LUISS

Department
of Business and Management

Bachelor's Degree in Management and Computer Science
Course Artificial Intelligence and Machine Learning

Artificial Intelligence

in the Global Supply Chain

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Academic Year 2021/2022

Abstract

This thesis intends to identify and propose solutions to some important issues arising in the management of global supply chains, when they face disruption, be it caused by a natural or a man-made disaster, a pandemic, or any kind of geopolitical instability.

Now more than ever, in response to the pandemic of COVID-19 and tensions in Eastern Europe, businesses and stakeholders are focusing more on supply-chain resilience, and technology can play a crucial role in helping them to achieve this ambition.

AI-based solutions are effective tools for enterprises to address these issues and to give meaning and stability to the massive amount of data that flows within and between supply chains, to turn this into actionable insights for industry, to enable visibility within the supply chain, and finally enhance decision-making.

Apart from the expected success coming from the adoption of AI, the importance of adequately preparing the company for its implementation is also stressed.

Acknowledgements

I would like to sincerely acknowledge all the following people without whom I could not have completed this work.

First of all, I would like to express my sincere gratitude to my supervisor Prof. Giuseppe Francesco Italiano for his support and guidance during the writing of the thesis and for the valuable lessons I received throughout these years.

I would like to infinitely thank my parents for being always present in my life, for never hindering my ambitions and for giving me the opportunity to undertake this course of study, during which they have always supported and encouraged me.

A special thanks to my sisters and role models, Giulia and Silvia, who, strengthened by their past experience, have always been able to judiciously advise me. I love you with all my heart.

I must spend a few words for Silvia, the best part of me, for the time she devotes to me, for all the esteem I feel for her and for being the best life partner I could wish for.

Finally, I would like to thank all my relatives, friends and colleagues, for the good times spent together.

Contents

Introduction

This work investigates some important problems in the management of global supply chains, that are continuously and increasingly exposed to disruptions, bringing instability and threatening long-term growth and prosperity for the firms. Threats to supply chains are many and of different nature, from the recent pandemic and climate crisis to geopolitical tensions and emerging technologies. It also discusses some possible solutions to counteract these issues and enhance the overall global supply chains resilience, in particular the deployment of AI-based systems.

This thesis consists of four chapters.

The first chapter depicts the theoretical background, with the basic concept of Supply Chain (SC) as well as the phenomenon of globalization, the definition of Supply Chain Management (SCM) and the problems arising for it in a global context. Moreover, it explores various sources of supply chains disruption.

A supply chain is an integrated and dynamic network between a corporation, its suppliers, and its customers, in which the nodes reflect the processes involved in producing and distributing a certain product or service to the final buyer, and the links between them indicate the flow of information, materials, and finances between stages.

From receiving an order to fulfilling the customer's request, a supply chain's activities and functions include product development, production planning, procurement, sales forecasting, marketing, operations, distribution systems, accounting and financing, and customer support.

Global strategy has caused supply chains to become more international and globally configured, entailing greater coordination of geographically dispersed activities: more than two thirds of world trade currently take place within globally operating supply chains.

Supply chain management (SCM) is the supervision and control of the multiple linkages across the supply chain: its implementation entails determining which are the supply chain members with whom it is critical to link, what processes must be linked, and what type/level of integration applies to each process link, with the ultimate goal to maximize value. Supply Chain managers can be viewed as planners: they analyze and interpret information, revise plans, and ensure that expected demand is met with a steady supply stream.

In today's highly competitive and complex marketplace, a company with a more effective and efficient supply chain can have a competitive advantage over its competitors (internetwork competition); optimized supply chains, in fact, result in lower costs, higher product quality,

increased profitability, and a faster production cycle, all of which benefit the firms' competitiveness: SCM is viewed as a source of competitive advantage, a crucial area of the business. A single link failure can have a negative impact on the rest of the chain and be costly. Global Supply Chains (GSC) are composed of firms and firms face risks. When a company experiences a disruption, the effects are often felt throughout the supply chain it is part of.

Supply chain shocks are defined as a combination of an unanticipated triggering event and the consequences stemming from it, which significantly compromise the flow of material and information as well as normal business activities. Natural disasters (such as floods, hurricanes, fires, blizzards, earthquakes...), man-made disasters (labor union strikes, bankruptcy of a member of the chain or terrorist attacks, for instance), geopolitical instability (e.g., trade and industrial policy changes) and pandemics (e.g., the recent outbreak of the COVID-19 pandemic) are examples of disruptions, that can have far-reaching consequences: postponed or paused deliveries, closed ports, canceled cargo flights, unbalanced supply and demand…

The economic impact of the COVID-19 pandemic has been felt in nearly every sector, but global supply chains have been among the hardest-hit, due to border restrictions that cut off access to key suppliers (compromised links in the network), changing demand for certain products, shortages of materials, risen shipping costs…

Depending on the severity of the situation and their ability to adapt, some supply chains may even come to a halt. Recovery can be time-consuming, costly, and difficult.

Many CEOs now see supply chain disruption as the greatest threat to their companies' growth and the economies of their countries.

Although the ultimate impact of natural disasters, human actions, and pandemics is difficult to predict, businesses can take some preventive measures to be prepared to risk, minimize the damages, and ensure a speedy recovery: they must improve the efficiency and resilience of their supply chains (e.g., diversifying risk, better future forecasting, transparency, automated decision-making).

The second chapter deepens the impact that the COVID-19 has had and continues having on global supply chains and retraces the crucial stages of the pandemic.

Since the Coronavirus outbreak, people have become more aware of global supply chain disruptions as a result of supply shortages and longer waiting times for products' deliveries.

The pandemic has hampered operations at all levels on the supply side: unannounced shutdowns of manufacturing and distribution facilities, bottlenecks at borders, and sick workers have caused blockages in the production and retailing chains, squeezing supply.

The fact that disruptions in production and delivery coincided with a rapid recovery in goods demand exacerbated the situation, especially after the economic downturns brought on by the health crisis caused shipping companies to forecast a drop in demand.

All these factors have contributed towards an increase in transportation times and costs, and finally towards an increase in consumer price levels.

The most apparent examples of recent failures in global supply chains were personal protective equipment, microprocessors, and toilet paper, all of which are explored in the chapter.

After more than two years, there's a growing feeling of optimism that the worst period is over, but such a limited view of current challenges disregards deep structural issues in supply chains; in fact, the global supply chain is still breaking down, impacted by COVID-19 and challenged by preexisting and new menaces: is the case respectively of climate change and geopolitical tensions produced by the current political crisis between Russia and Ukraine. These are all systematic risks that require changes to business models worldwide.

Understanding and addressing the causes of global supply chains' turmoil and how the COVID-19 pandemic has played a role is critical to avoid regular breakdowns in the future.

The pandemic has significantly changed the business environment for many organizations all over the world, emphasizing the importance of being able to react promptly, adjust flexibly, and refine crisis management systems in order to forecast and deal with uncertain situations. As businesses strive to improve their operations and business resilience, the importance of supply chain resilience and risk management is becoming clearer than ever.

If they haven't already, companies should become fully acquainted with their supply chains: the inputs they get, how often and in what amount, all the information about suppliers as well as distributors and customers. To cope with what-if scenarios, companies together with risk managers should set ahead of time contingency plans and countermeasures.

In order to build supply chains that are resilient (capable to promptly recover from a shock, able to anticipate, respond to, and recover from it in a timely and cost-effective manner) but also robust (able to keep producing despite the shock), companies should first increase buffers, but, since this would come with a risk, industry players should share the costs of maintaining extra raw materials and goods; moreover, to understand with whom to share the risk, a transparent and clear supply chain, whose nodes are well defined and known, is of utmost importance.

Furthermore, companies should seize the opportunities offered by new technologies and AI.

All these possible and recommended measures are extensively treated.

After a brief explanation of what Artificial Intelligence is, the third chapter investigates how AI can be exploited in and be beneficial to supply chain management and which steps companies should undergo in order to get ready for AI integration in their operations.

The global supply chain's machinery, robots, IoT devices, and applications generate a huge and continuous flow of data. Supply chain managers have traditionally spent many hours manually gathering data from a variety of separate systems and tried to make sense of it all. Given the enormous quantity of data at hand after a business has grown beyond a certain threshold, it's simply no longer possible for the human mind to account for everything, thus AI seems to have gone from being nice-to-have to being a requirement.

AI-based supply-chain management solutions are built to give meaning to all of this information, to bring stability to the chaos of all the data, and to turn this into actionable insights for industry, to bring visibility into all elements of the supply chain, and finally enhance decision-making, with an accuracy and methodology that humans simply can't match on such a large scale.

Integrating AI into supply chains will have a higher economic impact and influence a wider number of enterprises than most other AI uses. Throughout the chapter, several examples are reported regarding the use of AI in every step of the supply chain, namely in procurement, production, planning, logistics and distribution, sales, and inventory management.

Traditional analytic techniques, including tree-based ensemble learning, classifiers, clustering, regression analysis, and other types of statistical inference, have the largest range of applicability. The employment of neural network-based approaches, which we associate with the latest generation of AI, is not yet common, in part due to the technology's relative immaturity and the organizational obstacles of implementing these techniques.

AI and machine learning can provide unparalleled value to supply chain and logistics management: they will result in substantial production cost savings, more capable and effective workforce, mitigated risk, improved supply chain forecasting, faster deliveries via more optimized routes, and improved customer service.

The main mentioned and analyzed benefits that organizations can derive from agile AI strategies are the following: decreased operational costs, better quality and increased revenues; accurate inventory and warehouse management; near real-time data, enhanced end-to-end visibility and intelligent decision-making.

Overall, we can say that AI is nowadays essential to enhance an organization competitiveness. In order to get the most out of these solutions it is not simply a matter of technology: since the required initial investments are significant, both in terms of money, people, and time, for them

to bear fruit, the companies must take organizational steps and prepare themselves to capture the full value coming from AI.

Among the various proposed practical implementation examples, the most interesting one is the use of artificial intelligence systems to build virtual replica of existing supply chains, the so-called digital twins, and use them to simulate supply chain system functioning, explore different possible scenarios, perform stress tests…

Finally, the fourth and last chapter goes into detail about the fundamental steps to be taken by an organization to prepare adequately for AI integration.

Taking on an AI-driven supply chain transformation is a challenging task, and firms should be entirely aware of the difficulties. AI has the potential to provide enormous value, but it is expensive to set up: if a company is not ready to integrate it into its operations, it may not fully enjoy the potential benefits and suffer losses. Many are the registered failures experienced by organizations adopting present AI solutions: missing or insufficient data, not enough attention paid to the potential business effect, not well prepared or overburdened IT departments are all common causes of misfunctioning.

AI is still located in the first part of Gartner's Hype Cycle for supply chain strategy in 2021, the so-called Innovation Trigger, which means it could take another decade before the technology matures. It is already transforming the manufacturing environment and revolutionizing supply management, but since machine learning is still at its beginnings and AI will not disappear for a long time, companies that haven't started their digital transformation should not be too alarmed. This does not imply they should wait for AI technologies to completely develop before investigating their utility, but instead they should begin preparing a clear implementation plan now and actively try to grasp the potential transformation benefits and applicability of AI through small-scale projects.

The advantages coming from advanced analytics are a result of competitive and market dynamics, as well as numerous actions and choices made by firms and individuals.

Companies should use AI tools extensively in areas where the biggest potential possibilities are, where they can best use their abilities to turn data complexity into a competitive advantage. Only few businesses do a proper diagnostic from the start, yet this activity may ensure that businesses have a complete list of all value-creation prospects.

After this analysis, the proper data foundation must be built: data is the fuel for AI and huge amounts of them are needed to maximize AI-based returns.

Using AI systems, particularly neural networks, effectively necessitates big, labeled training data sets as well as adequate computing infrastructure. Traditional approaches' performance

tends to flatten as the training data set size grows larger (overfitting); however, the performance of advanced AI systems that use properly designed and trained deep neural networks tends to improve. The information will have to be gathered in a method that addresses privacy concerns. Along with challenges regarding data volume and variety, also velocity is a requirement: AI techniques demand models to be retrained to fit possibly changing conditions, which necessitates frequent data refreshment.

While adopting AI technologies, companies also face legislative barriers, as well as social and user approval. Authorities frequently require intelligible regulations and selection criteria. However, most of the times complex AI models are difficult to explain in human terms. Another issue concerns the generalization of the results, since very often it is difficult to transfer AI models from one set of circumstances to another.

Moreover, organizations that want to implement large deep learning efforts should think about a variety of possibilities: building a complete in-house AI capability, either gradually or more quickly via acquisitions, outsourcing, or adopting AI-as-a-service solutions are among the choices.

On the human side, much of the creation and optimization of deep neural networks still necessitates actual specialists to make significant performance improvements. At the moment, demand for these abilities significantly outnumbers supply. Companies interested in developing their own AI solutions should assess if they can attract and maintain these specialist capabilities.

On the governments side, even more after the disruptive impact that COVID-19 had on the global economy, countries should prioritize their digital infrastructure and supply chain investments. AI is also posing new challenges for policymakers: they will have to find a balance between promoting AI technology development and managing any risks posed by the misuse of AI techniques and the data they use. Given the magnitude of the positive influence on business, the economy, and society, the goal should not be to limit AI adoption and application, but rather to encourage its beneficial and safe application.

Furthermore, governments could directly stimulate the creation of training data through open data programs and establish consistent data standards.

Even when focusing on technology solutions, firms must pay attention to critical supporting components such as organization, change management, and capability building to solve skills gaps. In fact, each significant investment in technology must be accompanied by organizational reforms, business process upgrades, and upskilling efforts. Only then will businesses realize the desired return on investment.

1. What is Global Supply Chain Management

1.1 What is a Supply Chain

A supply chain is defined as *"the network of organizations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services in the hands of the ultimate consumer"* (Christopher, 1992)[i]; *"a series of integrated enterprises that must share information and coordinate physical execution to ensure a smooth, integrated flow of goods, services, information, and cash through the pipeline"* (Coyle & Langley, 2003)[ii].

A supply chain is thus a network between a corporation, its suppliers, and its customers, in which the nodes reflect the processes involved in producing and distributing a certain product or service to the final buyer, and the links between them indicate the flow of information, materials, and finances between stages.

One important feature is the concept of an integrated network or system: if we wanted to represent a supply chain, a linear diagram would oversimplify reality, not considering the dynamism of the system; in reality, supply chains are generally characterized by numerous nodes, and information and products can travel through multiple paths to reach the final user: as shown in Figure 1, it is more a web than a line of participants.

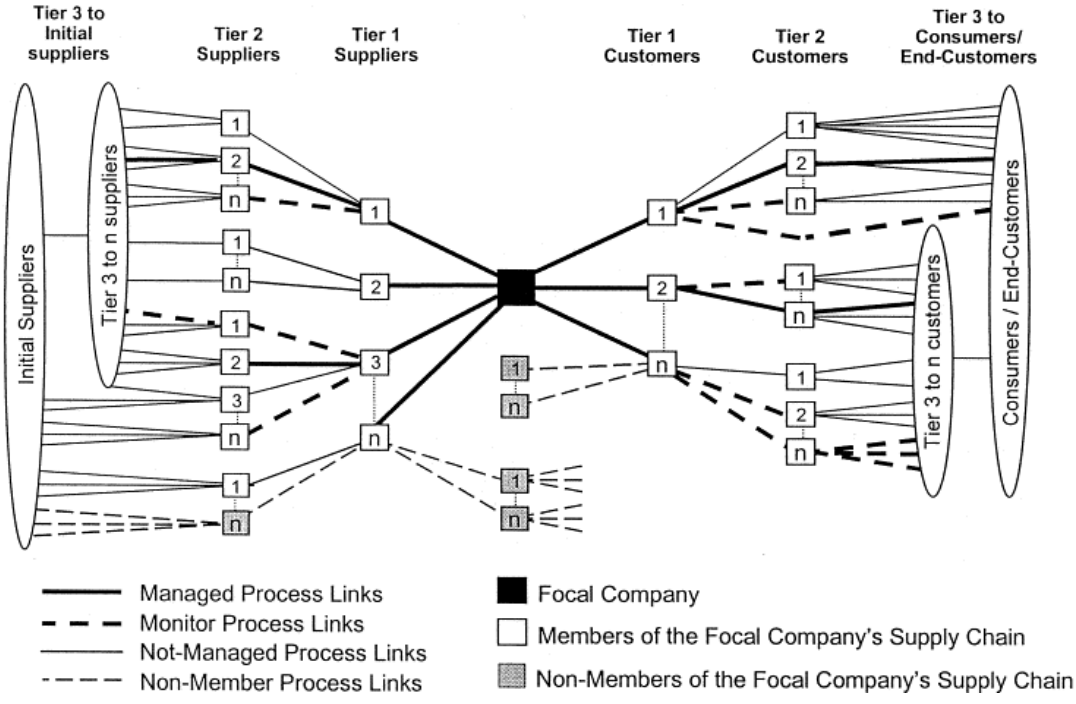

Figure 1: Model of a supply chain web and the several types of links existing between its participants [iii]

Different functions, people and entities belong to the supply chain network.

A supply chain's major steps include:

- inventory and production process planning to ensure that supply adequately meets demand
- obtaining/producing the materials required for the end product
- transferring, assembling, and turning raw materials into final goods
- testing the product
- packaging the product for distribution or retaining it in inventory
- transporting and delivering the obtained goods to the distributor, retailer, or customer

From receiving an order to fulfilling the customer's request, a supply chain's activities and functions include product development, production planning, procurement, sales forecasting, marketing, operations, distribution systems, accounting and financing, and customer support.

The member firms and the linkages between them make up the supply-chain network structure: these entities include producers, vendors, warehouses, transportation companies, distribution hubs, and retailers.

The structure and linkages of a company's supply chain depends on various factors such as market and sector in which it operates, geographic scope of activity, product diversification… It is important to recognize that no two supply chains are identical, and hence each one faces a unique risk of disruption.

International companies have expanded their geographic scope of operations in recent decades, and as a result, the dispersion of manufacturing facilities has expanded as well. Globalization can be explained using Yip's four internationalization drivers (shown in Figure 2): market, cost, government, and competitors.

Global strategy has caused supply chains to become more international and globally configured, entailing greater coordination of geographically dispersed activities: more than two thirds of world trade currently take place within globally operating supply chains.

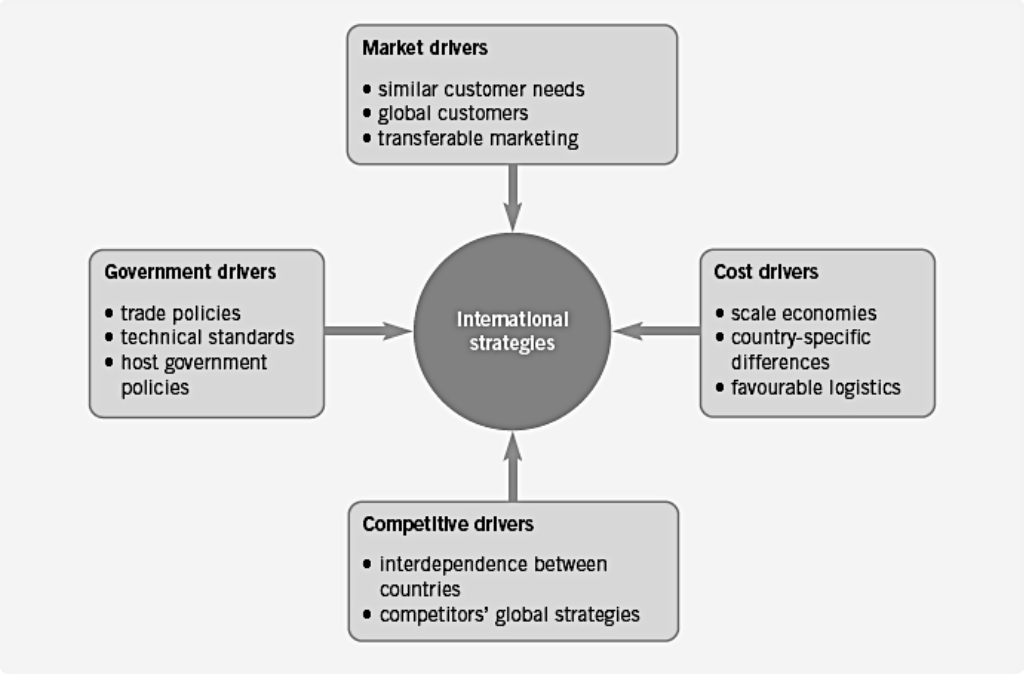

Figure 2: Yip's four drivers of internationalization [iv]

1.2 Supply Chain Management (SCM)

We are entering an era of internetwork competition that has repercussions in modern business management: individual businesses no longer compete as solely autonomous entities, but rather as supply chains. In this new competitive environment, a company's success will be determined by management's ability to integrate its complex network of business relationships. Supply chain management (SCM) is the management of the multiple linkages across the supply chain: it provides the chance to capitalize on the synergy between intra- and inter- company integration.

In today's highly competitive and complex marketplace, a company with a more effective and efficient supply chain can have a competitive advantage over its competitors; optimized supply chains, in fact, result in lower costs, higher product quality, increased profitability, and a faster production cycle, all of which benefit the firms' competitiveness: SCM is viewed as a source of competitive advantage, a crucial area of the business. A single link failure can have a negative impact on the rest of the chain and be costly.

The Council of Supply Chain Management Professionals' official definition of Supply Chain Management is as follows: *"Supply chain management encompasses the planning and management of all activities involved in sourcing, procurement, conversion, and all logistics management activities. Importantly, it also includes the coordination and collaboration with*

channel partners, which can be suppliers, intermediaries, third-party service providers, and customers. In essence, supply chain management integrates supply and demand management within and across companies. Supply chain management is an integrating function with primary responsibility for linking major business functions and business processes within and across companies into a cohesive and high-performing business model. It includes all the logistics management noted above, as well as manufacturing operations, and it drives coordination of processes and activities with and across marketing, sales, product design, finance, and information technology." (CSCMP Supply Chain Management Definitions and Glossary, 2022)[v]

To summarize, SCM refers to the supervision and control of all activities required for a company to convert raw materials into finished products that are then sold to end users (planning, design, manufacturing, inventory, and distribution). SCM implementation entails determining which are the supply chain members with whom it is critical to link, what processes must be linked, and what type/level of integration applies to each process link. The goal of SCM is to maximize value, not just for the company, but for the entire supply chain network, including the end customer. As a result, supply chain process should be designed to improve process efficiency and effectiveness across the system: to increase productivity at each stage of the product lifecycle, eliminate inefficiencies, and deliver products on schedule and smoothly.

A Supply Chain Manager is in charge of ensuring that a company can source raw materials, manufacture products, store inventory, and transport shipments to consumers or wholesalers in an efficient manner. Their responsibilities include analyzing logistics data to improve the supply chain, negotiating business deals, and communicating with suppliers and distributors.

A Supply Chain Manager's role is to understand how each step in the production, manufacturing, and distribution process interacts with one another, maximizing efficiency and reducing waste. Supply Chain Managers coordinate the activities of various teams to ensure that products are delivered to customers on time, taking into account factors such as transportation time, product returns, and other delays. They create long-term plans for the company to ensure that they have enough stock at all times to meet demand.

Hence, Supply Chain managers can be viewed as planners: they analyze and interpret information, revise plans, and ensure that expected demand is met with a steady supply stream.

1.3 Natural and man-made disasters, pandemics, and geopolitical instability: sources of supply chain disruption

Global Supply Chains (GSC) are composed of firms and firms face risks. When a company experiences a disruption, the effects are often felt throughout the supply chain it is part of. The likelihood of disruptions propagating throughout a supply chain increases as it is globally expanded, and companies pursue speed and efficiency in the processes. In practice, each organization's decisions and actions have an impact on the supply chain's overall performance. A problem at any step feeds other problems at later stages.

Supply chain shocks are defined as a combination of an unanticipated triggering event and the consequences stemming from it, which significantly compromise the flow of material and information as well as normal business activities. Natural disasters (such as floods, hurricanes, fires, blizzards, earthquakes...), man-made disasters (labor union strikes, bankruptcy of a member of the chain or terrorist attacks, for instance), geopolitical instability (e.g., trade and industrial policy changes) and pandemics (e.g., the recent outbreak of the COVID-19 pandemic) are examples of disruptions, that can have far-reaching consequences: postponed or paused deliveries, closed ports, canceled cargo flights, and unbalanced supply and demand just to mention a few.

Depending on the severity of the situation and their ability to adapt, some supply chains may even come to a halt. Recovery can be time-consuming, costly, and difficult.

The 9/11 terrorist attacks[vi], the 2011 Japanese earthquake and tsunami, and the 2017 hurricane in Puerto Rico[vii] are all well-documented examples of this type of events.

The terrorist attacks on September 11, 2001, served as a wake-up call to the government that borders were not secure. Every plane, ship, and container became suspect all of a sudden. Previously, ships carrying goods would arrive at U.S. ports uncontrolled, and the contents of containers were frequently unknown. Then, with terrorism on the horizon, the government demanded more information, putting the burden of security on supply chains.

The 2011 Tohoku earthquake and tsunami cost Japan $210 billion and disrupted supply chains around the world. Toyota and Nissan all temporarily shut down facilities in both the United States and Japan due to inability to ship or receive needed parts.

When Hurricane Maria hit Puerto Rico in September 2017, it caused damage to the supply chains of two of the island's most important industries: pharmaceuticals and medical devices. Authorities had to ensure that critical drugs and medical supplies did not run out. The effects spread throughout the United States as the storm knocked out many of the facilities in Puerto

Rico that make sterile saline bags. Hospitals were forced to ration saline, and patients thousands of miles away were affected too.

These examples demonstrate the dramatic consequences and interdependence of supply chain entities, as well as their vulnerability to destructive events. The risk of supply chain disruptions has increased over the last decade as a result of globalization and outsourcing trends.

Companies are not defenseless against disruptions, and with the right mitigation strategies, they can significantly reduce the impact of a disruptive event.

Both Nokia and Ericsson were affected by a fire in a supplier's semiconductor manufacturing facility in 2000, but Nokia was able to handle the situation proactively by changing the design of their chips and quickly utilizing backup suppliers. Due to their agility, Nokia was even able to take away market share from Ericsson.

Similarly, as already mentioned, there could be outbreaks of extremely contagious diseases such as the coronavirus (COVID-19): its spread, the millions of deaths and the significant restrictions on travel has caused a lot of damage to the economy and society globally. Many affected countries decided to implement a total lockdown within their borders in order to prevent further transmission of the infection within communities. The majority of international and domestic flights have been delayed or stopped in various countries. Train, truck, and vehicle transportation were also prohibited, with the exception of those transporting essential commodities. Industries have been suffering greatly because many of them have been closed for an extended period of time, production levels have fallen and people working in the tourism and transportation industries have faced extreme difficulties. Inflation and unemployment rate have highly increased even in the economically leading countries.

The economic impact of the COVID-19 pandemic has been felt in nearly every sector, but global supply chains have been among the hardest-hit, due to border restrictions that cut off access to key suppliers (compromised links in the network), changing demand for certain products, shortages of materials, risen shipping costs…

Many CEOs now see supply chain disruption as the greatest threat to their companies' growth and the economies of their countries.

The system shock caused by the pandemic has had an unprecedented impact on how businesses view the supply chain: now the focus is on an increased communication among suppliers and an efficient use of technology.

Although the ultimate impact of natural disasters, human actions, and pandemics is difficult to predict, businesses can take some preventive measures to be prepared to risk, minimize the

damages, and ensure a speedy recovery: they must improve the efficiency and resilience of their supply chains (e.g., diversifying risk, better future forecasting, transparency, automated decision-making).

To mitigate against future disruptions and to ensure future business continuity and growth, companies must analyze, reimagine, and manage their supply chains in new ways.

2. COVID-19 pandemic: Global Supply Chain issues

Since the Coronavirus outbreak, global supply chains have been at the center of economic debates and their resilience is now mentioned as a policy goal in several countries' recovery plans.

People have become more aware of recent global supply chain disruptions as a result of supply shortages and longer waiting times for products' deliveries, which have affected their everyday life. These shocks aren't going away anytime soon and will continue for yet an undetermined amount of time. Understanding the causes of global supply chains' turmoil and how the COVID-19 pandemic has played a role is critical for the future.

The pandemic was global in scope, even if it has had different trends and developments according to the regions. Shocks rarely are widespread, long-lasting and affect multiple sectors and nations at the same time and this is what was new about the COVID-19. It has revealed that modern global supply chains are like cards houses, prone to collapsing when put under prolonged pressure. Despite the fact that the vast majority of companies have always contingency plans in place, many businesses have been caught off guard by lockdowns: even the most advanced and powerful multinationals were not ready for a shock of such magnitude.

After more than two years, there's a growing feeling of optimism that COVID-19 worst period is over. It is easy and tempting to believe that if we begin to see the end of the crisis, we have hit the problem and solved it, but such a way of thinking is not recommended: such a limited view of current challenges disregards deep structural issues in supply chains. If these problems are not addressed, they will result in regular breakdowns in the future.

Before moving forward, we should reflect on the mistakes made in the past; in fact, new challenges are present (e.g., climate change) or could come and find again companies unprepared.

The COVID-19 pandemic has significantly changed the business environment for many organizations all over the world, emphasizing the importance of being able to react promptly, adjust flexibly, and refine crisis management systems in order to forecast and deal with uncertain situations. As businesses strive to improve their operations and business resilience, the importance of supply chain resilience and risk management is becoming clearer than ever.

If they haven't already, companies should become fully acquainted with their supply chains: the inputs they get, how often and in what amount, all the information about suppliers as well as

distributors and customers. To cope with what-if scenarios, companies should focus on business continuity, and, together with risk managers, they should set ahead of time contingency plans and countermeasures.

Each company must gain a better understanding of where choke points exist (e.g., at the manufacturing or at the distribution level) so that they can be addressed, alleviated, or even eliminated. In addition, more research is needed in the field of behavioral economics, to better understand how consumers react in times of crisis.

This world we live in is continuously changing, increasingly interconnected and potentially dangerous, and, as we are learning in the hard way, global supply chains do not adjust automatically.

2.1 What happened: many challenges to Global Supply Chain resilience

With regard to various aspects, from people's daily lives, to business and international trade, the last few years have been turbulent. Already since Britain's Brexit, there had been initial concerns about its impact on global supply chains; then, COVID-19 pandemic has represented a much broader shock.

According to the Business Continuity Institute Supply Chain Resilience Report 2021[viii], which conducted a survey on 173 companies in 62 countries, nearly a quarter of them experienced heavy and severe disruptions in 2020, mostly attributed to COVID-19, compared to less than 5% in 2019.

Lockdowns in China during the early stages of the pandemic (beginning of 2020) forced the closure of factories in the province of Hubei, whose capital is Wuhan, where the virus was detected for the first time, and delayed the shipment of goods. Firms all over the world, dependent on intermediate inputs produced in this province, experienced an upstream supply chain disruption, while Covid remained primarily restricted to China. As a result, some US companies shifted manufacturing out of China to other countries, but, despite this, the coronavirus continued to spread among workers in meat processing plants, warehouses, and grocery stores, impeding food production and distribution (for example, a meat processing plant in Minnesota, producing 5% of the country's pork, closed in April 2020 after several workers contracted COVID-19)[ix].

Similar dynamics occurred over the following two years, for example in August 2021, the outbreak of the Delta variant prompted the shutdown of facilities in Vietnam, the US's second-

largest supplier of shoes and clothing after China, where only 3% of the population had been vaccinated against COVID-19.[x]

The pandemic has hampered operations at all levels on the supply side: unannounced shutdowns of manufacturing and distribution facilities, bottlenecks at borders, and sick workers have caused blockages in the production and retailing chains, squeezing supply.

The fact that disruptions in production and delivery coincided with a rapid recovery in goods demand exacerbated the situation. When mobility limitations were implemented in the spring of 2020 to manage COVID-19, consumers reduced their expenditure on services and increased their purchases of manufactured items. Individuals, being restricted in their homes for months, have driven up demand for a wide range of products. This strong increase has also contributed to shortages, especially after the economic downturns brought on by the health crisis caused shipping companies to forecast a drop in demand.

While demand for in-person services declined, Canadians, Americans, and Europeans began to spend more on consumer goods for use at home, such as exercise equipment and kitchen appliances.

The rise of e-commerce has put additional strain on factories, carriers, and ports.

Factories in Asia attempted to meet the increased demand. However, they struggled to transport goods due to a shipping container shortage, which was worsened when China redirected the use of containers to deliver COVID-19 protective materials to countries battling the pandemic. Large numbers of incoming ships began to overwhelm ports, as containers were unable to be unloaded, transported, and reused in a timely manner. Congestions have hampered trade, and the only way to alleviate the situation in the short term is to improve the performance of current facilities.

Factories shutdowns, lockdowns in various countries around the world, labor shortages, rising goods demand, bottlenecks in logistics networks, and capacity limits have resulted in significant increases in shipping costs and delivery delays: shipping a container of goods from Asia to the United States rose from around $2,000 before the pandemic to as much as $30,000 by September 2021. This sharp increase in transportation times and costs caused an increase in consumer price levels.

After more than two years of pandemic, the global supply chain is still breaking down, impacted by COVID-19 and challenged by preexisting and new menaces: is the case respectively of climate change and geopolitical tensions produced by the current political crisis between Russia and Ukraine. These are all systematic risks that require changes to business models worldwide.

The current geopolitical tensions among some of the world's leading economies may result in renewed trade battles, with significant implications for global supply chains as governments shift industry to more convenient regions, both from a geographical and political stand point.

2.2 Examples

The most apparent examples of failures in global 'just in time' supply chains were masks, hand sanitizer, protective equipment, microprocessors, and, rather ironically, toilet paper.

PPE and ventilators shortage [xi]

When the H1N1 flu broke out in 2009, we were in desperate need of N95 respirators and personal protective equipment. Reserves were drained, orders from health care centres were two to three years behind schedule, and workers in hospitals had to reprocess single-use protective clothing. The same mistakes were made again, and the situation has been repeated with the recent pandemic.

Political authorities have encouraged social distancing since COVID-19 was declared a worldwide epidemic, with the intention of slowing transmission and flattening the infection curve, trying to prevent an excessive pressure on the health-care system. However, the consequences of physical separation take weeks to manifest, and hospitals soon reported shortages of crucial devices such as ventilators and personal protective equipment (PPE) for medical personnel.

The nations' strategic reserve of ventilators was insufficient to cover the anticipated deficit. Equally alarming was the absence of proper PPE for frontline health care personnel, such as respirators, gloves, face masks, and hand sanitizer. Without sufficient PPE, health-care professionals would likely report higher rates of illness, threatening the smooth functioning of the health care system.

The human and economic implications of that scenario should not be underestimated.

These devices scarcity has been caused by a variety of factors, in particular issues with the global supply chain. Prior to the virus, for example, China manufactured over half of the world's face masks. As the illness spread throughout China, shipments ceased.

To fill the gap between the demand and the supply of PPE and ventilators various strategies have been followed. State governments have encouraged some businesses to shift manufacturing to make this needed equipment. Because the components of PPE are specific but do not need extensive capital expenditure, smaller regional enterprises can play an

important role in filling the gap. From a regulatory viewpoint, state collaborations with these corporations would be substantial and flexible.
Furthermore, masks and gloves used in a variety of non-medical contexts, such as construction enterprises, labs, and so on, might be donated to health care professionals.

However, in the case of ventilators, for example, only a few businesses have the expertise to manufacture them. To guarantee an adequate supply of ventilators, various sectors should cooperate: governments should direct suppliers to maximize supply of raw materials and engage other industries in this effort. Automakers, for example, had stated that they could have been able to manufacture ventilators.
Collaboration with tech firms to track equipment availability and predict demands in real time, guaranteeing a close match between supply and demand, would also be beneficial.

Microprocessors shortage [xii]

Prior to COVID-19, there was already considerable pressure on the manufacturing of microprocessors and similar products, given the limited global production capacity and increased demand. As production and delivery limitations have been confronted with increasing pandemic-driven demand, the pandemic has put further strain on an already stressed segment.
Previously, problems in microchip manufacturing tended to affect solely the production of smart phones, tablets, laptops, and smart televisions.
However, those disruptions are now affecting also vehicle production, since microprocessors power the computers that ensure that our automobiles function as they should: chips are increasingly being employed in power steering and brake systems, information and entertainment devices...

Automakers canceled orders for microprocessors early in the COVID-19 outbreak, fearing a sharp decline in vehicle sales. Demand for such microprocessors in consumer electronics skyrocketed almost in the same period: parents purchased tablets for their children's distance learning, and all those who found themselves forced to work remotely purchased laptops. Then, due to a fire at a semiconductor factory, even less of these microprocessors were produced, being in short supply by the time vehicle sales began to improve.
Due to the worldwide semiconductor shortage, for example, both General Motors and Ford Motor Company had shut down a number of their factories in North America. And because automakers are newcomers to the microprocessor industry, they lack the power of the other customer industries.

To put it another way, the reason why car manufacturers can't acquire the microprocessors they need has little to do with their sector. This example shows how your supply chain risks are not limited to your customers or rivals, but also to other businesses who use your same inputs: in this scenario, for example, General Motors and PlayStation that do not usually consider themselves as competitors, have been contending the same limited resource.

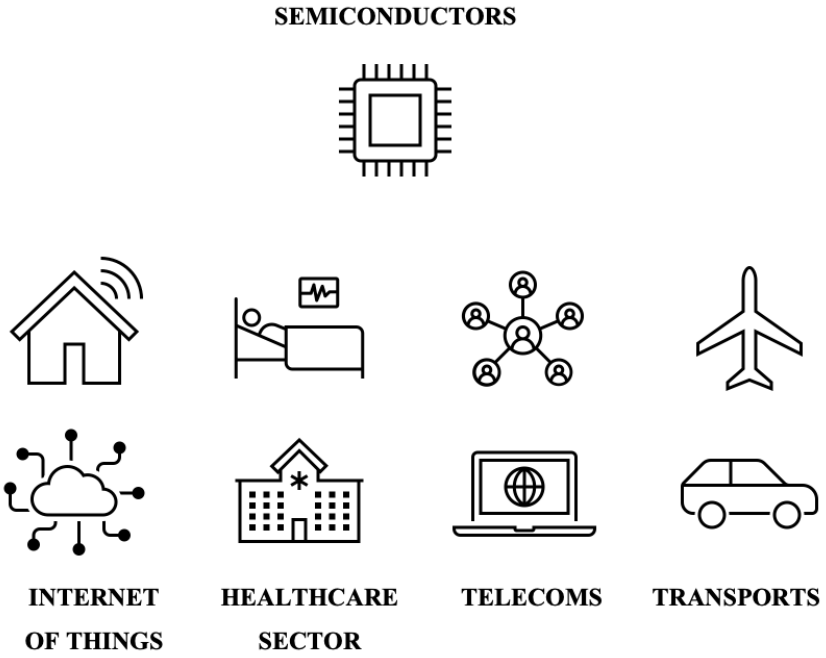

Figure 3: Sectors strongly dependent from the semiconductors supply

As more commodities become smart through wifi or Bluetooth technology, the situation for automakers is only anticipated to worsen.

The growing list of items that require microchips is puzzling, even more if we think that these components are almost entirely manufactured in China, Taiwan, South Korea, Malaysia, Thailand, and the Philippines, which are among the world's most dangerous countries in terms of natural disasters and geopolitics. In pre-pandemic times, the widespread offshore of chip manufacture from the United States to these nations made economic sense; in fact, East Asia has long developed a substantial advantage in semiconductor production due to availability of both low-cost supplies and labor.

However, it is pretty clear that this situation should change, since the existing microchip production facilities are required not enough, and they should be placed in areas with lower risks.

Furthermore, semiconductor chip manufacturing entails a complex series of procedures, from design through front-end production to back-end assembly, tests, and packaging. Different

enterprises and nations carry out each of these operations, and each has established competitive advantages in different parts of the supply chain. Microchip design, for example, is located in the United States, equipment suppliers are based in the Netherlands and Japan, fabrication facilities (foundries) are concentrated in East Asia. This results in the fact that no country has total end-to-end control of chip manufacture and, consequently, reshoring projects are extremely ambitious.

President Joe Biden claimed that some legislation was required both to offer future employment and to increase and enhance competition with China. Such supply chain flaws, along with the awareness that semiconductors are a strategic resource, have encouraged a movement in Washington to re-establish American chip production. In June 2021, the United States Senate passed the U.S. Innovation and Competition Act (USICA), which would spend $52 billion to boost the semiconductor sector in the United States; in February 2022, the America COMPETES Act was enacted by the House of Representatives on the same matter.
The Senate USICA, has a more limited view of which businesses are eligible for assistance, restricting it to microchip producers. The House Act, instead, takes a broader approach and includes support for firms that supply chip-making equipment and materials. However, the House plan cuts over $200 billion in funding for regional technology centers, in contrast with the Senate bill. It is thus clear that now a reconciliation process between these laws is necessary.

However, in addition to the problem of differences in laws, there is an underlying issue: reshoring the semiconductor supply chain is unlikely to alleviate the supply-chain shocks created by the pandemic: building the most crucial nodes, especially chip production, would necessitate not just massive initial investment, but probably an indefinite stream of government support. As politicians debate how best to position the US to keep access to a critical technology, it's worth examining what a more comprehensive plan for addressing semiconductor availability may look like.

The new facilities may strengthen the manufacturing base, but enterprises are experiencing both blue-collar and white-collar workforce shortages, which will be difficult to fix due to negative demographic, educational, and economic trends.

According to estimates, the silicon wafers produced in Arizona will be more expensive than those produced in Taiwan, and these extra expenses will be passed on to customers at a time already characterized by rising inflation.

First, the US should prioritize enhancing engagement with East Asian supply-chain partners; moreover, it should change immigration restrictions to attract more qualified workers,

bolstering the talent pool during a time of labor shortages and enhancing national competitiveness.

Although the semiconductor sector has attempted to improve production, large gaps between supply and demand still exist.

To conclude, it is important to refer to even more recent events: both Russia and Ukraine offer critical semiconductor inputs like nickel, palladium, and neon, and the recent Russian invasion of Ukraine is expected to cause more pain to the global microchips supply chain.

Toilet paper shortage [xiii]

A joke told by Johnny Carson in 1973 resulted in a toilet paper shortage. Harold Froehlich, a Wisconsin congressman, said in a statement in December 1973, "The next thing we're going to have to worry about is a potential toilet paper shortage." The warning was grasped by Johnny Carson, who claimed that there was a severe shortage of toilet paper in the US during his late-night show. The audience, and consequently other people around the country, crowded supermarkets around the country, collecting as much toilet paper as they could. Very soon, people walking into the local store only found empty shelves and, in particular, no toilet paper. There were no shortages of raw materials or production flaws, and no one had come up with new applications for toilet paper: it was simply panic buying by regular people, and supply chains couldn't keep the pace. So, rumors had produced an excess of demand at retail locations. However, today's supply chain issues are no joke, they are true, but they are challenges that we have previously encountered and even addressed.

During COVID-19, we have experienced a new toilet paper shortage. Manufacturers had adequate capacity, but not the proper kind: they had a lot of commercial toilet paper on hand, which is nothing like the toilet paper that customers use at home. We are talking about nine-inch-wide rolls of thin paper that you find in public restrooms, offices, restaurants, and hospitals, clearly built for cost rather than comfort. Because people are staying at home due to business closures, consumer toilet paper demand has increased while commercial toilet paper demand has declined. Retailers couldn't keep enough stock on the shelves, the manufacturing process took some time to catch up, and the supply chain was put under pressure.

2.3 What can firms involved in GSCs do to mitigate the effects of supply disruptions

We can't predict how often future pandemics or globally disruptive events will unfold, but COVID-19 is likely to cause turmoil for some more months or even years. The end date for supply chain disruptions and shortages is unknown yet. At the end of last year, industry analysts predicted that most of the supply problems would be mostly resolved by mid-2022; however, the Omicron wave, as well as the conflict in Ukraine, have added more uncertainty. All things considered, the Organization for Economic Cooperation and Development predicted that major economies won't resume pre-pandemic growth before 2023, instead they may even have to wait until 2025.

Before going to see some measures that companies should take to mitigate the effects of supply chain disruptions, we should clarify the critical distinction existing between resilience and robustness.

Resilience is described as the capability to promptly recover from a shock, as well as the ability to anticipate, respond to, and recover from it in a timely and cost-effective manner. Much of the focus on ensuring resilience is on planning the supply chain by always keeping in mind the riskiness of the various sites. Organizations could and should make their supply chains more resilient from this point forward, through risk diversification, improved forecasting, and the construction of buffers, such as inventory stockpiles or additional manufacturing equipment.

Instead, robustness refers to the ability to keep producing despite the shock. External supplier redundancy or numerous manufacturing sites for internally produced components are important aspects of robustness plans. Moving towards robust global supply chains, however, is not simple because they've traditionally aimed to build fragmented and thus fragile networks in the name of short-term profits and financial efficiency. While this may have offered short-term benefits, flaws such as the fragmentation of decision-making processes and the overall limited coordination between the various nodes have all aggravated the vulnerability of global supply chains. These chains have no clear centralized entity or authority directing and supervising them. Rather, numerous businesses collaborate and compete for the value provided. However, the world needs robust supply chains built on the principles of transparency, sustainability, trust, cooperation, and diversification. Teamwork is beneficial to global supply chains, hence global SCM should be seen as a collaborative activity. When buyers and suppliers collaborate, they can benefit from greater quality of services, higher product availability, and significant cost savings.

Now let's look more specifically at the actions that companies should take to build supply chains that are resilient but also robust: first they should increase buffers, but, since this would come with a risk, industry players should share the costs of maintaining extra raw materials and goods; moreover, to understand with whom to share the risk, a transparent and clear supply chain, whose nodes are well defined and known, is of utmost importance.
Furthermore, companies should seize the opportunities offered by new technologies and artificial intelligence.

Build more buffers to be used in times of a crisis and share the related risk

Building extra buffers is an obvious solution to supply shortages, so that if something goes wrong anywhere along the chain, the next user is never left with empty hands. Retailers usually hold additional inventory because they can't exactly forecast what we'll buy: it can happen that they run out of a particular model (e.g., white skinny jeans), but they are unlikely to run out of a whole category. On the other hand, we have an increasingly wide range of products, and we observe that enterprises across sectors are carrying less backup inventories than they used to: storing additional raw materials or idle equipment is simply too expensive for many businesses and the competition is already fierce.

However, in a crisis, buffers are essential. It has been observed that firms holding a higher level of precautionary inventories managed to absorb part of the shock and to mitigate the input disruption. So, how can we solve the cost-related issue? As in the insurance industry, even in supply chains we could pool risk for low-probability, high-impact incidents, whose consequences could be devastating, except we're pooling a tangible resource instead of money. Industry participants may come together to share the burden of storing excess raw materials or even equipment in exchange for a regular charge, with the stocked resources only being used in emergencies. Many countries, for example, maintain critical medicines on hand, but only a few keep their active ingredients (APIs). During normal times, pharmaceutical companies might spread the cost of keeping additional APIs, so that in a crisis, they could draw from that reserve without risking to run out of critical medications.

Furthermore, according to Cap Gemini research, 68 percent of businesses are aggressively expanding their supplier relationships.[xiv] Technologies can help to ease inventory concerns by intelligently pooling supply capacity with areas of high buyer demand.

Improving transparency and traceability across supply chains

In the previous section we have mentioned risk sharing. But in order to perform it, we need to know which industry players share the same risks. And in order to get this information correctly, we must significantly enhance supply-chain transparency.

In the microprocessor shortage example, we have highlighted how your supply chain risks are not limited to your customers or rivals, but also to other businesses who use your same inputs. As a result, simply knowing who your direct suppliers are is insufficient. You must identify your supplier's suppliers, where they source their raw materials, who else buys from them, and so on. Several seemingly unrelated product lines can usually be traced back to a single supplier: often it happens that we erroneously believe to have diversified supply chains. We are part of a network and if important members in that web fail, numerous supply chains will be compromised. We need detailed, clear and current maps of important inputs and their origin in each particular sector if we want more robust supply chains.

It is becoming increasingly clear that resiliency is hard to achieve unless buyers, suppliers, and other stakeholders in the chain are open to sharing information and collaborate. Technology could bring huge benefits in this regard, maximizing the traceability of networks and giving a better insight into deeper tiers within the supply chains. Businesses could exchange sensitive data with partners by developing virtual spaces, where collaborative teams can conduct analysis without danger of competitive information being disclosed. Data sharing could benefit from blockchain technology, which allows for safe, access-controlled data exchange.

Exploit technological advances to better prevent and address supply chain disruptions

Artificial intelligence advancements and new technologies, like blockchain, may provide chances for future improvement of supply chains.

Fundamentally, supply-chain managers are planners. They analyze the collected data, and accordingly update their plans to fulfill predicted demand with a consistent stream of supply. The better the data are, the better are the decisions they lead to. However, too much data could be impossible to manage and understand without the help of technology: thanks to innovations in data mining, artificial intelligence, and machine learning, computers can increasingly assist us in analyzing hundreds or millions of sets of data, predicting problems before they occur, notifying management, and even recommending measures to take.

Take microprocessors as an example: no volume of information could have predicted which companies would have been affected, which companies do not use them, and which do. However, a computer could have assisted in recognizing the issue among the data points.

Reduced production and COVID-19 shutdowns, combined with the fire at the manufacturing plant, a surge in demand as sales of technological devices increased, and a sharp increase in trucking costs, would have been enough to warn managers about the incumbent risk and recommend what they could have done about it (look for other suppliers, trucking companies; notify customers about the delay…). This is similar to what airline companies so: to reroute hundreds or even thousands of people in a day, computers examine data on available flights, weather conditions, customer locations, and their destinations.

2.4 Are the efforts that have been made so far sufficient?

All the measures taken, and efforts made so far have certainly helped, but if we want to build more resilient supply chains that can withstand the next major crisis, we have to stop making the same mistakes and also to be creative, trying to come up with new ideas to improve the resiliency of our supply chains.

The final partial resolution of shortages of masks, vaccines, and tests suggests that the system has worked well in the end. Actually, the achievement was mostly due to good luck, collective optimism and good will, rather than to specifically designed policy.

We should ensure that not only have we learnt lessons from the previous two years, but that governments and businesses are deeply committed to take actions to shape an economy that is more resilient to the flaws of globalization.

3. AI in supply chain

3.1 The flood of data has made it necessary to resort to technology

Supply chains have become increasingly difficult to manage in recent years. Physical flows are becoming longer and more interconnected and product portfolios more sophisticated. The pandemic highlighted pre-existing weaknesses and worsened market volatility; as a result, businesses have realized the value of agility, the necessity of developing flexible supply chains with real-time insight. External data (weather patterns, logistics bottlenecks, and supplier issues) may be used to make instantaneous corrective decisions and enhance supply predictions. Furthermore, growing focus on the environmental impact of supply chains is driving regionalization and flow optimization.

As a result, businesses and stakeholders are focusing more on supply-chain resilience, and technology can play a crucial role in helping them to achieve this ambition.

The SCM goal is to enable the efficient exchange of information, be it physical or financial, both within an organization and throughout all supply chain participants (suppliers, customers, sub-contractors, retailers, wholesalers, etc.), to fulfill its objectives in terms of monetary competitiveness, performance, and quality of service. This is extremely hard in a global economy characterized by trade-flow complexity, intensified competition, and long-term improvement requirements to be met.

Throughout this dynamic and unpredictable environment marked by massive data exchange, advanced technologies such as artificial intelligence and machine learning have caught the interest of SCM experts: their use is fundamental to manage the connection with each supply chain member, to optimize procedures, to increase the safety and efficiency of firms who use it and to ensure the general smooth functioning of supply chains.

3.2 What is Artificial Intelligence?

Artificial intelligence is a field that uses logic, if-then rules, decision trees, and machine learning (including deep learning) to enable computers and machines to emulate the problem-solving and decision-making capabilities of human intelligence.

Because deep learning and machine learning are often used interchangeably, it's important to understand the differences between the two.

Machine learning is a branch of AI involving advanced techniques that allow machines to improve at tasks over time. It is concerned with the design and analysis of systems that can learn from data.

While in traditional programming, humans input rules (a program) and data to be processed according to these rules, and the answers are finally given, in machine learning, humans input data as well as the expected outcomes from the data, and the rules, that can then be applied to new unseen data, are produced.

Deep learning is a subset of machine learning that consists of methods that allow software to train itself to do tasks such as speech and image recognition by exposing multilayered neural networks (with more than three layers) to massive volumes of data.

The learning phase is where deep learning and machine learning differ. Deep learning automates most of the feature extraction step, removing some of the manual human intervention and allowing for the usage of bigger data sets. Machine learning, on the other hand, relies more on human intervention to learn.

Deep learning can use labeled datasets (supervised learning), to inform its algorithm, but it does not necessarily require them. Unlike machine learning, it does not require human intervention to interpret data: it can read unstructured data in its raw form (for example texts, photos) and automatically discover the hierarchy of features that distinguishes different types of data.

3.3 How AI can be applied within global supply chains?

Artificial Intelligence is already changing the supply chain industry, widening the gap between winners and losers.

The global supply chain's machinery, robots, IoT devices, and applications generate a huge and continuous flow of data. Supply chain managers have traditionally spent many hours manually gathering data from a variety of separate systems and tried to make sense of it all.

AI-based supply-chain management solutions are projected to be effective tools for enterprises to address these issues and to handle both the opportunities and limits in all business segments and departments (procurement, production, sales...). They're built to give meaning to all of this information, to bring stability to the chaos of all the data, and to turn this into actionable insights for industry, to identify relationships and enable visibility within the supply chain, and finally enhance decision-making.

The amount of workload required by AI is reduced by orders of magnitude. Given the enormous quantity of data at hand after a business has grown beyond a certain threshold, it's simply no

longer possible for the human mind to account for everything, thus AI seems to have gone from being nice-to-have to being a requirement.

It brings visibility into all elements of the supply chain by providing a more comprehensive perspective and by weeding out deeply embedded inefficiencies and uncertainties, with an accuracy and methodology that humans simply can't match on such a large scale.

Let’s now take a look at how artificial intelligence can be employed in the various steps of a supply chain. We will consider procurement, production, planning, logistics and distribution, sales and inventory management.

In the initial sourcing phase, AI could be helpful in dynamically selecting the best suppliers, by taking into account all possible variables, constraints and risk, and in the most suitable number according to the industry competitiveness and the expected product demand. Moreover, it would be essential to realize a full data integration with suppliers: an assured real-time information sharing would contribute to making the entire chain transparent and identifying possible issues in advance. Finally, AI could be useful to first forecast raw material prices trend and, according to that, understand what the optimal amount is to buy.

Moving to production, AI-based solutions could range from performing predictive maintenance on manufacturing machinery to optimize production in order to decrease costs, while increasing quality and output. In this regard, it is important to stress the importance of investing in R&D. At this stage, AI could be also used to assist the crucial make-or-buy decision, so that the company is always aware of which is the most convenient solution. In general, it is necessary to enhance manufacturing effectiveness and efficiency, productivity and quality of the offer.

Once the parameters of supply and production have been set, process planning is necessary. Here artificial intelligence comes into play providing end-to-end transparency and through dynamic planning optimization: it is of utmost importance to make sure that plans get executed and can adapt to unforeseen situations (such as demand shocks, shortages impact, transportation disruption, shutdowns…) in a timely manner.

Afterwards, AI could benefit logistics and distribution through the dynamic optimization of routing, the enhancement of the complex traced transport paths and the reduction of idle times, by taking into account logistics costs and environmental impact. For example, it could advise to share with another company a certain means of transport (for example, a ship or a train) in order to divide the costs or to opt for the automation of the physical flow of products.

Let’s consider as an example the design of a distribution network.

In order to satisfy future expansion expectations, a company needs to establish a new supply chain strategy. The current distribution network, like that of many other corporations,

is extensive and global, and traditional technologies, such as Excel-based scenario planning, reveal to be insufficient to reflect the complexity: they only allow to reach local cost optima, missing synergies that may instead result in further cost savings.

The company would be able to build the perfect supply chain network by incorporating AI-assisted simulation software into the strategy creation process. All essential internal and external aspects, including the location of each plant and warehouse, the evolving regional demands, the several methods of transportation, and local environmental and regulatory laws, might be taken into account. In this way, for the company it would be possible to save money while simultaneously meeting future development plans.

Artificial intelligence could bring added value in the final sales phase by providing more accurate price and demand forecasts across multiple product segments and geographies, by helping in promotion (for example defining the best price, analyzing demography, recognizing target customers, creating the right message…), all in all going to improve customer relationship management.

Ultimately, AI finds many applications in real-time inventory management, thanks to the use of modern visual pattern object detection/recognition methods, IoT and connectivity: it helps to maximize the usage of stocks and to understand when it's best to refill raw material stocks used in manufacturing operations.

Let's take as an example the warehouse management field. Businesses spend roughly 6,500 hours per year on average handling paperwork, updating purchase orders, and dealing with supplier requests. These are activities that should now be delegated to automated tools: AI can do the heavy lifting, by handling massive amounts of data and giving deep analysis on thousands of stock keeping units (SKUs). This allows for extremely precise inventory, supply, and demand forecasts. Supply chain planning and decision-making are more rapid and efficient than ever before when AI and machine learning are combined. As a result, supply and demand are more balanced, and product delivery is faster, all with minimal human intervention.

Integrating AI into supply chains will have a higher economic impact and influence a wider number of enterprises than most other AI uses. According to McKinsey, as we can see from the figure below, AI in supply chains is expected to generate almost $1.3 trillion in economic value. Many companies, such as Amazon, are already deploying machine learning-powered robots to increase the efficiency of their factories and warehouses. However, AI will have an impact on various other parts of supply chains.

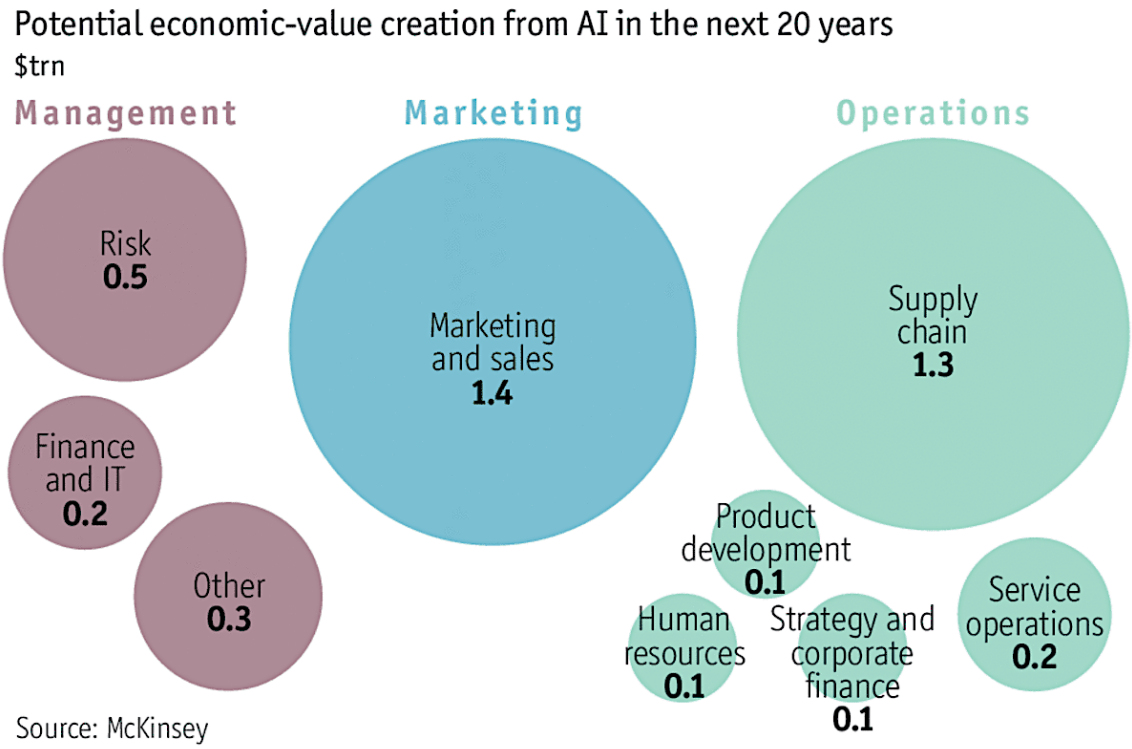

Figure 4: Potential economic-value creation from AI in the next 20 years in $trn, McKinsey

AI has a broad range of possible applications across industries and functions. Traditional analytic techniques, including tree-based ensemble learning, classifiers, clustering, regression analysis, and other types of statistical inference, have the largest range of applicability. The employment of neural network-based approaches, which we associate with the latest generation of AI, is not yet common, in part due to the technology's relative immaturity and the organizational obstacles of implementing these techniques. However, we can see that, among the several business activities, these techniques, particularly feed forward neural networks, may already be found, even if still to a small extent, in supply-chain management and manufacturing. [xv]

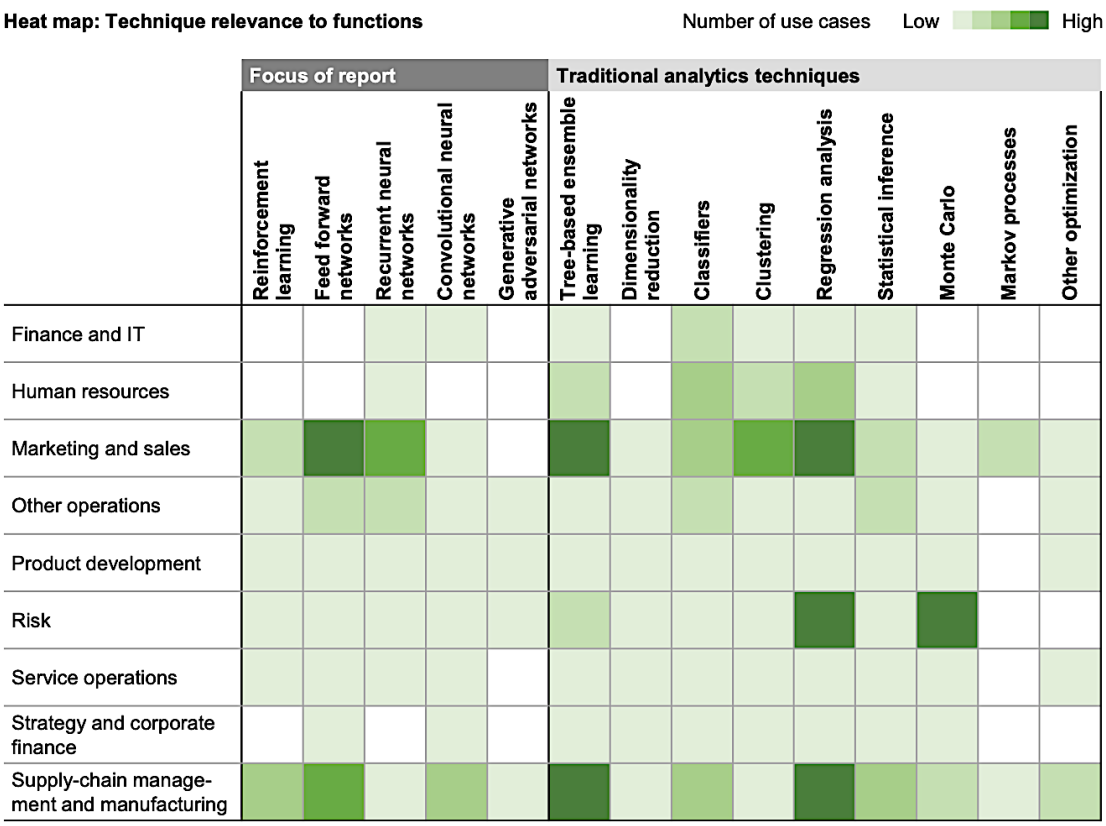

Figure 5: AI-technique relevance to function mapping, McKinsey Global Institute analysis

3.4 Benefits

Most of the platforms currently used by supply chain companies were designed before to the advent of AI, and as a result, they are unprepared for the demands of today's supply chain sectors. According to some studies, AI and machine learning can provide unparalleled value to supply chain and logistics management. Areas such as planning and scheduling, forecasting, expenditures monitoring, distribution route optimization are among the ones where the discussed solutions could bring the highest impact.

Newer platforms have been developed that are capable of handling data acquisition, storage, analysis, interpretation, and visualization. Rather than waiting for legacy vendors to integrate machine learning algorithms into their systems, supply chain organizations should invest in these tools right away.

They will result in substantial production cost savings, more capable and effective workforce, mitigated risk, improved supply chain forecasting, faster deliveries via more optimized routes, and improved customer service. This new approach to work will create interconnected value chains that will demand all involved parties to interact and integrate.

Let's now analyze the main benefits that organizations can derive from agile AI strategies.

Decreased operational costs, better quality and increased revenues

Generally, it is indeed tough for a human to detect where inefficiencies arise in supply chain operations. IoT-enabled physical sensors now provide a crucial source of data, valuable for monitoring and manipulating supply chain processes. With billions of these devices, manually evaluating this deluge of information can waste a lot of operational resources and cause production cycles to be delayed.

By taking advantage of AI tools, that are actively analyzing data and revealing trends, operations teams may cut the amount of time needed to derive valuable information and boost operational efficiency. Analysts can then use the data obtained in this way to spot possible opportunities for improvement, anticipate demand and inventory levels, plan maintenance and shutdown operations, and forecast future potential equipment failures.

Intelligent automated systems can work without errors for longer periods of time, minimizing the number of errors and workplace accidents, thus yielding a higher productivity rate.

AI enables organizations to achieve nearly perfect forecasts, allowing them to improve sourcing, reduce waste, thus becoming more sustainable, and finally decrease the overall costs of production.

It also helps identify target customers, improve customer experience, optimize R&D, and anticipate maintenance downtime in production, all of which contribute to higher quality.

Immense value is realized also in price planning: the evolution of the price usually depends on on-demand trends, product lifecycles, and stacking-the-product against the competition. The proper analysis of all these data at once allows to establish the best price, avoiding the risk of fixing one that is too low, that would not allow to maximize revenues, or excessively high, that would lead to the loss of customers in favor of competitors.

Accurate inventory and warehouse management

AI-based technologies could be exploited to improve inventory management thanks to their ability to handle large amounts of data. These intelligent algorithms can swiftly scan and understand large datasets, revealing new consumer habits and offering timely supply and demand forecasting, including seasonal projections, while reducing the costs of overstocking undesired products and the risk of lack of supply of a requested product.

When supply and demand are anticipated with high accuracy, customer needs can be met more quickly, and enterprises could become aware more easily of the eventual decline in sales for a specific product or the market growth for a newly released one.
Maintaining optimal stock levels is one of the most difficult problems experienced by supply chain companies: an accurate inventory management may prevent overstocking (which can result in excessive storage costs), insufficient stock, and unexpected stock-outs.

An effective warehouse is an important aspect of the supply chain, and automation can help with the efficient collection of items from warehouses and their smooth delivery to customers.
In general, numerous inventory-related procedures, such as order processing, picking, and packing, can become extremely time-consuming and error-prone.
AI systems can help with a variety of warehouse concerns, for example by simplifying complicated tasks, accelerating work thus saving time, and drastically lowering the need for, and expense of, warehouse personnel; in fact, they can contribute to reduce reliance on manual labor, rendering the overall process faster, safer, and more intelligent. For example, robots equipped with cameras can distinguish objects and pick them more quickly.
Warehouse robots are faster and more accurate, resulting in higher productivity.

AI-based automated technologies can improve workers' safety and materials integrity, by analyzing stocking parameters and workplace security data and consequently informing manufacturers about any possible risks: for example, they can detect if a particular machinery needs to undergo maintenance.
This enables companies to act swiftly in order to keep warehouses safe and in compliance with existing regulations.

Near real-time data, enhanced end-to-end visibility and intelligent decision-making

Most supply chain professionals strive to build an end-to-end profitable strategy, particularly as globalization, expanded product portfolios, increased complexity, and variable consumer demand become more common. This endeavor is made considerably more difficult by the lack of comprehensive insight into existing product portfolios due to unpredictable events, factory shutdowns, or transportation issues.

With today's complicated supply chains, it's key for manufacturers to achieve full, end-to-end transparency of the whole network with little effort. Many businesses today lack essential actionable information that may be used to drive timely decisions that fulfill expectations with speed and agility. Cognitive automation powered by AI has the ability to filter through vast

quantities of dispersed information to find patterns and evaluate tradeoffs on a far larger scale than conventional systems. Thanks to the availability of real-time data rather than redundant historical information, AI-driven automated platforms can help companies and in particular SCM, to uncover cause and effect relationships, predict and minimize bottlenecks or any kind of unforeseen abnormality, and identify improvement opportunities along with suggesting solutions. All of this would be beneficial towards the streamlining of the entire production plan.

AI-powered supply chain optimization softwares come up with and stress the optimal decisions to be taken. Furthermore, by continuously learning over time, it refines these recommendations depending on conditions and parameters that vary. This has the potential to improve overall supply chain performance.

Another application of artificial intelligence is the analysis of different possible scenarios, which allows for better decision making, predictions, and recommendations. A comprehensive analysis should be evidence-based and include the modeling and testing of all the various scenarios available. The existence of different options makes it possible to have contingency plans that accounts for the possibility of having to quickly rollback and change supply chain aspects.

The quick identification of the best possible scenarios and strategies thanks to near real-time data analysis leads companies to maximize their global value, performance, and profit.

There are numerous ways in which AI may be used to innovate throughout supply chains and bring benefits, some of which we have mentioned previously, and we should expect to see even greater advancements as technology progresses. According to Gartner's 2021 projections about the future of supply chain technology, about 50% of supply chain firms will invest in artificial intelligence and advanced analytics solutions by 2024.[xvi]

Overall, we can say that AI is nowadays essential to enhance an organization competitiveness. It is no longer a "nice-to-have," but rather a requirement to remain competitive. Cost efficiency can be improved in a variety of ways by incorporating these technologies into a company's supply chain. Processing time will be decreased, and more intelligent, faster decision-making will be enabled. AI can provide insight into market dynamics and even weather patterns that could have an impact on the activities, and this data can make an enormous difference in establishing solid customer connections and good industry reputation. It is apparent that artificial intelligence is transforming the way the supply chain sector operates: knowing when,

where, and why bottlenecks arise may transform a company's processes and dramatically boost its profitability.

With the help of AI, we are already seeing results that point to a cleaner and more cost-effective world. More and more companies and supply chain executives, in order to keep up with the ever-changing market, will continue investing in solutions that incorporate, augment, or employ AI and advanced analytics capabilities. And, to avoid wasting time waiting for outdated platforms to catch up with new technology, they will do better to partner with third-party AI vendors.

Businesses that apply scalable and integrated solutions to their processes will be the most successful.

3.5 Steps that each organization should take before adopting AI-based solutions

In order to get the most out of these solutions it is not simply a matter of technology: companies must evaluate whether they are prepared or not to embrace them and, if not, take the necessary steps to allow their implementation and integration.

Since the required initial investments are significant, both in terms of money, people, and time, for them to bear fruit, the companies must take organizational steps and prepare themselves to capture the full value coming from AI.

Identifying AI deployment opportunities is dependent on a variety of characteristics that are unique to various industries and, within those industries, to different types of enterprises. Given the huge range of possible applications, the best way to figure out where AI can add the greatest value is to follow the money. New solutions must be carefully selected, designed, and tailored to specific business needs. They must also be in line with the company's strategy.

When it comes to the adoption of new AI technologies, organizations invest significant amounts of money in R&D to identify the finest AI solutions for their business operations: companies should not invest in AI solutions blindly, but rather examine exactly what will benefit them the most in the long run. They must also consider the ethical problems linked to data collection and analysis that AI may pose to the firm.

3.6 Examples

Suppliers' evaluation, selection and monitoring

Having a clear picture about what's going on throughout the supply chain helps to make better, more educated decisions.

The complete visibility of an n-tier supply chain is more crucial and at the same time more difficult to attain than it has ever been before. Production factories used to have an eye on the whole production process until some decades ago. If one machine failed, it was quickly identified and corrected. However, then we have began to heavily outsource and nowadays that direct visibility no longer exists.

Supply chains are vast, linked webs of activity in which getting an accurate view beyond the second tier of providers is difficult.

One of the lessons that the pandemic has taught us is that gaining visibility into a company's whole supplier base is essential for understanding how good each of its suppliers is doing and identifying potential threats on time.

The pharmaceutical sector, for example, has been under the global attention for a little while now. There has been a huge demand for vaccines that has caused their shortages in many regions.

Due to timing and warehousing concerns, some governments have had to pause vaccine administration, extend the injection times, and in some cases, throw out entire batches. Bringing together important suppliers and developing proper contingency plans could have been done ahead of time.

Businesses even in many other industries as well had visibility only over a few large suppliers, so they often had no idea which ones were shut down or where exactly their orders were processed. The worldwide nature and intricacy of most supply bases made it particularly difficult.

However, if a corporation lacks access to critical information, it doesn't take a pandemic-sized shock to throw a usually functioning supply chain off, but even a minor issue would be enough. A missed shipment of raw material from a single upstream supplier, for example, can be multiplied across the supply chain, potentially producing substantial problems further downstream till the end consumer.

Now that we have data and technology to handle them, it's time to take action. Companies may collect data from their whole supply chains, combine it on the cloud, and apply sophisticated AI models to it to get a real-time overview of their suppliers' status. Companies

can use this information to spot possible suppliers-caused danger and to anticipate how it could affect the supply chain. Scenario modeling can then assist a company in identifying the best alternatives so that it is prepared in the event of a disruption.

Supplier scorecards represent one of the most effective strategies to manage suppliers strategically.

They make it possible to rank and group suppliers based on several variables such as past performance and sustainability, and finally obtain the best strategic combination.

However, since the data flow is massive and continuous, every time bringing new information (new laws and regulations, new industry entrants, different competitive landscape…), to implement an exhaustive and effective supplier scorecard is incredibly time-consuming and often nearly impossible.

Luckily, these suppliers' data can be continuously collected, evaluated, and updated thanks to modern machine learning algorithms, allowing you to change your supplier strategy on the go because you always have access to up-to-date and reliable suppliers' information.

AI algorithms can simulate a supply network all the way down to the nth-tier, allowing you to anticipate interruptions and make real-time smart adjustments to increase value and performance improvements.

This means you won't be caught off guard if a second- or third-tier supplier faces any kind of disruption.

Thanks to these tools, organizations can also enhance their corporate social responsibility mission by ensuring that suppliers' carbon footprints are within established limits and that suppliers source and produce commodities in a sustainable manner.

Continuously improve internal processes through predictive and prescriptive analysis

Artificial intelligence is very often exploited to enrich the quantity of data available, for example by performing predictive and prescriptive analytics.

Predictive analytics, currently the more popular among the two, consists in collecting past data and examining historical performance to develop predictions of what will be the most likely outcome in the future. It can be used to estimate whether or not a cargo will arrive on time even before you place an order.

It should always be followed by prescriptive analytics, that instead uses the previously obtained predictive data as input and combines them with advanced AI, to deliver some valuable recommendations to solve issues, everything within the scope of clear and preestablished boundaries and business regulations.

For example, if you now know that a particular provider is expected to be late or that there is congestion in a particular port or road, the system will provide you with many options that fit your schedule, objectives, and quality requirements. Or again, if an increase in the price of a raw material is anticipated, the system suggests you to buy a call option[1] in order to have access to that material in the future without being hit by inflation.

Route efficiency and delivery logistics optimization

Customers today expect fast, reliable delivery, and they're more than eager to switch company if one fails to satisfy them.

Delivery logistics is a challenging and critical field: for example, there are roughly 15 septillion different ways to transport 25 products by van.

Using real-time forecasts and behavioral coaching, AI- and GPS-based solutions can cut costs and improve distribution efficiency. AI systems can optimize the itinerary of distribution, improving fuel consumption and lowering related costs, and shortening delivery times, both according to traffic and by analyzing the myriad of route options (an unsolvable puzzle with only traditional methods) and selecting the most efficient ones. Additionally, via sensors that monitor vehicle location, vehicle performance, and driver behavior, drivers could receive real-time coaching, including when to accelerate or decrease speed based on the duration of the red traffic light, to minimize vehicle stop time, which can be costly from a fuel consumption standpoint. This optimizes fuel usage and lowers maintenance costs.

Furthermore, transporting goods around the world is getting more and more costly. AI could be used for example to negotiate better shipping and procurement terms and choose the best transport contracts.

Timely maintenance

Data from IoT devices may offer significant insights on the health status and runtime of the costly equipment required to keep products moving across supply chains: starting from these information, AI systems could be trained to make maintenance recommendations and predict likely failures for a broad variety of means of transportation and shipping containers, including

[1] An option contract is a right (not an obligation) to make a transaction. A call option gives its owner the right to buy an asset (the underlying asset, in our example the needed raw material) at a predetermined price on or before a specified (maturity) date.

trucks, trains, ships, and planes. This enables businesses to remove vehicles from the chain before performance concerns cause cumulative delays.

Autonomous trucks

Among the various innovations in the supply chain field that technology can enable, there is for sure the deployment of AI-powered, autonomous vehicles. They do have the potential to solve a key global challenge in supply chains: driver shortages, issue exacerbated by the strict in force restrictions that limit drivers to work no longer than 11 hours per day and take at least an 8-hour long break. Taking all of this into account, a driverless truck, that in principle could operate ceaselessly, would be an unparalleled benefit to the industry and would allow global supply chains to gain back efficiency, effectively boosting the quantity of goods transported and bringing down costs as well as carbon emissions significantly.

However, it is to be stressed that, in the foreseeable future, despite the deployment of autonomous trucks, actual drivers will still be required to carry out certain assistance tasks.

Another interesting topic is that automated vehicles could have a positive impact in attracting new categories of drivers, such as younger and female ones, because of the increased employment of technology and therefore the introduction of a fresh and appealing factor.

Digital twins

To overcome supply-chain disruptions and in particular to forecasts events along the path and enhance visibility, several businesses, in addition to what we have so far discussed, are turning to digital twins: on one side, these technologies identify vulnerabilities and anticipate possible disruptions across the network before they happen; on the other, they provide recommendation on how to address them and to improve resilience.

A digital twin is a virtual replica or an online version of an existing supply chain, mirroring all its resources (assets, collaborators, products…), ports, hubs and warehouses, and highlighting any kind of flow and process taking place within it, that can be used to simulate supply chain system functioning in a computer, evaluate its performance, and to measure any plausible loss and risks. Digital twins have to be fed with as much real-time data as possible, concerning suppliers, logistics, consumers (taken from social media for example), geopolitical situation, socioeconomic trends… so as to best learn to react to unforeseen events, even global pandemics.

Theoretically, this technology could be beneficial to every company, be it of any size, but in reality, since required initial investments are substantial, only mature and large organizations, such as Amazon and Google, are adopting them, because they can afford to incur

some loss, and the result is a growing digital divide between firms. To shrink this gap and keep the pace, small firms will require some kind of assistance, for instance government investment.

Thanks to digital twins, companies can explore different possible scenarios, evaluate in each one of them the level of efficiency and resiliency, and finally choose the framework that fits best the organization goals and market expectations. In fact, if we apply reinforcement learning on these virtual replicas, the system would learn through trial which are the strategies to be adopted in different what-if situations.

One use case of digital twins is to perform stress tests on the supply chain to assess its resiliency: they're used to examine the operational and financial implications of severe market disruptions, natural catastrophes, and other extreme occurrences. These tests could help firms identify network flaws, quantify their impact on the whole system, understand whether a new allocation of resources is necessary, assess the overall carbon footprint in order to guarantee that it meets sustainability goals...

4. Digital readiness of organizations to implement AI

The purpose of artificial intelligence is to transform raw data into information, this one into awareness, clarity and valuable insights, and finally these latter into competitive advantage.

Taking on an AI-driven supply chain transformation is a challenging task, and firms should be entirely aware of the difficulties. Nevertheless, the prospective improvements coming from AI-based solutions to supply chain turmoil are evident and substantial.

Artificial intelligence in SCM enables businesses to adapt to the evolving customers' requirements as well as the problems posed by global trends. Forecasting demand and planning production, for example, has become considerably more difficult as variety of products and components has increased. Furthermore, changing demographics has so far restricted labor supply, demanding for much higher salaries and more appealing job profiles. Future supply chains have to become increasingly resilient, agile and sustainable in order to meet these problems. Another example is the growing awareness of sustainable development, which necessitates considering additional data and factors while optimizing processes.

The client will be focus of attention of AI-powered supply chains. Advanced demand forecasting and decision-making support will boost operational flexibility, enhancing the customer experience and earnings.

Simultaneously, future supply chain management will consider the full supply chain, from n-tier providers to aftersales services, and this broad view will enable them to merge data from procurement, distribution, production scheduling, and other functions. Surplus buffer inventories, obsolete equipment, and hurried shipments will all be minimized thanks to end-to-end control. Simulations will aid in the holistic design of networks and processes to better allocate resources like assets and energy usage. Automation will allow to employ the workforce for more value-adding activities, rather than waste it for repetitive operations.

Companies will be able to obtain considerably higher transparency and better decision making by integrating AI and advanced analytics to available data, and they will be able to improve efficiency as well as enhance sales and profitability. They could see both an increase in revenue and a decrease in costs (the biggest savings will be provided by reduced need for labor force in warehouses, inventory reductions, and reduced transportation costs).

AI has the potential to provide enormous value, but this value differs significantly among sectors, based on the exact use cases, the availability of large amounts of

structured data, legislative constraints, and other restrictions. To evaluate the chances to produce value enabled by AI, each organization should examine the specifics of its business.

It's no surprise, then, that the supply chain industry is further and further adopting AI-based technology. According to MarketsandMarkets, AI value in the supply chain market is predicted to increase from 730.6 million $ in 2018 to 10,110.2 million $ by 2025, at a CAGR[2] of 45.55% between the two mentioned years. [xvii]

Availability of data, quicker but also less expensive machinery, open-source platforms, and ready-to-use AI solutions particularly created to tackle business challenges have all evolved in recent years, propelling AI adoption.

The arrival of AI-powered supply chain solutions couldn't have come at a better moment, with supply chains still dealing with the consequences of pandemic-related limitations. However, AI is still located in the first part of Gartner's Hype Cycle for supply chain strategy in 2021, the so-called Innovation Trigger, which means it could take another decade before the technology matures. [xviii]

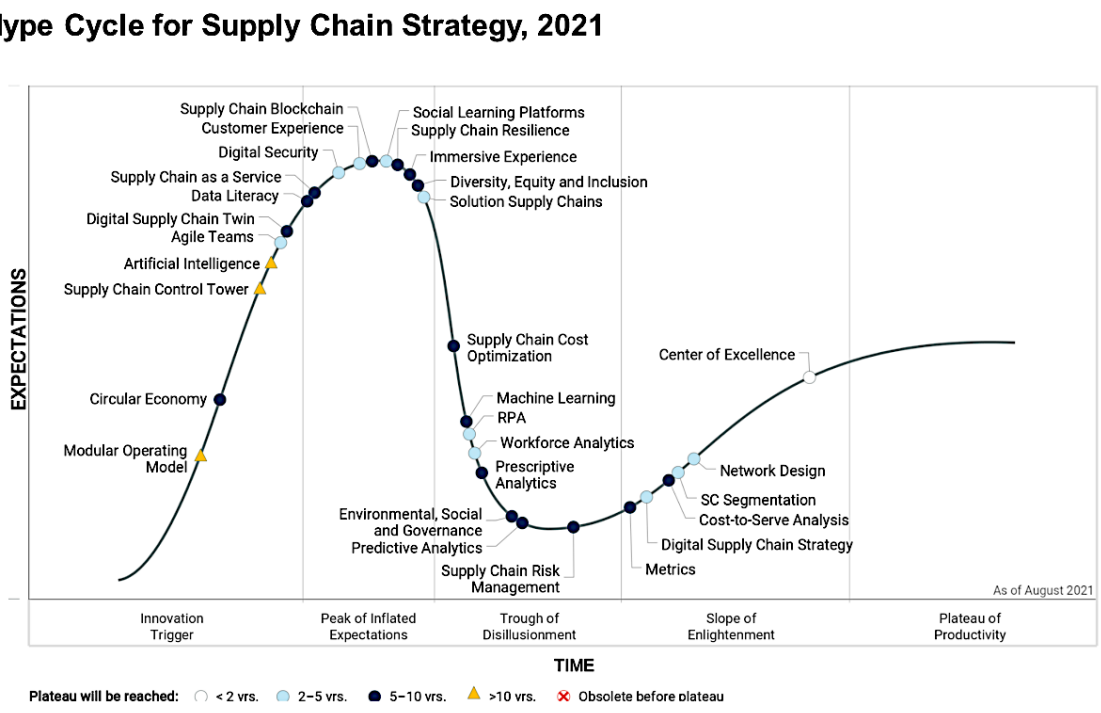

Figure 6: Hype Cycle for Supply Chain Strategy, 2021; Gartner, August 2021

[2] The compound annual growth rate (CAGR) is the annualized average rate of revenue growth between two given years, assuming growth takes place at an exponentially compounded rate. The CAGR between given years X and Z, where Z - X = N, is the number of years between the two given years, is calculated as follows:
CAGR, year X to year Z = [(value in year Z/value in year X) ^ (1/N)-1]
(Source: https://www.gartner.com/en/information-technology/glossary/cagr-compound-annual-growth-rate)

4.1 What is a Gartner Hype Cycle?

A Gartner Hype Cycle is a graphical depiction of the maturity and diffusion of technologies and systems, and also of how likely they are to help businesses solving real-world and seizing new opportunities. It provides a picture of how a tool will change over time, allowing you to best manage its implementation in the framework of your business-specific objectives.

Gartner produces every year several Hype Cycles in various fields to help clients track technology development and potential value. In these representations, a technology's life cycle is divided into five stages: these are the Innovation or Technology Trigger, the Peak of Inflated Expectations, the Trough of Disillusionment, the Slope of Enlightenment, and the Plateau of Productivity. [xix]

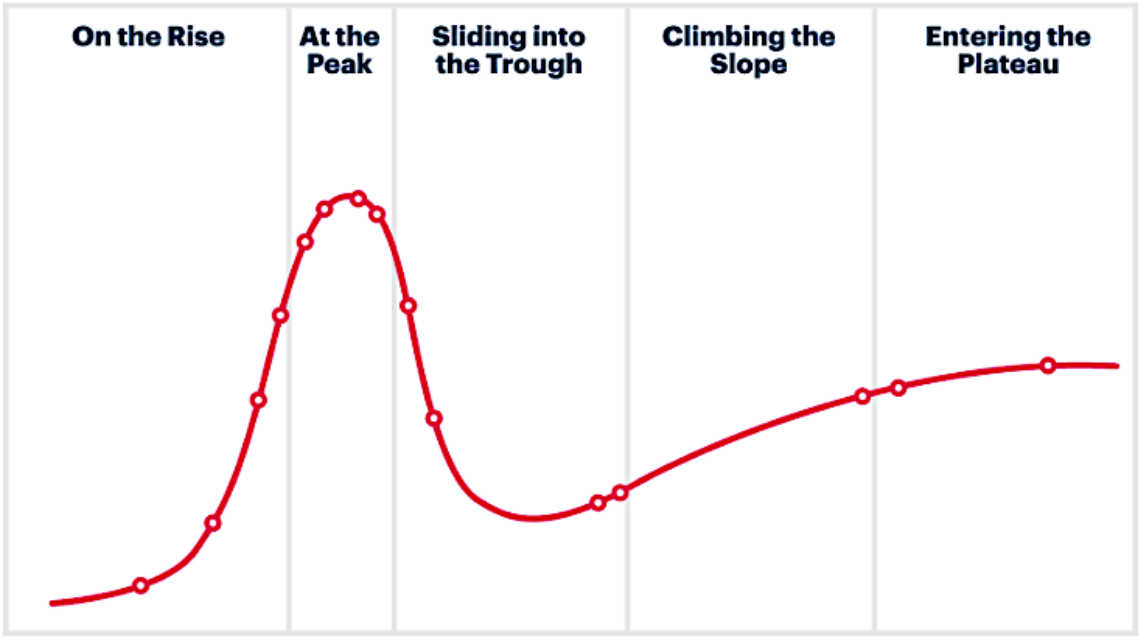

Figure 7: Gartner's general Hype Cycle five phases

Innovation or Technology Trigger: in this part of the cycle, you can find all tools on the rise, currently leading a technology breakthrough that is arousing interest among media and making people talk. Often there are still no usable products, and its commercial profitability is not yet demonstrated.

Peak of Inflated Expectations: the large amount of initial advertising leads various companies to adopt the new technology, so at this stage its use increases despite the fact that there is still no proof about the benefits that it can bring.

Trough of Disillusionment: here, the initial enthusiasm begins to fade as a consequence of results below the expectations experienced by the early adopters. The technology providers either invest and try to improve the product or fail.

Slope of Enlightenment: in this phase the early adopters begin to see some good results; new possible uses of the technology to the benefit of the company come out and its surviving suppliers have produced second or even third generation products.

Plateau of Productivity: here, the benefits brought by the adoption of the technology are clear and tested and the majority is now using it to remain competitive.

4.2 AI in the Gartner's 2021 Hype Cycle for Supply Chain Strategy

Let's now focus on the Hype Cycle shown in Figure 6, which is useful to our analysis.

To understand how active the supply chain sector innovation is currently, we have to take a quick glance at the Peak of Inflated Expectations stage, which seems to present a cluster of new tools such as blockchain, and immersive experience and new frameworks like Diversity-Equity-Inclusion, promising to have a big impact to supply chains. Many of them, though, have yet to develop and prove that they have lasting power. As a result, supply chain managers should consider testing those capabilities in small or secondary projects to better understand not only their potential but also the problems they would face in their implementation.

At present, AI has been located in the Innovation Trigger stage of maturity, meaning that it could take another decade before the technology matures. AI is already transforming the manufacturing environment and revolutionizing supply management, but since machine learning is still at its beginnings and AI will not disappear for a long time, companies that haven't started their digital transformation should not be too alarmed. This does not imply they should wait for AI technologies to completely develop before investigating their utility, but instead they should begin preparing a clear implementation plan now.

CEOs and supply chain directors see AI as a game-changing technology for their companies. Supply chain firms should actively try to grasp the potential transformation benefits and applicability of AI through small-scale projects. They should avoid experimenting it for huge projects requiring huge expenditures and investments. They must first assess organizational readiness, data and skills availability, and the areas where AI could bring the best support.

AI enables exceptional efficiency through big data analysis and recommendations to improve performance; it is pushing supply chains for a more sustainable and cost-effective future. But

to reach this, it is crucial to understand how AI is currently exploited and how to enhance its implementation AI to improve supply chain processes. In fact, despite the apparent benefits of using AI in SCM and the majority of managers believing that AI will help them make better decisions, many are the registered failures experienced by organizations adopting present AI solutions. Missing or insufficient data, not enough attention paid to the potential business effect, not well prepared or overburdened IT departments are all common causes of misfunctioning.

4.3 Preparation to integrate AI in the operations of a company

The advantages coming from advanced analytics are a result of competitive and market dynamics, as well as numerous actions and choices made by firms and individuals, including business model decisions. For example, technology developers and policymakers determine the broader framework, and customers make purchasing decisions. Some of the deriving value will reveal in various ways (e.g., more popular products and services, increased revenue, cost reductions, or even consumer surplus...) and maybe it won't show up in the aggregate numbers reached by the company, but in the gains coming from specific applications.

Companies should use AI tools extensively in areas where they can best use their abilities to turn data complexity into a competitive advantage. The public sector represents a precious source of data, both from a volume and a variety standpoint. However, in developed economies, legislation and standards for data privacy and interpretability pose substantial barriers to its utilization, limiting the value potential.

Executives and leaders should try to make sense of where the biggest potential possibilities are. This will assist them in setting goals and identifying areas where AI can be beneficial.

AI is expensive to set up, and if a company is not ready to integrate it into its operations, it may not fully enjoy the potential benefits and suffer losses.

Companies should first identify and give priority to all areas of value creation across functions, from sourcing of raw materials and logistics, to commercial. Only few businesses do a proper diagnostic from the start, yet this activity may ensure that businesses have a complete list of all value-creation prospects.

Determining a clear digital supply-chain strategy enables a better alignment with the company's business plan. Furthermore, an evaluation independent of the solution allows businesses to identify the needed process redesign, organizational restructuring, and competencies to improve performance and develop a strategic road map.

Every firm should undertake a self-awareness test before committing and investing huge sums of money, and not only, in new technologies and AI implementation. Make key internal stakeholders meet to discuss about the proposed implementation's targets and ambitions and to quantify expectations for the short and long term. Then you should compare these potential achievements to the estimated implementation costs, which include technology acquisition costs, consequences on temporary production disruption, and staff training labor costs. At this point, creating new KPIs, linked to organization's typical strategic objectives, to track the impact of AI in supply chain management can be beneficial.

Once the company has set the expected ROI, assessed the potential implications of digital transformation and estimated the related costs, the next step is to decide about the project timeline. It is always necessary to keep in mind that investments hardly ever pay off immediately. The advantages are progressive, and the firm would probably have to make some short-term compromises to reap large long-term rewards.

4.4 Building a proper data foundation

After this analysis, the proper data foundation must be built in order to prepare the business for digital transformation. Data is the fuel for AI and huge amounts of them are needed to maximize AI-based returns. Most corporate leaders are aware of this, and many believe they don't have enough of them to justify an AI investment. This is a typical misunderstanding. There is usually an amount of data generated, saved, and forgotten within most businesses. The problem for many businesses is not gathering new data, but rather locating, integrating, and evaluating current data. Your company most likely has more data than you realize. Stakeholders that argue there isn't enough data, that it isn't clean, or that they don't know which data is relevant are making a common mistake. They imagine scarcity when the real issue is availability, since information is siloed and thus not beneficial. Therefore, before using AI in supply chain management, companies may need to invest time and resources to break down these data silos.

But let's first see some terminology linked to big data.

Big Data properties

Volume, velocity, variety and veracity is the most common set of properties used to evaluate data.

- Volume

Big data applications are characterized by extremely large amounts of data (terabytes, petabytes, or even more). Nowadays, we are experiencing a dramatic increase in this volume, often dictated by the increase in the number of sources that produce the data.

The amount of data produced often defeats the processing power of standard database technologies: to handle the volume of big data, centralized database architectures often need to be replaced by distributed ones.

- Velocity

Data velocity refers to the rate at which data is collected and it is increasing at an unprecedented pace.

Data sources, particularly in the business sector, are extremely dynamic, producing new data at an extremely rapid rate. Also, mobile devices and IoT sensor produce data continuously.

For example, each hour Walmart collects from 1 million customers around 2.5 petabytes of unstructured data.

To deal with data velocity, we often try to process data as soon as it is available, on the fly. Such techniques are particularly useful when data is too large to be stored, so the usual procedure is to process and discard them.

- Variety

Data is extremely heterogeneous, meaning that the format of the data and the logical design of the information may be different. We might want to combine text from social networks with data coming from sensors or XML files, for example.

The data we need to handle may be more or less structured, depending on their source. Dealing with unstructured data presents the difficulty of extracting useful insight from data that may be represented in a variety of ways, such as words or images.

An important challenge in this context is entity resolution, where we try to understand whether two or more pieces of information talk about the same individual (entity).

Consolidating data is a long-standing challenge in data management.

- Veracity

Data carrying no meaning have no value. In data management, we often refer to this property of data as quality or veracity, to use another word starting by V. It is the property of data to be faithful to the reality of interest and therefore to carry value.

Quality of data could be measured through some techniques, such as the evaluation of information consistency, accuracy, completeness and upgrade level with respect to the real world, that can be used also in the big data setting.

Big data create challenges, but they also provide large opportunities.

Using AI systems, particularly neural networks, effectively necessitates big, labeled training data sets as well as adequate computing infrastructure. Traditional approaches' performance tends to flatten as the training data set size grows larger; however, the performance of advanced AI systems that use properly designed and trained deep neural networks tends to improve. Deep learning techniques are also very effective at extracting patterns from complicated, multi-dimensional data types like pictures, video and sound. The information will have to be gathered in a method that addresses privacy concerns.

Deep learning algorithms require thousands of data records to become somewhat good at categorization tasks, and millions in some situations to perform at human levels: unless a certain volume of data is reached, AI may not be able to add value to traditional analytics methodologies.

For many organizational use cases, these enormous data sets can be difficult to access or develop, and categorization remains an issue. For example, teaching an autonomous vehicle to manage deal with urban traffic necessitates massive image data sets in which all relevant items (every possible vehicle or pedestrian, road signs...) are labeled in all weather and lighting scenarios. The majority of current AI models are developed using "supervised learning," which necessitates humans labeling and categorizing the underlying data. However, interesting new techniques, such as reinforcement learning, are emerging to overcome these data limitations.

Organizations must create and implement techniques that allow them to obtain, integrate, and process information at a large scale. With such large datasets, they must avoid both "overfitting," which occurs when a model is too closely matched to the "noisy" and random features of the training data set, resulting in a loss of precision in future performance on unseen data, and "underfitting," happening when the model fails to capture all relevant features. In order not to leave distinct types of data separated, it's critical to perform every possible linkage between consumer groups and channels and production data, being careful to the regulatory risks of exchanging data across several business areas.

Continuous data collection and model updates, at least monthly and perhaps daily, are required for training AI systems continuously. Along with challenges regarding data volume

and variety, also velocity is a requirement: AI techniques demand models to be retrained to fit possibly changing conditions, which necessitates frequent data refreshment.

4.5 Dealing with other limitations

Artificial intelligence is drawing increasing amounts of business investment, and the potential value that might be realized is certain to expand as the technologies advance. Only a few forward-thinking companies have implemented AI at scale so far.

While AI technologies are promising, they are not immune to limitations and problems, which include not only the already mentioned data-related issues but also legislative barriers, as well as social and user approval. However, the potential value that might be realized gives a strong motivation for technology developers, businesses, policymakers, and individuals to try to fix these issues.

As previously said, the volume, type, and categorization of data are all aspects that could limit AI's use.

Second, among other requirements, authorities frequently require intelligible regulations and selection criteria. However, most of the times complex AI models are difficult to explain in human terms: how did we come to make a certain decision?

Another issue concerns the generalization of the results, since very often it is difficult to transfer AI models from one set of circumstances to another. That means businesses must devote resources to training new models, even if the use cases are similar to prior ones. One intriguing approach to this issue is transfer learning, in which an AI model is educated to perform a specific task and then swiftly applies that learning to a comparable but unique activity.

Given the value of data, it is critical for businesses to adopt methods for creating and/or acquiring training data. However, implementing AI effectively also necessitates addressing other challenges, such as establishing effective data governance, defining conceptual frameworks, managing models and regulatory constraints over time...

In order to meet society's concerns, businesses and other consumers of data for AI will need to continue to improve economic models tied to data use. Furthermore, legal requirements and limitations vary by country and industry. For example, automated decision-making algorithms in the European Union will be shaped by the EU-wide general data protection regulation, which came into force in 2018, and provides for a right to an explanation for some machine decisions.

Organizational issues with technology, procedures, and people can delay or obstruct AI deployment.

Organizations that want to implement large deep learning efforts should think about a variety of possibilities. Building a complete in-house AI capability, either gradually or more quickly via acquisitions, outsourcing, or adopting AI-as-a-service solutions are among the choices.

Some firms will keep their own data centers because of legislation or security concerns, but the operating expenses could be large, particularly when using specific hardwares, given the significant processing requirements of deep learning. Another approach is to use cloud vendors.

On the human side, much of the creation and optimization of deep neural networks is still an art, necessitating actual specialists to make significant performance improvements. At the moment, demand for these abilities significantly outnumbers supply. Companies interested in developing their own AI solutions should assess if they can attract and maintain these specialist capabilities.

Organizations can already explore the potential when AI techniques and data are accessible, and the value is clearly demonstrated. However, while the techniques and data are mature in some areas, the cost and risk of adopting AI may not be worth it considering the value that may be delivered. For example, it could happen that the expense and privacy concerns may outweigh the benefits.

In the most uncertain case, the data, both in terms of variety and volume, or the procedures, are simply too new and unpredictable to the market to tell how much value they can unleash.

4.6 What can policymakers do?

Even more after the disruptive impact that COVID-19 had on the global economy, countries should prioritize their digital infrastructure and supply chain investments. A good example is the digitization of ports and borders management. Port handling and procedures can be sped up with automation and AI systems, that can be used for example to process pre-arrival data and to optimize port calls.

AI is also posing new challenges for policymakers to consider: they will have to find a balance between promoting AI technology development and managing any risks posed by the misuse of AI techniques and the data they use. Certain policy improvements will almost certainly be required to keep up with these constantly changing technology. Given the magnitude of the positive influence on business, the economy, and society, the goal should not

be to limit AI adoption and application, but rather to encourage its beneficial and safe application: it's in policymakers' interest to see AI become more widely used because it can lead to increased productivity levels, economic expansion, and overall prosperity. Public investments in research and development, as well as funding for a variety of training programs, can aid in the development of AI expertise. Furthermore, governments can directly stimulate the creation of training data through open data programs: data from the public sector can help the private sector innovate. Establishing consistent data standards can also be beneficial.

4.7 Investing in change management and skills building

Supply-chain management has never been such an arduous function, but efforts and remedies are possible to simplify it. AI will be able to provide employees with more accurate and frequent insights than ever before.

Even when focusing on technology solutions, firms must pay attention to critical supporting components such as organization, change management, and capability building to solve skills gaps. In fact, each significant investment in technology must be accompanied by organizational reforms, business process upgrades, and upskilling efforts. Only then will businesses realize the desired return on investment.

In order to reap the full benefits of the incurred investments in IT assets, employees will have to adapt to new methods of working, and a concerted effort will be needed to educate the personnel on why the changes are important. Of course, also incentives to encourage the desired behaviors should be designed and put in place.

The involved staff must have a fundamental understanding of optimization techniques, statistical and machine learning tools, to make AI-based planning a success. Without this information, people may be suspicious of the value that new data-driven solutions can provide and not commit to the maximum of their abilities.

To work on cultural change and help the organization convey an AI-centric mindset to its workforce, companies should take the following measures to address these concerns. First of all, the HR department should be consulted, in order to gain a comprehensive picture of the personnel composition and to understand who is going to experience the impact of the technological transition. There's a strong chance that the company will need to hire people to fill new positions in your company, so you'll need a strategy for finding and hiring them. As regards internal staff, the firm should invest time and money to create and run training programs and pilot projects that cover the fundamentals of AI and related subjects and that explains to

employees how their responsibilities and workflows could be modified. To guarantee that these training programs are successfully conducted, interest and help from all levels, such as the HR department and management, could reveal essential. Moreover, data-driven strategy experts within the organization should be identified, so that they could concentrate on educating their coworkers about the advantages of AI and the significance of additional training.

Conclusions

This thesis has illustrated the concept of global supply chain management and has addressed several issues arising when global supply chains face disruption, be it caused by a natural or a man-made disaster, a pandemic or any kind of geopolitical instability. These problems include sudden plants shutdowns, supply shortages, bottlenecks at borders, lockdowns, delivery delays, labor shortages, obstacles in the logistic network, capacity limits, increase in shipping costs…

Now more than ever, in response to the pandemic of COVID-19 and tensions in Eastern Europe, businesses and stakeholders are focusing more on supply-chain resilience, and technology can play a crucial role in helping them to achieve this ambition.

The broad impression of applying AI in supply chain management is a positive one. AI-based SCM solutions are projected to be effective tools for enterprises to address the discussed issues and to handle both the opportunities and limits in all business segments and departments (procurement, production, sales...). They're built to give meaning and stability to the massive amount of data that flows within and between supply chains, to turn this into actionable insights for industry, to enable visibility within the supply chain, and finally enhance decision-making. While considering implementing AI-based solutions to gain and keep competitive advantage for the SC participating companies, the benefits of the integration should not be considered alone but should be compared to the costs.

The several examples that have been presented highlight how the adoption of AI can contribute to increase the resiliency, reactivity, agility and overall performance of the supply chain, and can positively impact the profitability and ROI of an organization. It could be helpful in dynamically selecting the best suppliers, to first forecast raw material prices trend and, according to that, understand what the optimal amount is to buy, to assist the crucial make-or-buy decision, so that the company is always aware of which is the most convenient solution, to provide end-to-end transparency and perform dynamic planning optimization, to dynamically optimize routing by taking into account logistics costs and environmental impact, to maximize the usage of stocks and to understand when it’s best to refill raw material stocks used in manufacturing operations.

Apart from the expected success coming from the adoption of AI, the importance of adequately preparing the company for its implementation was also stressed. First of all, companies should be aware of the fact that integrating AI in their operations, as a part of the

digital transformation process, requires a considerable capital investment. Moreover, as we have stated, using AI systems effectively necessitates big, labeled training data sets as well as adequate computing infrastructure: hence, the proper data foundation must be built. Above all, for a successful implementation, companies should identify and set priorities across functions, from sourcing of raw materials and logistics to commercial. Identifying where and how this increasing value can be captured is becoming one of the key business challenges of our era.
In addition, top management is already focusing on training and attracting more professional expertise in this subject.

AI technologies are still in their early stages and many companies are still in the piloting phase. They are already transforming the manufacturing environment and revolutionizing supply management, but since machine learning is still at its beginnings and AI will not disappear for a long time, companies that haven't started their digital transformation yet are still in time for preparing a clear implementation plan, but they should do it now, to keep up with the change of pace.

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