way up to the raw material, to the final consumer. It provides real time feedback to the decision-makers regarding where, when, who as well as what of their operations.

Unlike the current traditional tracking systems where the partial updates are delivered, the recent visibility solutions give a single version of the truth that connects the data in procurement, manufacturing, logistics, and distribution. With the flowing data, the managers will be able to prevent risks, utilize the resources optimally, and make quicker and informed judgments.

1.2 Why Visibility Matters

- Visibility is not just an operations strength it is a strategic requirement.
- Agility: Ensures that organisations are able to respond to disruptions on a real time basis.
- Efficiency: reduces inventory costs and transportation costs.
- Trust: Facilitates customer, regulatory, and stakeholder transparency.
- Sustainability: Offers carbon footprint and ethical sourcing tracking.

A high visibility tool enabled the company to heal 30-40 times faster than the rivals in the case of the COVID-19 because they could reroute the shipments, find other suppliers, and rearrange the production in real-time.

Computerized replica of Supply Chains.

2.1 What Is a Digital Twin?

A digital twin is a digital component of a physical supply chain system - an accurate digital replica of that system, which receives live information fed back into it in the real world. It simulates the supply chain behaviour under various conditions after using IoT sensors, enterprise systems and analytics platforms.

When thinking about making a change in real life, think about the chance to perform a test with a new supplier, distribution route or factory layout, before actually changing it. The power of the digital twin is that it helps the managers to peep into the future.

2.2 How Digital Twins Work

A digital twin is not merely a visualization notion, although it is actual life breathing entity of a virtual community of a physical supply chain. This digital image is continually updated with real-time data and this allows managers to simulate processes, trial options and make predictions with spectacular accuracy.

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The digital twin is well-structured i.e. it is reflective of the physical supply chain structure i.e. suppliers, manufacturing plants, distribution centers and even demand trends of customers. Any decision or change of operations in the physical world is projected in the virtual model. This gives a tremendous feedback loop that helps the organizations to shift to the reactive management to the prescriptive and prescriptive decision-making.

To understand how a digital twin can operate, it is beneficial to sub-divide a digital twin into three basic layers:

The Foundation of Reality - The Data Layer.

The data layer is the key element of any digital twin that acts as an interconnectedness between the physical and the digital world. It processes streams of information on an ongoing basis on a variety of sources within the supply chain such as:

IoT Sensors and devices: Tracking of temperature and humidity, vibration, and position of goods and equipment.

Enterprise Resource Planning (ERP) Systems: This includes operational information such as inventory information, purchase orders, production and supplier information.

Warehouse Management System (WMS) and Transportation Management System (TMS): Both of them offer real-time information such as feedback on storage capacity, truck routes, and delivery outcomes.

External Data Sources: The list includes weather forecasts, fuel price data, port congestion data, and geopolitical data (which might also influence the performance of the supply chain).

This layer will enable the provision of high-quality live data to the digital twin to maintain the digital twin in tune with the real world operations. There is no way that a high-tech model will operate without appropriate data input, this is why the key to successful implementation of any digital twin project is data governance and integration capability.

The Modelling Layer The Virtual Mirror of Supply Chain.

Once the input is absorbed by the data layer, the modelling layer transforms the input into a large-scale digital representation. This layer will enable the managers to view the material, information and finance flow of each stage of supply chain. The model will consist of the physical elements (factories, suppliers, warehouses and transport nodes) and the process elements (lead times, production schedules and procurement policies).

Digital twins are modelled using two broad categories:

Mathematical Modelling: Uses algorithms and equations to approximate the behaviour of systems in varying conditions They can be applied to give a guess on how the delay of the supplier will affect a production cycle or inventory levels.

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Graphical/3D Modelling: This provides a visual interface of viewing their supply chain at work on the factory floor layouts or real time shipment tracking of their supply chain routes the world over.

The Analytics Layer – The Brain of the Twin

Decisions and intelligence occur on the analytics layer. It accepts data layer as an input and digests the flow of constant information through the aspects of analytical, predictive and optimization tools to draw meaning and find areas of improvement.

This layer generally comprises:

Descriptive Analytics: What is really going on? by providing performance measures and dashboards.

Predictive Analytics: Uses past and live data to make forecasts in advance of demand increased, a piece of equipment failing, or a transportation of goods becoming jammed.

Prescriptive Analytics: Suggests the most optimal actions - like recommending the shipment be rerouted, or a change in the production times or the selection of a new supplier.

The other digital twins integrate machine learning and artificial intelligence (AI) with this layer and thus the system learns constantly on the experience. The smarter the twin gets the more new data processed and accurate predictions and suggestions.

The Continuous Learning Loop.

The three layers (data, modelling, and analytics) are connected to one another in a feedback. As the information about the physical supply chain is updated with the data about the digital twin, the information is processed by the analytical models, which generate insights, and transfer the recommendations to the managers or even automated control systems.

2.3 Benefits of Digital Twins

Predictive Planning: This is when the lost time such as delays by suppliers or a bottleneck in the transportation process is anticipated.

Operational Optimization: Discover Inefficiency and simulate.

Reduction of Costs: Reduce inventory, fuel and maintenance expenses.

Sustainability: Pattern carbon Emissions and improve greener outcomes.

Examples Case Siemens uses digital twins to simulate material flows in the global plants. The operation of predictive models also reduced the logistics costs of the company by 15% and maximized their delivery reliability by 12%.

IoT and Real-Time Tracking

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3.1 The Internet of Things in SCM

One of the systems, Internet of Things (IoT) is the use of physical resources (trucks, containers and warehouses) to the digital form, through sensors, and smart devices. The IoT can be used in supply chains to allow businesses access real-time data on the location, condition, and performance of the goods in transit.

RFID tags, GPS tracking gadgets and temperature sensors have transformed the visibility of logistics. To illustrate this, a pharmaceutical company transporting vaccines can now be capable of monitoring the alterations in temperature every one second and this is as per the safety standards.

3.2 In-Time Information and Proactive response.

Tracking will also be done in real-time to ensure that the managers will not wait to receive the reports at the end of daily or weekly. They can respond instantly: they can reroute deliveries, inform their clients about delays, or anticipate doing pro-active maintenance before it begins to unravel.

Predictive Maintenance: Equipment can have sensors that can detect its vibration, or temperature variations and predict maintenance before failure.

Openness to the customer: Live monitoring of the shipment enhances the degree of contentment and faith.

Loss Prevention: The managers will have an alert concerning the possibility of the movement of the goods outside of the planned paths or their damage.

Case Study: Maersk, a shipping company that is global, has embraced the implementation of smart containers using the Internet of Things (IoT) technology to check the condition of cargo anywhere in the world. This has reduced the spoilage rates to a minimum and increased the operation efficiency between routes.

Achieving End-to-End Visibility.

4.1 Beyond Tier 1 Suppliers

The fact that you can know where your direct suppliers are is not as great as true visibility. It reaches Tier 2 and Tier 3 - those that provide your suppliers. The layers will contain concealed weaknesses.

4.2 Barriers to Visibility

- Data Silos: single systems do not permit the flow of information.
- Smaller Vendors: They are unwilling to share the data due to the fear of competition.
- Cybersecurity Risk: There is a risk of breach as more and more people get connected.
- High Implementation Cost: Advanced systems require infrastructure and integration.

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4.3.1 Visible Supply Chain Construction.

- Unified Data Platforms: Get ERP, IoT and logistics information on a single dashboard.
- Collaborative Partnerships: (Form) Trustful relationships that underpin data exchange.
- Blockchain Technology: Provided tracks records of impossibility to modify and legitimacy.
- Standardization: ISO 28000 security standard and GS1 traceability standards, purchase standards.
- Managerial Implications
- Visibility and digital twin technology is far beyond technical upgrading or IT expenditures, yet it is a transformation in how managers lead, plan and make decisions in the present supply chains. As the world business is getting more complex, the ability to convert the data into knowledge and vision is becoming a characteristic of the competitive advantage. The managers are therefore forced to get out of the firefighting operational mode and adopt a method of data-driven, collaborative and anticipatory leadership.
- There are four key areas that managers should improve to leverage the visibility and digital twin technologies effectively:

Invest in Data Governance

Managers ought to create competent data governance procedures that provide the data ownership, its gathering procedure, storage, validity and its distribution within the organization. This includes:

- Unification of data collection procedures with the suppliers and business units.
- Guarantees correctness of data that is vindicated by a computer and auditing on a regular basis.
- Establishing of cybersecurity control to ensure classified information.
- Promote transparency without breaking privacy law and business ethics.

As data governance gains prominence, the organization will feel confident about the analytics of the organization and thus will be able to make fast and decisive decisions using actual-time knowledge and not guesses.

Advance Interdepartmental Teaming.

The supply chain visibility is not attached to a department, supply chain work is an outcome of collaboration among other departments, which include procurement, logistics, and finance, manufacturing, and information technology.

Silos are one of the biggest inhibitors of end-to-end visibility. Their systems, information formats and purposes may not allow free flow of information especially between the departments. To overcome this, the managers must:

Cross-functional teams can be formed that can unite skills.

Make the open conversation and exchange of information simple and eliminate the blind spots.

The solution consists in aligning performance measures and incentives at the department so as to develop common goals.

Develop a sense of ownership where all people know what impact is produced by their operations on the overall appearance and performance.

Construct a visionary Management.

The past management of the supply chain was in a reactive form where the managers responded to any disruptions, delays or shortages only after they had occurred. On the other hand, digital presence and twin technology offers the capability of managing pro-actively whereby the leaders can anticipate the challenges even before they spiral out of control.

Real-time dashboards, predictive analytics, and simulation tools will help managers to identify the signs of danger early on, experiment with the alternative scenario, and undertake preventive measures. The preventive measure is advantageous:

- Minimize risks by preventing issues prior to causing major inconveniences.
- Minimize inventory and reduce unwarranted costs.
- Improve customer satisfaction through timely and reliable deliveries.
- Online and Analytical Skills Training.

People will bring value rather than technology itself, will. To come up with useful lessons depending on visibility systems and digital twins, managers and their staffs must be digitally savvy and analytically proficient.

The capacity building and training will assist in ensuring that the employees will be able to decipher complex information, master the process of the prediction, and making informed decisions. Managers should:

- Encourage the further research of analytics, IoT solutions and visualization solutions.
- Promote the inter-disciplinary education of IT specialists and operation managers.
- Know how to read data so as to go beyond technical knowledge - be able to convert knowledge into strategic behavior.
- Promote the culture of experimentation and continuous improvement rewards.

Suggestions

- Firm Data Integration Structures:

It is recommended that the organizations come up with consolidated digital systems which will integrate the ERP systems, IoT systems and the logistics systems to maintain a free flow of data and elimination of silos.

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- Introduce Scalable Digital Twin Models:

A digital twin applied on an enterprise-wide level can be scaled once pilot projects concerning high-impact aspects (logistics or inventory management, etc.) are undertaken.

- Enhance Supplier Partnership and Transparency:

Build the relationship of trust to disclose the data at all levels and especially Level 2 and Level 3 suppliers to eliminate the existence of some of the vulnerabilities which can be concealed.

- Invest in cybersecurity infrastructure:

As the connectivity grows, it is urgent to use advanced encryption, blockchain verification, and access control to ensure the safety of sensitive data of the supply chain.

- Listen to Sustainability Analytics:

Monitor the environmental performance through digital twin systems by incorporating carbon-tracking modules to facilitate the green supply chain goals.

- Develop Workforce Capabilities:

It ought to be done by continuous training of data analytics, AI-powered tools, and IoT functioning to enhance digital literacy and empower managers to make data-oriented decisions.

- Encourage Predictive and Prescriptive Analytics:

Naturally, grow beyond descriptive dashboards and transition to predictive and prescriptive intelligence by proposing the most appropriate course of action in the event of disruptions or change in demand.

- Promote Standards within the Industry:

Encourage the implementation of global systems of traceability, such as GS1, ISO 28000 and blockchain based systems, which will ensure data integrity and interoperability.

Conclusion

The digital twin and the visibility technologies refer to the dawn of a new epoch in the supply chain management: the possibility to respond to an issue immediately is replaced by a proactive intelligence and a dominating power. Organizational transparency can be achieved in a level such as in the past by integrating IoT sensors, real-time analytics, and virtual modelling. The evolution gives managers powers to foresee disruptions, maximization of resources, and the organization of operations according to sustainability and customer expectation.

However, technology does not result in end-to-end visibility, but cultural change, teamwork and control. The companies should invest into robust data ecosystems and train digitally competent experts and culture of lifelong learning and innovation. The global supply chains are getting more and more complex and hence, those with capability of

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viewing, anticipating and acting promptly will not just react to the disruption but also shape the competitive landscape in the future.

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