Adding Value to Manufacturing, Retail, Supply Chain, and Logistics Operations with Big Data Analytics

Ishita Gupta and Manjunath Kamath

MHI Solutions community

CICMHE
COLLEGE-INDUSTRY COUNCIL ON MATERIAL HANDLING EDUCATION

Adding Value to Manufacturing, Retail, Supply Chain, and Logistics Operations with Big Data Analytics

Ishita Gupta and Manjunath Kamath
School of Industrial Engineering and Management
Oklahoma State University, Stillwater, OK 74078

Introduction

The concept of big data has been around for many years. Only in the last few years have organizations started to understand how they can use big data to gain insightful knowledge about their business operations, which is enabling them to make better business decisions. While there is no single definition, big data usually works on the principles of four Vs - Volume, Velocity, Variety, and Veracity. As the name suggests, big data is really big, meaning a huge amount of data is being generated daily, reaching the scale of petabytes. This data comes in all forms - structured, semi-structured, and unstructured and is pouring in from all directions and generated by many systems and devices, such as transactional systems, log files, GPS devices, smartphones, RFID readers, surveillance cameras, sensor networks, Internet of Things (IoT), and social media. Finally, as big data becomes an important asset for enterprises, the focus is also on the trustworthiness of data and its sources.

According to Gartner, Inc., "Big data is high-volume, high-velocity and high-variety information assets that demand cost-effective, innovative forms of information processing for enhanced insight and decision making."[a] In this article, we first elaborate on the big data concept and present the storage and processing technologies that have been developed to deal with big data. We then briefly discuss the evolution of traditional analytical processing to today's big data analytics. Through several applications and use cases, we illustrate how big data analytics is adding value to manufacturing, retail, supply chain, and logistics operations. Finally, we conclude by discussing key challenges that businesses have to face as the use of big data analytics becomes more widespread.

Understanding Big Data

Regardless of the decision to be made - optimized production/work schedules, accurate forecasts, customer preferences - data nowadays has the potential to help businesses succeed more than ever before. From an organizational perspective, big data is a holistic approach of obtaining actionable insight to create a competitive advantage over others.[1] There are two distinct approaches to applying big data - improve the existing processes by focusing on the current business needs or create products and services as new value propositions. A challenge that organizations increasingly face is finding and working with trusted data. Working with inaccurate and untrusted data can be worse than having no data at all. As data requirements and regulations become more complex, organizations must be aware of where all their data is coming from, where it is getting stored, and who is interacting with this data as conclusions are drawn.[2]

---

[a] https://www.gartner.com/it-glossary/big-data/

What is Big Data?

The evolution of the world wide web has redefined the kind of data that needs to be handled and tracked, the speed at which the information is flowing into online systems, and the number of customers a company must deal with on a regular basis. Because of the changes happening in the Web environment, new definitions for big data have been proposed, with a focus on technologies that handle this data. O'Reilly defines big data as "Big data is data that exceeds the processing capacity of conventional database systems. The data is too big, moves too fast, and doesn't fit the structures of traditional database architectures. To gain value from this data, organizations must choose an alternative way to process it."[3]

To understand how big data is transforming businesses, we need to understand its nature as most definitions of big data focus on the size of data in storage.[4] Size is important but there are other aspects to big data namely variety, volume, and more recently, veracity.[2] Together they are called the 4 Vs of big data: Volume, Velocity, Variety, and Veracity.

Going Beyond Traditional Data Warehouses

Big data is not limited to traditional storage methods where structured data was stored and retrieved from relational databases, data warehouses, and data marts.[6] Here, the data is uploaded to operational data stores using Extract, Transform, and Load (ETL) tools which extract data from internal and external sources, transform the data to fit the operational needs, and finally load the data into the data warehouse. The key point is that the data is getting cleaned, transformed, and cataloged before being made available for data mining and online analytical functions. This traditional data warehouse approach discourages the incorporation of new data sources until they are cleansed and integrated.

Since data is ubiquitous these days, big data storage environments need to be "magnetic" in nature, attracting data from all sources. Hence, big data calls for Magnetic, Agile, and Deep (MAD) analysis skills, which differs from the traditional data warehousing approach. Given the growing number of data sources and the sophisticated tools for data analysis, big data storage should allow analysts to easily process and use data rapidly. Solutions like distributed file systems and Massive Parallel Processing (MPP) databases are available nowadays for providing high query performance and platform scalability. Non-relational databases such as Not Only SQL (NoSQL) were developed for storing and managing unstructured data.[7] These newer technologies aim for scalability, data model flexibility, and simplified application development and deployment. They separate data management and data storage and focus on high performance scalable data

4 Vs of Big Data

Volume. The ability to process a large amount of information available and produced from transactional records to social media, from Internet of Things to system logs, etc.

Velocity. The rate at which data is getting created every second of the day. With digitization being a major contributor, more data is being generated and logged than ever before.[5] Also, the rapid adoption of social media and the Internet of Things has created a deluge of data. Advances in machine learning and AI have made previously useless data much more useful now.

Variety. It is the diversity of data which organizations are witnessing. Companies are used to managing and processing a limited set of data, such as transactional records and logs. Advances in technology have enabled the analysis of unstructured data which includes images, voice recordings, videos, and texts generated from several platforms including social media to deliver new insight.

Veracity. It is not just the quality of data, but also the trustworthiness of data sources. Basic issues are the accuracy and applicability of data. Accuracy of data is affected by uncertainty due to inconsistencies, incompleteness, ambiguities, etc.

storage, allowing management tasks to be written in the application layer instead of having it written in database specific languages.

Why Big Data?

When organizations adopt big data as a part of their business model, the first tangible question is usually what value this big data will provide to the company.[7] Data must be used to make better decisions, to optimize resource consumption, and improve process quality and performance. It should also aim to perform precise customer segmentation, optimize customer satisfaction, and increase customer loyalty. New business models should be enabled with the use of big data which complement the revenue streams from existing products and create additional revenue from new products.

Newer Data Sources, Newer Opportunities

The new sources of big data include industries which are taking a big step step towards digitization, and as a result, data growth in the past few years has been phenomenal. Some of the areas where data is coming from include social media, internet browsing pattern data, advertising response data, financial forecasts, location information, driving patterns, vehicle diagnostics, and traffic and weather data from sensors, monitors, and forecast systems. Other sources of data include data from healthcare, where the healthcare industry is implementing electronic medical records and digital imaging, which is used for short-term public health monitoring and long-term research programs. Similarly, low cost gene sequencing can generate hundreds of terabytes of data that must be analyzed to look for genetic variations and potential treatment effectiveness in life sciences.[8] Another area is data from video surveillance which is transitioning from CCTV to IPTV cameras and recording systems that many organizations want to analyze for behavioral patterns for security and service enhancement. Transportation and logistics industry has been generating and storing enormous amount of data coming from sensors, GPS transceivers, RFID tag readers, smart meters, cell phones, material handling equipment enabled with sensors, etc. This data can be used to optimize operations and derive operational business intelligence to realize immediate and future business opportunities.

Analytics and Big Data Analytics

Data analytics is the science of analyzing raw data with the purpose of drawing conclusions about information contained therein.[9] It involves applying algorithmic processes to derive insights. Analytics is used to extract previously unknown, useful, valid, and hidden patterns and information from large data sets.[6] While the focus of analytics has been on inference, it can also provide prescriptive insights as explained later in this section. Hence, analytics has a significant impact on research and technology, as businesses recognize its great potential in helping them gain competitive advantage.

“Big data analytics is the use of advanced analytic techniques against very large and diverse data sets that include structured, semi-structured, and unstructured data from different sources, and in different sizes from terabytes to zettabytes.”[b] It helps in uncovering hidden patterns, unknown correlations, market trends, customer preferences and other useful information. Advanced analytics can help organizations discover what has changed and how they should react. Analytics is the best way to discover new customer segments, identify the best suppliers, associate products of affinity, understand sales seasonality and so on.[4] Organizations are implementing specific forms of analytics tools and techniques which include data mining, statistical analysis, data visualization, artificial intelligence, machine learning, and other data capabilities

[b] https://www.ibm.com/analytics/hadoop/big-data-analytics

which support analytics[4]. Though these techniques have been around for many years, organizations are using them now as most of these techniques adapt well to very large, multi-petabyte data sets.

Big data's worth is only realized when businesses can indulge in decision making using this data. To enable such data-driven decision making, organizations must use efficient processes to turn the high volume of fast moving and diverse data into meaningful insights. Analyzing big data allows researchers and businesses harness their data and use it to identify new opportunities which in turn leads to better and smarter business moves, more efficient operations, higher profits and satisfied customers and an overall competitive advantage.[6] Big data analytics could be viewed as a sub-process in the complete process of knowledge extraction from big data.

Evolution of Data Analytics Tools

As organization began to adopt data analytics in the late 1990s and early 2000s, they faced many hurdles. Data was not that easily accessible as it is now and was mostly locked down and managed by IT professionals. Analysts used to spend more time collecting and preparing data than analyzing it. They focused on finding more accurate and reliable solutions to business problems, while keeping the solutions simple at the same time so that business users could understand it. Some examples of tools used during this time period are *SAS*, a tool for building backend data inference and modeling; *Oracle* and *Teradata*, detailed solution suites for easy development of solutions; *IBM CPLEX*, a tool for solving large optimization problems; and *Cognos* and *MicroStrategy*, tools for visualization, mostly in the form of reports.

In late 2000s, social media giants like Google and Facebook and other internet-based companies in general started uncovering, collecting, and analyzing newer types of data which later evolved into big data. In addition to the data generated by companies in their internal operations and transactions, newer data was brought in from external sources including public data sources, social media, and mobile devices. Analysts realized this new data was qualitatively different (e.g., unstructured text, pictures, audio, and video) along with the much larger volumes as compared to internal company data. This led to the development of newer tools and technologies, examples of which are *Hadoop*, a pioneer in distributed data storage and processing with low cost, flexibility, and scalability; *Python* and *R,* open source programming languages with vast and ever-evolving libraries for statistical data analysis; *Tableau*, *Looker,* and *Microsoft Power BI*, popular visualization products to develop, customize, and build visually appealing and interactive web dashboards.

Descriptive, Predictive, and Prescriptive Analytics

Analyzing data is not limited to deriving insights from the past, but it can also help businesses in predicting future outcomes and optimizing business performance. Currently organizations use three types of analytics at different stages in their decision-making process - *Descriptive*, *Predictive*, and *Prescriptive* analytics as shown in Figure 1. The latter two are also referred to collectively as advanced analytics.

Descriptive analytics does exactly as the name suggests, 'describe' or summarize the data and convert it into something useful. It is the most basic type of analytics and almost 90% of the organizations today use this technique. Descriptive analytics is the analysis of historical data using data aggregation or data mining and lies at the bottom of the big data analytics value chain. However, it is extremely valuable because it provides insight into past behaviors which can help in understanding how several factors can influence the organization's future.

Descriptive analytics is an important step to make raw data understandable to its users, and it helps in answering questions like "What is happening?" Consider for example, a metric that companies get from web servers using Google Analytics tools, namely page views. It can be used to determine if a strategy was a success or not. The main objective in descriptive analytics is to find the reasons behind the previous performance patterns of the organization and to identify and address areas of weakness and strength so that it can help the organization in strategizing.

The majority of the statistics we use comes from descriptive analytics – e.g., calculations as simple as averages and standard deviations. Descriptive models use basic mathematical and statistical techniques to derive key performance indicators that can highlight the historical trends in data. *STATA*, *MS Excel*, and *SPSS* represent the older generation of descriptive analytics tools, while *R* and *Python* are quickly becoming the preferred tools in industry because of vast open-source libraries and the ease of development and deployment. Descriptive analytics can yield historical insights into an organization's production, inventory levels, sales, operations, financials, and customer behavior.

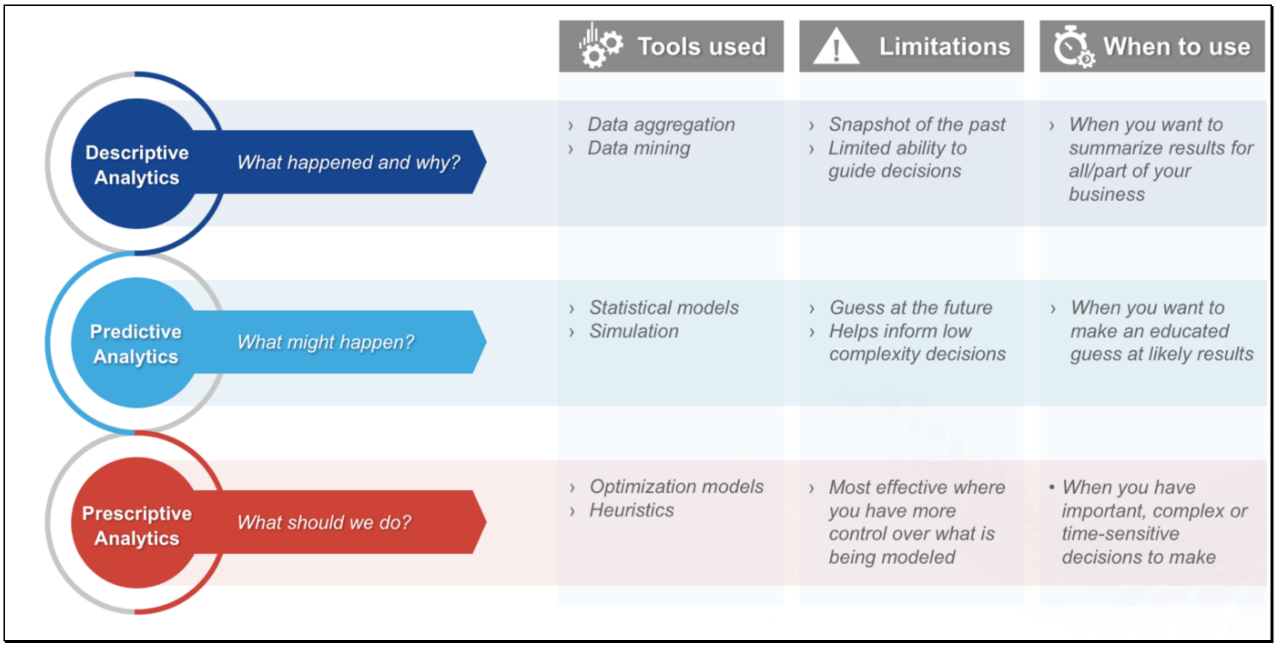

Figure 1. Analytics Framework by Tom Davenport[26]

Predictive analytics can be defined as the ability to "predict" what might happen and a better understanding of future outcomes. It is one of the more sophisticated types of analytics techniques and employs statistical techniques and machine learning. It is used to detect clusters, tendencies, and exceptions, and to predict future trends, making it a valuable tool for forecasting. The foundation of predictive analytics is probability. It takes the data which the user has and tries to fill in the missing data values with best guesses. It helps in finding the answer to 'What could happen?' With properly tuned models, predictive analytics can support complex forecasting in marketing and sales. This helps an organization to set realistic goals for business, restrain expectations, and do effective planning.

Tools used to apply predictive modeling vary by the nature of model's complexity, but some commonly used tools are *SAS*, *MATLAB*, *R*, *Python*, among others. The common functionality of these tools is that they combine historical data found in POS, ERP, CRM, and HR systems to identify patterns in the data and apply algorithms such as random forest and Generalized Linear Model (GLM) for prediction, and K-means clustering for identifying clusters. Finally, simulation can be employed to statistically predict the outcomes of specific decision scenarios.

An application of predictive analytics is to produce credit scores, which are used by financial services to determine the probability of customer making timely payments. Other business uses include, how sales might close at the end of a year, inventory level forecasts, predicting what items a customer might purchase together and other customer purchasing patterns. Despite all the advantages that predictive analytics brings to the table, it is important to understand that forecasting is just an estimation, and its accuracy depends on the quality and stability of data.

Prescriptive analytics is the most sophisticated analytics approach which makes use of optimization techniques to explore a given set of options and prescribe the best possible solution for a given scenario. As the name suggests, it "prescribes" a solution to a specific problem. One approach is machine learning employing neural networks where optimization models are used to determine coefficients or weights of neurons using training data sets. Once trained, the neural network model can suggest the optimal course of action supporting the business objective for a given set of business inputs. Simulation, a predictive analytics tool at its core, can also be part of a powerful prescriptive analytics approach when combined with appropriate search or optimization techniques. Prescriptive analytics not only predicts 'What will happen?', but also determines "What the company should do?" It provides recommendations for the actions to be taken to achieve optimal business performance. Because it has power to suggest optimal solutions, prescriptive analytics is the ultimate frontier for advanced analytics.

Prescriptive analytical models are complex in nature. However, when implemented efficiently, prescriptive analytics can have a significant impact on the decision-making effectiveness of the organization. Technical advancements such as cloud computing have made deployment of these complex models much easier. Companies which have access to analytics experts and the powerful computing resources needed are using prescriptive analytics to optimize production and inventory decisions in supply chains, optimize customer experience, and to make sure that the right product is being delivered at the right time. Airline systems use sophisticated prescriptive models for optimal seat inventory allocation for a given price structure based on travel factors, demand levels, purchasing patterns, timings, etc., in order to maximize the revenue generated.

Increasing number of organizations are realizing that big data analytics gives a competitive advantage and hence, they are ensuring to choose the right kind of analytics solutions to reduce operational cost, enhance service quality, and increase ROI.

Big Data Analytics Applications and Use Cases

Supply chain activities produce a huge amount of data, which is being continuously generated by systems and devices such as POS, ERP, SCM, RFID, GPS, blogs, and wiki entries, not to mention the unlimited data generated from sources like CCTVs, digital clickstreams, imagery, social media posts, and discussions on various forum platforms. Advanced connected devices and technologies which support today's supply chain such as sensors, smart devices, and tags are continuously gathering real-time data and providing an end-to-end visibility in the supply chain. It becomes the task of supply chain managers to tap and process this data to make insightful decisions which could help boost productivity and reduce costs.

Applications of Big Data Analytics			
Application Area	**Company**	**Technique/Technology/ System**	**Impact**
Manufacturing	Raytheon	Supplier Insight Program	Greater insight into suppliers' financial stability, performance, and ability to provide services.
		Immersive Design Center	Achieved product excellence, reduction in time-to-market through co-development and co-production. Better alignment between engineers, suppliers, and customers.
	Lennox International	Integrated Forecasting System	Better service level; accurate prediction of customer needs and demand; automated planning and forecasting operations.
Retail	Walmart	Data Café	Inventory management with streaming analytics, real-time data delivery and updates every few hours, and accurate performance analysis of each store.
	Groupe Danone	Machine learning-based planning system	Improved forecasts and sales with better prediction accuracy and greater profit margins.
	Granarolo	Machine learning application	Accurate forecasts, reduction in delivery time by upto 50%, and better service levels.
	Levi Strauss & Co.	IoT and Predictive Analytics application using Intel's *Trusted Analytics Platform*	Better tracking of in-store items using RFID tags; updating item location and inventory; helping salesperson track misplaced item to avoid lost sales.
	Morrisons	Data-intensive forecasting method	Increase in forcasting accuracy; reduced inventory, stockouts, and obsolescence; better access to company's logistics needs.
Supply Chain and Warehouses	Amazon	Anticipatory shipping	Orders packed and pushed into logistics network before actual customer orders.
		Flexible automation	Robots bring items from storage locations to picking and packing area.
		Drone-based delivery	Goods delivered to locations less than 30 minutes away from an Amazon warehouse
	Logivations	Cloud-based 3D warehouse layout planning	Improve storage efficency and picking productivity of an exiting warehouse by simulating new configurations
		Camera guided AGVs and Tracking	Optimize picking accuracy, inventory turns, and warehouse productivity in real-time using inputs from sensors, such as shelf weight and weight on forklift.
	IBM	Quality early-warning system	Reduced rework, increased productivity and cost savings, higher quality standards, and improved service levels, by detecting and prioritizing quality related issues much sooner in the supply chain.
		Buying analysis tool	Greater demand and supply visibility, better distribution channel management, better service level, and improved inventory management.
		Accounts receivable tool	Optimized the resources needed for revenue collection.
	Merchandise Warehouse Co.	Real-time monitoring and tracking	Greater visibility for customers, better pallet management, optimized space utilization, greater labor productivity, inventory accuracy of 99.9%, and improved customer satisfaction.
Logistics	UPS	ORION	Optimized 55,000 delivery routes in North America, saving close to $400 million annually. Reducton in cost and emissions by selecting the right mode of transportation.
	DHL	SmartTruck	Optimized initial route planning based on incoming shipment information, reduction in mileage and cost, and improved CO2 efficiency.
		Resilience 360	Accuracy in risk detection, prevent production inefficiencies and revenue losses, maintain service levels, and reduce emergency cost by efficiently re-routing shipments in case of unforeseen events.
		Geovista	A tool for small and medium scale industries to analyze potential business opportunities. Real-time information provides realistic forecast of competitors in a given location.
		Address Management	Improves shipment delivery accuracy in areas where quality of address information is poor. Real-time ddress verification to optimize route planning.

Applications and Use Cases in Manufacturing

Raytheon**,** a major U.S. based defense contractor and industrial corporation, made use of data analytics to reduce costs within their supply chain and production operations. They developed a *Supplier Insight* program, which integrated structured and unstructured data from internal and external sources.[10] With more than 10,000 suppliers, they needed a platform that could provide rapid, data-driven decision making capability. With this new system, they could track suppliers' financial stability, performance, and their ability to provide services in the face of disruptive events. Raytheon was able to immediately identify if a supplier could provide what they needed, and quickly made decisions that reduced any adverse impact on their customers. *Supplier Insight* has allowed them to negotiate the cost better, by engaging in long-term contracts with suppliers for multiple programs.[10] They now have an ability to look across all their suppliers and programs to achieve cost reductions. Raytheon has also developed smart factories which have the capacity to handle big data coming from different sources like sensors, instruments, CAD models, internet transactions, simulations, and digital records in the company, which equips them with real-time control of various elements of the production processes. For example, their *Immersive Design Center (IDC)* makes use of a 3-D immersive environment to achieve product excellence and decrease time-to-market through co-development and co-production of products by immersive data visualization and interaction.[10] This also resulted in better alignment between their engineers, suppliers, and customers. They work together to refine the design and detect potential problems without the work and rework associated with expensive prototypes, resulting in reduced costs.[10]

Lennox International, a U.S. based cooling and heating devices manufacturing company, integrated machine learning into its forecasting system to ultimately improve customer satisfaction while coping with their expansion throughout North America.[11] With the help of machine learning algorithms, they accurately predicted customer needs, while understanding customer demand better. It also helped the company to automate its planning and forecasting operations.

Many companies gather data on supplier information and purchasing volumes for annual supplier performance review, spend analysis, and cost savings analysis functions to support strategic decisions. For example, a pharmaceutical company created a database of all the bids submitted for packaging.[12] This data was then evaluated to understand the cost structure of suppliers and to create detailed cost models for different packaging options. Such models can help in the selection of the most cost-effective supplier for new packaging.[12] Another example is how IoT with its network of sensors embedded in millions of devices can enable new opportunities in manufacturing. For example, real-time information on a machine's condition can initiate a production order for a spare part, which then can be shipped using a drone to the plant engineer for replacing the faulty or near faulty part.[12] It also helps in determining when and how critical maintenance is required by a specific machine, thereby avoiding costly equipment breakdowns and improving the overall production efficiency.

Daily production needs to be monitored to maintain the efficiency and output of a company. Big data analytics uses the data collected from operational machines, employee records, and data logs of the number of units produced, to provide insights to the operations manager, helping him/her to make changes that are profitable for the company. Manufacturers are also exploring predictive analytics to realize significant savings in product testing and improving product quality. Since different products and parts require different tests, instead of performing numerous quality tests on each part, data mining and pattern recognition can be used to determine the type and number of tests truly needed for each part or product.[13]

Applications and Use Cases in Retail

Walmart**,** the number one fortune 500 company, has the world's largest private cloud, which helps support real-time data feeds to its decision makers. Walmart's *Data Café* based at their Bentonville, Arkansas headquarters takes care of most of this cloud architecture.[14] Their original data infrastructure only enabled managers to get weekly reports, which prevented them from making decisions based on real-time market conditions. Also, the reports were standardized with little room for customization. Data café, which was built on SAP's HANA in-memory analytics engine, enabled inventory management with streaming analytics, and provided an enterprise view of timely information flow for a large cross-sectional staff looking to resolve every-day business issues.[14] The data delivered through this system is almost real-time and updated every few hours. Furthermore, the system was designed to be responsive to providing reports and queries required by managers in the given time frame, which helped them gain timely insight and make better decisions. These insights are derived from "200 streams of internal and external data which includes 40 petabytes of recent transactional data, and can be manipulated, modeled, and visualized."[14] *The importance of near real-time insights is crucial since it helps managers respond to challenges in real-time as they arise.* For example, on Black Friday, Walmart's Data Café provides near real-time insights on the performance of east-coast stores, which enables Walmart to make pricing adjustments for west-coast stores before they open.[14] During a recent Halloween, sales analysts were able to see that two stores were not selling a novelty cookie that was very popular in most stores. Using near real-time data from Data Café, it was discovered that simple stocking oversight led to the cookies not being put on shelves in these stores.[14] The company was able to react in real-time to avoid additional lost sales. Data Café also provides automated alerts to managers when a metric falls below a threshold in a department. This tool has reduced the problem-solving time from weeks to minutes using reliable internal and external sources of data.

Levi Strauss & Co, a leading American clothing company, provides better in-store shopping experience for its customers by helping them find the product they want and avoids missing sales by locating misplaced items using IoT technology coupled with advanced analytics. Levi's in collaboration with Intel® implemented a solution using Intel's *Trusted Analytics Platform (TAP),* which helped salespersons to quickly find misplaced items in the store.[15] This application made use of RFID tags woven into clothing items, in-store antenna sensors installed in the ceiling of the store to continuously track the RFID tags, and a gateway system located in the store to collect data from these sensors and send smaller data sets to a cloud-based analytical tool built on TAP for detailed analysis. This technology helped determine when items are no longer in their correct place or no longer available at that time. TAP algorithms use data collected overnight to determine the exact location of various groups of items, and during store hours sensors track the location of items and an algorithm determines if an item is in its assigned location. If an item is placed in its assigned group location, no action is generated by the algorithm. Suppose a pair of jeans is lying in the T-shirt section or left in the fitting room, the TAP algorithm will generate an alert on the mobile application instructing the salesperson to put the item back in its assigned location.[15] This helps the salesperson to keep the item where it belongs and avoid lost sales. Levi's also aims to generate customer insight using big data analytics with the data collected from sensors tracking customers' in-store behavior to better understand their preferences.[15]

Groupe Danone, a French multinational food-product corporation, found itself making accurate predictions only 30 percent of the time for responses to promotional offers, which was resulting in significant losses to the company.[11] When they implemented machine learning in their planning architecture, they saw significant improvement in both sales and forecasting. Similarly, Granarolo**,** an Italian dairy company, used machine learning to increase its forecasting accuracy by 5 percent, decreased delivery times by up to 50 percent of the original time, which resulted in better service levels.[11] Morrisons, one of UK's largest food retailers, was able to dramatically improve same store sales and achieve a 30% reduction in shelf gap and a 2 to 3 day reduction in store inventory by implementing a demand forecast and replenishment solution from Blue Yonder, which uses AI technology to "improve demand planning and reinvigorate replenishment based on customer behavior in every store."[16] Blue Yonder's data-intensive forecasting methods deployed as cloud-based services is making such advanced capabilities accessible to other retailer's as well.[12]

Applications and Use Cases in Supply Chains and Warehouses

In supply chain operations, planning and forecasting are among the most data-driven operations, which use an array of supply chain planning tools supported by ERP systems. With the use of supply chain analytics, it is now possible to re-envision the planning processes by using external and internal data sources to make real-time decisions based on market trends, uncertainty, seasonality, and other fluctuations.

IBM understood the value of big data analytics early and employed it in optimizing their supply chain operations. They have used various analytical tools to solve a range of problems, and a few of them are discussed here.[17] IBM's *Quality Early-Warning System (QEWS)* was typically deployed upstream at suppliers, IBM's operations, and in the field. QEWS detects and prioritizes quality related issues much sooner than the traditional quality control processes. Analyzing big data coming from across their supply chain, IBM was able to reduce rework, increase productivity, ensure higher quality standards, and improve customer satisfaction, leading to significant cost savings. For a company like IBM, ensuring correct inventory levels with so many business partners was challenging. They made use of *IBM Buying Analysis Tool,* which not only provided demand and supply visibility, but ensured better distribution channel management, delivery of the right product at the right time to meet customer demand, while maintaining proper inventory levels. IBM also used a tool named *Accounts Receivable,* which uses advanced analytics to optimize the resources needed to collect revenues. They also make use of *supply chain social listening*, an innovative way to use social media to monitor channels and provide valuable data on events which may disrupt the supply chain.[17] It also helps them obtain timely information and feedback on their products. As an early adopter, IBM has been using predictive and prescriptive analytics in its supply chain over the last several years.

Warehousing is another area where big data analytics is creating new opportunities. Logivations, a German supply chain solutions provider, offers a cloud-based 3D warehouse layout planning and optimization tool, camera-guided AGVs and tracking, and various other supply chain analytics solutions.[18] Such technologies help in warehouse design optimization and in improving storage efficiency and picking productivity of an existing warehouse by simulating new configurations. Another example is the analysis of images and videos captured by AGVs, and sensor inputs including shelf weight and weight on the forklift, to monitor picking accuracy, inventory turns, and warehouse productivity in real-time.[12] Also, forklift drive picking productivity and route optimization can be achieved by analyzing the route choices and driving behaviors.[12] *A leading forklift provider is looking into all these opportunities, and figuring out how a forklift truck can be used as a big data hub - collecting real-time data to identify additional sources of waste in the warehouse operations, using a hybrid of analytics and ERP and WMS data*. Amazon is another warehouse automation pioneer, deploying Kiva robots that bring the items (racks) to the picking and packing area in their fulfillment centers. With increasing pressure to reduce order-to-delivery times, warehouses are turning to a flexible automation strategy by using autonomous technologies such as Amazon's Kiva[c] robots and GreyOrange's Butler[d] system to increase their picking efficiency. Amazon has also tried to deliver goods

[c] https://www.amazonrobotics.com/#/

[d] https://www.greyorange.com/butler-goods-to-person-system

to people living less than 30 minutes away from an Amazon warehouse or distribution center via a drone. Amazon has also patented an "Anticipatory Shipping" technology to identify which orders should be packed and pushed into the logistics network before the actual customer orders are placed.[12]

Merchandise Warehouse Co. (MW)**,** a logistics provider of multi-temperature warehouse services in the US mid-west, provides services such as tempering, inspection, blast freezing, temperature monitoring, labeling, import/export, and packaging.[19] With such operations there is little room for error, since clients' food products could get spoiled if they are not maintained at correct temperatures.[19] MW needed real-time information technology which would help them track the state of items in its warehouses at all times and enable quality assurance with comprehensive traceability. They wanted this for all operations including inspections and holds.[19] Technologies such as CCTV, WMS, electronic data interchange, mobile computers, and scanners were employed to help track and analyze data to get real-time information in the warehouse and manage inventory. It helped MW's customers gain visibility by having on-line access to temperatures, activity reports, and information about inventory levels. MW's solution also includes tools for pallet management for tracing every pallet from the time it arrives in the warehouse to until it leaves. Special functionalities for cold storage such as temperature reading and recording and the ability to restrict inventory to marked temperature zones were provided by the new system. It also ensures greater labor productivity and accuracy using workflow-based warehouse management and could automate processes designed for specific customer needs. MW reaped various other benefits from this initiative like accurately capturing billing events in real-time resulting in reduced labor used for billing and paperwork. The system helped the company deal with the issue of "catch weight", where the actual weight of the product, especially meat, varies when it hits the retail shelves, a common problem in cold storage warehouses and food industry.[19] Increased customer satisfaction levels were also achieved, since clients had real-time access to information and reports when needed. The solution helped MW achieve an inventory accuracy of 99.9 percent from a previous 98.6 percent.[19]

Applications and Use Cases in Logistics

Logistics companies need to keep the goods moving at all times, even in the face of disruptions such as storms, cargos getting stranded due to ship crashes, and geopolitical events in order to keep the businesses running. A Netherlands based logistics management company uses big data analytics on Microsoft's Azure cloud to keep its customers informed about the number of goods in each container, their location at a given time, and expected delivery times.[20] Purchase orders are tracked using mobile applications to identify challenges which could delay the delivery of an order. Tariff calculations and fees related to the movement of shipping containers are calculated by another application which can be accessed by the client, giving them a greater insight into financial risks.[20] These mobile applications make use of big data analytics in conjunction with Microsoft cloud technologies to combine and analyze data coming from news feeds and internal supply chain operations to provide actionable business insights. Previously the time it took to identify a challenge and develop a solution to address it could be anywhere from 3 to 9 months. With the use of big data technologies, this time has been brought down to a couple of weeks depending upon how complex the problem is.[20]

Companies managing their own supply chains and those outsourcing to third-party logistics providers manage a massive flow of freight, goods, and products daily while at the same time creating vast data sets. Millions of shipments are tracked daily from origins to destinations, generating information such as the content, weight, size, location, and route of each individual shipment, across a large number of networks. Companies are exploiting and analyzing these large data sets to improve their operational efficiencies, effectiveness, and customer service. A study by the Council of Supply Chain Management Professionals shows that 93 percent of shippers and 98 percent of 3PL providers feel that data-driven decision making is a crucial supply chain activity.[21] Also, 71 percent of these believe big data improves performance and quality. Logistics companies can utilize big data analytics to consolidate, interpret, and store the data coming from various sources for immediate or future use based on their requirements.

Courier and delivery companies like UPS use real-time routing of deliveries using the trucks' geo-location and traffic information data. *UPS* spent almost 10 years developing its *On-Road Integrated Optimization and Navigation* system (ORION) to optimize close to 55,000 routes in North America in its delivery network.[22] This system saves the company \$300 million to \$400 million annually by saving about 100 million miles per year, which is a reduction of 10 million gallons of fuel consumed and reducing CO_2 emissions by almost 100,000 metric tons.[22] Data mining techniques also help logistics companies deliver services with fewer delivery attempts, by using predictive analytics to predict when a customer is more likely to be available at home.[12] Costs and carbon emissions can also be reduced by selecting the right mode of transportation for deliveries. An example is the use of supply chain analytics to understand the priority of shipments and determine which ones need immediate air or truck deliveries and which still have time and can be delivered by rail.[12]

Better transportation planning can be achieved with the use of *Transportation Management System* (TMS) which can help identify future shipping patterns, optimize routes, carrier selection, or loads, and secure necessary capacity. This is achieved by tracking shipment frequency and identifying the endpoints of supply chains by studying precise inbound and outbound statistics. Direct application of predictive analytics is helping logistics providers make real-time decisions which result in reduced costs, greater reliability, and improved customer satisfaction. For example, data streams produced by sensors on delivery trucks, beacons which broadcast their presence to nearby devices such as computers and smartphones, radar devices, and IoT help a company determine the likelihood of a shipment arriving on time or getting delayed by employing simulation models.[23] When a shipment is going to be late, a carrier can make real-time adjustments to prevent bottlenecks further down the supply chain.[23]

DHL, a global logistics provider, has extensively explored big data analytics in their supply chain activities and is currently employing several smart systems around their services. Increasing the last mile efficiencies is often the most expensive step in the supply chain.[24] Last mile optimization is an extensively studied area and researchers have found promising applications of big data analytics here. Data analytics is applied to achieve real-time optimization of delivery routes, where streams of data are processed to maximize the performance of the delivery fleet. Rapid processing of real-time information supports the goal of route optimization on the last mile, saving time in the delivery process. When the vehicles are loaded and unloaded, manual sequencing of shipments is eliminated by the use of sensors, and dynamic calculations are used to find the optimal delivery sequence. Based on real-time traffic conditions on the road, telematic databases are used to change the delivery route automatically. DHL's *SmartTruck* uses data mining, machine learning, and other data analytics techniques to optimize the initial tour planning based on incoming shipment on a daily basis.[24] Dynamic routing system recalculates the routes depending on the traffic situations and delivery times. This also results in cost reduction and improved CO_2 efficiency by reducing the miles travelled.

It is vital for robust supply chains to be able to cope with unforeseen events in today's rapidly changing world. Apart from being flexible and resilient, businesses need accurate risk detection systems to keep running smoothly. Big data analytics and complex event processing algorithms are used to alert businesses when a pattern falls in the set of critical conditions such as tornadoes or floods in an area, or breakdown of fleet. These alert systems send a report on the probability and impact of the risk and provide suitable actionable insight to alleviate potential interruption. With this information on hand, customers can re-route their shipments or manage supplies from other distribution locations. DHL's *Resilience 360* risk management solutions aims to provide such functionalities.[24] It is equipped with two components, a risk assessment portion and supply chain monitoring instruments, both operating in real time. This improves the resilience of the supply chain and prevents production inefficiencies and revenue losses. *Resilience 360* is designed to maintain prescribed service levels, protect sales and operations, and reduce emergency costs, creating a competitive advantage for the company.[24]

Future economic development is often modeled on global transportation of goods and services. The type of goods shipped indicate the local demand and supply preferences. Logistics providers make use of big data analytics tools to extract detailed microeconomics insights from data generated by millions of daily shipments by their distribution networks. These shipment records are a valuable resource for market intelligence research, and logistics providers refine this data to substantiate existing market research. Regression analysis techniques are used to produce demand and supply forecasts with the use of the shipment records and market research outcomes. The primary target group for these advanced data analytics services are small and medium-sized enterprises, which lack capacity to conduct their own market research. The results from regression-based analytics have high predictive value, which can help these enterprises serve a larger customer base, and generate accurate forecasts based on industry, geography, and product category. DHL *Geovista* is one such online geo-marketing tool available for small and medium-sized enterprises to analyze potential business opportunities.[24]

DHL *Address Management* system is another useful tool making use of big data techniques to deliver shipments more accurately.[24] Customer's delivery address verification is a fundamental requirement for any logistics provider. This can be troublesome in developing countries and other remote areas, where the quality of address is usually poor due to lack of structured naming schemes for streets and buildings in an area. Address Management uses daily freight and parcel delivery data and matches this data with reference data and returns the incorrect incoming data with validated data from the database, in order to verify the address in real-time and optimize route planning for retailers and public sector entities.

Other Applications

There are several other applications of big data analytics which a company can encounter on a regular basis. Locating a new store is a strategic decision for a company, and big data analytics could play an important role here. Extensive data analysis is performed by the analysts in exploring customer data, demographic factors, retailer network, location of other competitors in the area, and market potential. A recent example of this is the location for Amazon's HQ2. Visualizing the growth of a company has become easier with the use of data analytics, since it is now possible to quickly compare the performance matrix of different sites and identify the reasons behind such results. Predictive analytics comes in handy in analyzing the market and gaining insight on questions related to global growth strategy, site relocation, new product introduction, and supplier selection.

Price optimization is crucial for a company as having the right price for both customer and retailer keeps a business profitable.[25] Data analytics tools simplify the process of price formation, which not only accounts for the cost of production of an item, but also the spending capacity of the customers and presence of competitors in the market. Price flexibility, buying patterns of the customers, competitors' prices, and seasonality are analyzed using the data coming from various sources. Machine learning algorithms help identify the costs which meet the business standard by using customer segmentation to record the responses to changes in prices. Furthermore, using real-time price optimization techniques, retailers can attract new customers and retain existing customers by adjusting the price as per market trends. Recommendation engines is another great way of predicting customers' behavior, since they give a retailer insight into customers' reviews and opinions. It also helps the retailers to increase sales and stay abreast with trends.

Based on machine learning algorithms, recommendation engines make adjustments depending on customer preferences, previous shopping and browsing experience, demographic data, need, and usefulness. Collaborative or content-based data filtering is used in this process to gain useful insight which gives leverage to retailers on customers' opinions.

Big Data Challenges

Companies often fail to understand what big data is, its benefits, and more importantly the computing and the human infrastructure required to realize its true potential. Without a clear understanding of the concept of big data, adopting and implementing a project using big data tools can seriously challenge its success. Having discussed various applications and use cases of implementing big data technologies in manufacturing, retail, supply chain, and logistics, it is important to understand the associated challenges. We can say that handling big data is complex and companies should identify what they aim to achieve when they decide to invest in technologies using big data.

The first challenge that a company is likely to face is making sense of the *complex big data landscap*e and reducing their dependence on *legacy systems*. Even though the industry is shifting its focus to the digital age with adoption of IoT and artificial intelligence, it is still a long way before the full potential of big data is realized. Industry has to develop an awareness of the various elements of the big data landscape, which include sensors to social media that collect data, in-memory to cloud for data storage, data mining to deep learning to convert data into useful business insights or actions. Any new business solution will involve a combination of these elements and the role of people in the resulting work system is likely to change significantly. Most people are resistant to change, and it shows in companies when workers stick to to an old way of thinking and doing work. An example is the use of Excel, which to the present day remains one of the popular tools in many companies, despite having many limitations when compared to newer tools.[27] While there is a need to educate industry to change this legacy mentality, there is no need for an abrupt or complete shift to newer tools. A viable option is to slowly augment existing systems with big data analytics tools and capabilities.

With the phenomenal increase in the size of data, the problem of *storage space* for big data has become a real problem for many companies. Cloud storage is soon becoming the only viable alternative with the ever-increasing need for storage space. With the maturity of the cloud computing infrastructure, which includes storage, applications, and computing platforms, companies are beginning to consider shifting to the cloud infrastructure for most of their computing needs. But transitioning from the traditional in-house computing infrastructure to the cloud infrastructure has its own challenges. According to McAfee, "Most organizations that have been around awhile have a hodgepodge of hardware, operating systems, and applications, often described as 'legacy spaghetti'."[28] First, companies have to address legacy system issues and simplify their system before moving to the cloud. For the most part, cloud is cost-effective compared to building and running an IT infrastructure. However, a company needs to carefully evaluate the cost factor based on their specific needs, for example, in-house applications requiring continuous transfer of large data sets.

Academic institutions have begun to address the need for *skilled professionals* in the field of big data analytics with specialized MS degrees in Data Science. These degree programs are housed mostly in business schools or computer science departments. Engineering schools to a large extent are still lagging in providing adequate training in data science to their graduates. Data science professionals can manage and analyze large volumes of real-time data coming from multiple sources and in different formats. With several new technologies such as the NoSQL data management framework, Hadoop, cloud computing, and in-memory analytics, their skills are vital for the rapidly changing computing landscape. Given that engineering schools are still looking for the right curriculum mix (e.g., minors, degree options, and certificates) to train engineers in data science, training employees at entry level is a challenging and expensive proposition for companies dealing with these newer technologies. When industry hires data science professionals, akin to software developers and programmers, they need guidance from subject matter experts (SMEs) to build the right tools and techniques that can help industry harness the power of big data in the long-run. Industry needs to quickly educate SMEs to understand the big data analytics capabilities and empower them to develop big data strategies working alongside with the data science professionals.

As seen in recent times, *data privacy* has become one of the major concerns of organizations. With recent threats like hacking of personal data, individuals and companies have become apprehensive about linking data from multiple sources as it may compromise an individual's privacy. Also, with an increase in the number of connected devices within the industry, *data security* has also become a big concern and presently this risk is greater than ever. Big data analysis uses huge amounts of data for analysis and mining purposes to reach some meaningful conclusion, and security of this big data can be enhanced by using techniques such as authentication, authorization, and encryption.

Effective flow and sharing of information among supply chain partners is critical to the success of today's digital supply chains. Unauthorized disclosure and data leakage of information shared among supply chain partners have been identified as two main threats in today's digital supply chains.[29] Visibility needed within a supply chain and consumers' demand for transparency seem to be at odds with security requirements. With newer, secure technologies such as blockchain and data cleanroom, it is possible to achieve both visibility and transparency.[30] Data cleanroom is a shared environment between two or more supply chain partners that is completely secure from external access and where each partner can decide the level of visibility to their data. Blockchain, a decentralized, distributed database is one of the most secure options available for supply chain partners for real-time information tracking. Another important, but often overlooked challenge is the *ethical use* of data. The legal infrastructure has not kept up with the rapid development in technology, which is able to collect and store vast amounts of consumer data with or without their knowledge. While it may be legal, certain use of the data may be considered unethical. Such actions may have a negative impact on a company as today's consumers are more educated and have experienced negative consequences of such unethical usage.

In a recent survey of supply chain professionals conducted by APQC, "lack of people with the needed skills" was identified as the biggest barrier to advanced analytics applications in industry.[31] In addition, these employees need "a good understanding of the business to provide solid advice."[29] Resistance to change and lack of access to data across disparate systems were the second and third biggest barriers, respectively. In addition to lack of access to data, issues such as inconsistent and unorganized data are also issues in some cases as different companies record their data in different formats, platforms, and systems.[27] This results in difficulties in reconciling data from multiple sources and its subsequent analysis to gain useful insights.

The Way Forward

As companies make a push for big data analytics applications, they should first establish a clear business need such as "solving a problem or seizing an opportunity."[7] According to Watson, "big data initiatives should start with a specific or narrowly defined set of objectives rather than a 'build it and they will come' approach."[7] Pilot schemes are a good way to demonstrate the value of big data analytics.[32] It is common to focus the initial business case for big data analytics on customer-centric objectives.[7] The various applications and uses cases discussed earlier cover many different areas that have benefited from big data analytics. Whatever be the area, it is desirable that the pilot project address a problem tied to a specific business outcome. The pilot project should not only help solve a business problem, but also demonstrate the effectiveness of big data analytics for the organization and its stakeholders. Finally, for successful big data initiatives it is essential to have strong, committed sponsorship and alignment between the business and analytics strategies.[7] In the early stages of adoption, the sponsor could be the CIO and then shifting to function-specific executives as business opportunities are identified.

To benefit from big data analytics companies must also establish a data-driven decision-making culture, which calls for acting on insights from data rather than on pure managerial intuition.[32] Promotion of data-sharing practices, increased availability of training in data analytics, and communication of the benefits of data-driven decision making are some of the strategies for promoting a data-drive culture.[7] While workforce training needs to focus on improving technological and digital proficiency, the future work environment also demands training in certain soft skills. The work environment is changing with the rapid introduction of AI, automation, and analytics-driven solutions. Workers need to be open to new ways of working and have openness to agility, adaptability, and working in teams to cope with a constantly changing external environment. In the long-run, big data needs to become an integral part of the organization's operating model. There also needs to be clear ownership for big data in the organization with leadership positions such as a chief analytics officer.[32] Data science should become another established skill in the organization.

Acknowledgements

We would like express our gratitude to William Ferrell for his constant assistance and encouragement during the development of this white paper. We would like convey our appreciation to Scott Wahl for his guidance and feedback during the formative stages of this effort. We would also like to thank John Ashodian, John Hill, Ying Tat Leung, Juan Ma, Hari Padmanabhan, and John Paxton for carefully reading an earlier version of this white paper and providing several constructive suggestions and feedback, which have helped us greatly improve the quality of the white paper.

References

1. Morten Brinch, Jan Stentoft, and Jesper K. Jensen, "Big Data and its Applications in Supply Chain Management: Findings from a Delphi Study," *Proceedings of the 50th Hawaii International Conference on System Sciences*, 2017: 1351-1360.

2. IBM Corporation, "The Path to Data Veracity," IBM Big Data and Analytics Hub, May 2018, https://www.ibmbigdatahub.com/whitepaper/path-data-veracity

3. DataStax Corporation, "Big Data: Beyond the Hype," October 2013, https://www.datastax.com/resources/whitepapers/bigdata

4. Phillip Russom, "Big Data Analytics," TDWI Research, 2011, https://tdwi.org/research/2011/09/best-practices-report-q4-big-data-analytics.aspx?tc=page0&m=1

5. DXC Technology Company, "Five Industries Where Big Data is Making a Difference," November 2015, https://assets1.dxc.technology/analytics/downloads/DXC-Analytics-Five_Industries_Where_Big_Data_is_Making_a_Difference-4AA5-6292ENW.pdf

6. Nada Elgendy and Ahmed Elragal, "Big Data Analytics: A Literature Review Paper," In: Perner P. (eds) *Advances in Data Mining. Applications and Theoretical Aspects*. ICDM 2014. Lecture Notes in Computer Science, vol 8557, Springer, Cham., 2014, https://link.springer.com/chapter/10.1007/978-3-319-08976-8_16

7. Hugh J. Watson, "Tutorial: Big Data Analytics: Concepts, Technologies, and Applications," *Communications of the Association for Information Systems*, 34 (2014), Article 65. http://aisel.aisnet.org/cais/vol34/iss1/65

8. Richard L. Villars, Carl W. Olofson, and Matthew Eastwood, "Big Data: What It Is and Why You Should Care," International Data Corporation, 2011. http://www.tracemyflows.com/uploads/big_data/idc_amd_big_data_whitepaper.pdf

9. Sunil Tiwari, H.M. Wee, and Yosef Daryanto, "Big Data Analytics in Supply Chain Management Between 2010 and 2016: Insights to Industries," *Computers and Industrial Engineering*, 115 (2017): 319-330.

10. Bob Trebilcock, "Supply Chain, Data Analytics, and Big Data," Logistics Management, August 2015. https://www.logisticsmgmt.com/article/supply_chain_data_analytics_and_big_data

11. Kaushik Pal, "How Machine Learning Can Improve Supply Chain Efficiency," Techopedia, February-2018. https://www.techopedia.com/2/31846/trends/big-data/how-machine-learning-can-improve-supply-chain-efficiency

12. McKinsey & Company, "Big Data and the Supply Chain: The Big-Supply-Chain Analytics Landscape: Part 1," February 2016, https://www.mckinsey.com/business-functions/operations/our-insights/big-data-and-the-supply-chain-the-big-supply-chain-analytics-landscape-part-1#

13. Lorenzo Romano, "Big Data Analytics: A Key Ingredient for Agility in Manufacturing," May 2019, https://www.orange-business.com/en/blogs/big-data-analytics-key-ingredient-agility-manufacturing

14. Joe McKendrick, “Walmart’s Gigantic Private Cloud for Real-Time Inventory Control,” RT Insights.com, January 2017. https://www.rtinsights.com/walmart-cloud-inventory-management-real-time-data/

15. RT Insights team, “Levi’s Real-Time Tracking of Jeans: RFID in Retail,” RT Insights.com, April 2016. https://www.rtinsights.com/rfid-in-retail-customer-experience-levis/

16. JDA, “Store Replenishment at Morrisons,” 2017, https://jda.com/knowledge-center/collateral/by-morrisons-case-study

17. Hans W. Ittmann, “The Impact of Big Data and Business Analytics on Supply Chain Management,” *Journal of Transport and Supply Chain Management*, 9, no. 1 (2015). https://jtscm.co.za/index.php/jtscm/article/view/165/331

18. Logivation, https://www.logivations.com/en/solutions/plan/design_efficiency.php

19. RT Insights team, “Using Mobile Device for a Real-Time Warehouse,” 2016, https://www.rtinsights.com/zebra-omnii-xt15-datek-real-time-warehouse/

20. Motifworks, “How Big Data Analytics Can Benefit Supply Chain and Logistics Industry,” 2017. https://motifworks.com/2017/02/23/how-big-data-analytics-can-benefit-supply-chain-logistics-industry/

21. “2017 Third-Party Logistics Study,” https://jda.com/-/media/jda/knowledge-center/thought-leadership/2017stateoflogisticsreport_new.ashx

22. UPS, “ORION Backgrounder,” 2019, https://www.pressroom.ups.com/pressroom/ContentDetailsViewer.page?ConceptType=Factsheets&id=1426321616277-282

23. “Data-Driven Logistics: The Growing Use of Predictive Analytics,” July 2018, https://www.smith-howard.com/data-driven-logistics-the-growing-use-of-predictive-analytics/

24. Martin Jeske, Moritz Grüner, and Frank Weiß, “Big Data in Logistics – A DHL Perspective on How to Move Beyond the Hype,” December 2013. http://www.dhl.com/content/dam/downloads/g0/about_us/innovation/CSI_Studie_BIG_DATA.pdf

25. McKinsey & Company, “Big Data, Analytics, and the Future of Marketing and Sales,” March 2015, https://www.mckinsey.com/~/media/McKinsey/Business%20Functions/Marketing%20and%20Sales/Our%20Insights/EBook%20Big%20data%20analytics%20and%20the%20future%20of%20marketing%20sales/Big-Data-eBook.ashx

26. Gurobi Optimization, “The Power of Analytics,” accessed September 8, 2019. http://www.gurobi.com/resources/prescriptive-analytics,

27. Transmetrics, “ Big Data and Big Roadblocks: How the Logistics Industry can Overcome its Big Data Challenges,” March 2018, https://www.youredi.com/blog/logistics-industry-can-overcome-big-data-challenges

28. Andrew McAfee, “What Every CEO Needs to Know About the Cloud,” *Harvard Business Review*, Nov. 2011: 124-132.

29. Bharat Bhargava, Rohit Ranchal, and Lotfi Ben Othmane, "Secure Information Sharing in Digital Supply Chains," 3rd *IEEE International Advanced Computing Conference*, May 2013, https://www.cs.purdue.edu/homes/bb/Bhargava-Supply_Chain-Feb2013-india.pdf

30. Megan Ray Nicholas, "How to Share Data Safely Across your Supply Chain," https://www.smartdatacollective.com/share-data-safely-across-supply-chain/

31. APQC, "APQC Quick Poll: The Current State of Big Data & Advanced Analytics in Supply Chain," May 2019, https://www.scmr.com/article/apqc_quick_poll_the_current_state_of_big_data_advanced_analytics_in_supply

32. David Meer, "A Call to Action on Big Data," *Forbes,* October 2014, https://www.forbes.com/sites/strategyand/2014/10/28/a-call-to-action-on-big-data/#6a4b6c22314