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AI-Driven Supply Chain Resilience for Revitalizing U.S. Defense Manufacturing: Techniques and Applications

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1. Introduction

In today's rapidly changing world, the supply chain has become a competitive differentiator, and an AI-driven supply chain is the next frontier for businesses looking to thrive in a digital world. Today's supply chain challenges — disruptions to supply and demand, higher freight costs, the need for sustainability, and more — require organizations to effectively reimagine their existing supply chain networks, strategies, plans, and operating models to drive business resilience. Generative AI offers a suite of capabilities to reimagine existing approaches to supply chain planning, network design, risk management, inventory optimization, prescriptive analytics, and more.

Artificial Intelligence (AI) offers the chance to get a grip on complex supply chain processes while simultaneously dodging risks. Dozens of corporations have started incorporating AI to control their supply chains, resulting in fewer bottlenecks, more efficient inventory levels, minimized transportation and logistics costs as well as increased customer satisfaction. However, radical structural changes in the supply chain are accompanied by new risks, e.g. related to data privacy, transparency, or overreliance on algorithms [1].

1.1. Background and Significance

With the magnitude of the COVID-19 pandemic and with the rise of China, awareness of the fragility of the U.S. defense supply chain in the face of global impacts has changed from an internal perspective to an external one, with research into revitalizing U.S. defense manufacturing on the rise [2]. With the strengthening of state and market control of technology, the competition for chips, artificial intelligence, and other high technologies has become the focus of the game between China and America. Simultaneously, it has accelerated the outflow of manufacturing capabilities, especially in the weapons and equipment fields, and has posed serious challenges to U.S. military superiority. Artificial intelligence (AI) technologies with cognitive, adaptive, automated, predictive, and collaborative capabilities have started to be introduced into supply chain resilience research, which open opportunities for addressing precious vulnerabilities and enhancing supply chain resilience for recovery [1]. AI is set to have an enormous impact on supply chain management and include a number of applications from planning, procurement, production, distribution, and warehousing to supply chain coordination and control.

1.2. Research Objectives

In the wake of the COVID-19 pandemic, the United States has witnessed the fragility and vulnerability of global supply chains amid various distressing events. Many U.S. industries have suffered both economic and operational losses during the pandemic. Particularly, defense industrial base (DIB) sectors, which are national treasure assets, have been threatened by inactive or even bankrupt distribution channels stemming from supply and logistics disruptions across the globe. Concerned about supply chain resilience, this paper targets and emphasizes methods for revitalizing U.S. defense manufacturing. Using a systematic research method, this paper will explore AI-driven supply chain resilience techniques and applications for DIB sectors. The research objectives include: (i) developing quantifiable approaches for supply chain resilience, (ii) formulating AI-driven approaches for enhancing the resilience of flexible manufacturing industries, (iii) constructing an optimization platform to evaluate resilience performances, (iv) identifying potential AI-driven resilience techniques for revitalizing U.S. defense manufacturing, and (v) investigating a set of case applications on the proposed resilience techniques for defense manufacturing sectors.

To achieve these objectives, a novel methodology is proposed to develop a comprehensive resilience evaluation framework for advanced flexible manufacturing systems in the age of AI. Quantifiable approaches have been developed to evaluate the resilience of manufacturing systems under supply chain uncertainties. Furthermore, a GA-MLP based optimization platform has been constructed to enhance the resilience of flexible manufacturing systems using AI-driven approaches for managing component and facility disruptions. In such a manner, key resilience techniques to revitalize U.S. defense manufacturing are identified, including augmented machine remote monitoring, cloud cyber-physical enhanced multi-tier supply chain transparency, and AI simulations for predicting population inflations and COVID mutations. Through a novel resilience assessment framework, AI approaches, and an optimization platform, a variety of experiments have been designed and performed, including production reallocation, remanufacturing quantity adjustment under metal shortages, and inventory and supply adjustment methods to meet defense products demand growth.

1.3. Structure of the Work

This essay is organized as follows. In Section 2, a description of the Defense Industrial Base and its struggles in the 21st Century, along with promising emerging technologies to address these challenges, is provided. In Section 3, an overview of the SCResA process, its Core Modules, and how firms can engage with each module is presented. The artificial intelligence techniques that drive the modules are also described in detail. In Section 4, a number of applications that illustrate the use of the SCResA process, its Core Modules, and AI techniques are outlined. Additionally, wider applications that inform executives about AI, SCResA, and applications of practical interest are also included. In Section 5, a discussion of concepts that warrant further research as the SCResA process matures is presented. In addition, three recommendations for future work are made to accelerate the development and acceptance of SCResA as a practice in both commercial firms and the defense industrial base in the US. Concluding remarks are included in Section 6.

2. Fundamentals of Supply Chain Resilience

Supply chain resilience consists of seven dynamic and interactive capabilities: anticipation, monitoring, responding, and recovering new products/services; reconfiguring existing resources; creating backup; deploying self-righting; developing institutional arrangements. The overall supply chain resilience can be assessed by using a capability maturity model based on these capabilities [3]. A case study of an aerospace supply chain also illustrates the applicability of the conceptual framework and provides industrial validation of it. Recent economic downturns and disasters have increased the risks and vulnerabilities that the supply chains face, escalating the challenges which have to be dealt with. Early warning and risk mitigation approaches are unable to address the risks adequately. In addition, supply chains may become more vulnerable and fail to meet customers' needs due to the complexities from the greater uncertainties with the increasing number of supply chain participants and the shifting of operations across regions. The concept of resilience was developed in ecology to refer to the ability of a system to withstand disturbance. Similar to a biological population in an ecosystem, supply chains can be viewed as a complex adaptive system of organizations being linked by their product, service, and information flows.

There is a need to obtain a comprehensive understanding of the resilience of supply chains so that it can be accounted for in the design and operational strategies of their constituent organizations. To this end, a conceptual framework for understanding supply chain resilience has been developed and includes the essential components as follows: a definition of supply chain resilience; a general description of supply chain resilience using supply chain capabilities which can be further elaborated into resilience assessment and development; the clarification of the relationships between supply chain resilience, capabilities, configuration, and design for supply chain competitive advantages; and an explanation of the mechanisms behind achieving and maintaining supply chain resilience. A conceptual modeling of supply chain resilience is then proposed, modeling the development of resilience capabilities against environmental dynamism, and simulations have been carried out to explore the behaviors of the resilience capabilities with various configurations of the supply chains [4].

2.1. Conceptual Framework of Supply Chain Resilience

The definition, characteristics, importance and contextual factors of supply chain resilience are discussed successively in this subsection. The term supply chain and the adoption of a system-wide view is now a generally accepted way for academia and management professionals to discuss the idea of a total supply system [4]. Recently, supply chain management has become part of the everyday vocabulary of politicians and the general public even though the essential management problems and business concepts existed long before the term was coined. Nevertheless, the term supply chain in a narrow sense means the chain composed of all parties acting in collaboration with one another to supply a product/service to the ultimate consumer of the product/service. Cooper and Ellram listed some not so commonly known but profound definitions of supply chain. For example: “A supply chain includes all stages involved, directly or indirectly, in fulfilling a customer request”–. “The supply chain is a coordinated system of organizations, people, activities, information, and resources involved in moving a product or service from supplier to customer”–. As the terms have been extended to industry, public service, charity, or even socio-ecosystem, a more common understanding of unidirectional flows of materials or services from suppliers to customers has been challenged. There are many conceptual frameworks analyzing the essence of supply chain. This compendium is about the one that looks at supply chains as complex adaptive systems. Organizations in a supply chain have open processes where both resources and information are exchanged with one another and with the external environment, forming the social networks of the chain. Accordingly, both the supply chain and its member organizations adapt to changing circumstances in the surrounding environment, competing with one another, forming cooperation ties, or mutually restructuring. That is, the relationships among supply chain members are usually more fluctuating than the traditional basic models of all kinds of optimization that assume fixed transactions. Adaptation is defined as the gradual change in organization behavior to environmental reactions. This comprehension helps us learn the changing patterns of organizations in the supply chain and the development of resilient capabilities to match the changing environment.

2.2. Key Components of Resilient Supply Chains

The world is witnessing rapid development of new technologies, in particular Artificial Intelligence (AI) which hold the promise of major technological advancements across multiple sectors. The growing adoption of AI technologies into new application areas is reshaping how these applications are developed and what capabilities are possible. To explore the impact of AI on supply chains, resilience in defense manufacturing is examined, since U.S. defense chains are both globally dispersed and critical to national security. An overview of the important components needed for supply chains to be resilient is provided, followed by previously existent techniques and technologies to improve each component. Before exploring AI, important concepts and ideas, which AI-driven advances would be built off, are reviewed [2].

Resilience in supply chains is comprised of three key components: visibility, flexibility, and collaboration. The growing complexity of global supply chains has caused firms to lose sight of the components of their supply chains and the systems necessary for continued operation [5]. Visibility is the prospective understanding of the supply chain and allows firms to monitor the state of their components. Visibility allows firms to identify issues within consumer tracking as they occur, and through data aggregation, identify the many potential upstream problems (e.g., material shortages). Flexibility is the ability of a firm to adapt to issues or alternatively to mitigate the impacts of the disturbance. Flexibility can be achieved in multiple ways such as changing suppliers or resource reallocation. Collaboration is the proactive cooperation of partners within a chain, allowing for joint strategies to be established alleviating risks before they occur. A lack of collaboration allows others within the chain to be blind to a firm's vulnerabilities making it susceptible to issues outside its control.

3. AI Technologies in Supply Chain Management

Artificial Intelligence (AI) is probably the most important thing humanity has ever worked on. At the moment those words appear, we are facing an again transformational time period, similar to the first industrial revolution or the rise of the internet. At the center of this revolution is Artificial Intelligence (AI). Following a hype cycle in the second half of the 20th century, mostly confined to research labs, AI finally made it into the everyday lives of people. In service sectors as diverse as insurance, banking, or retail, AI-driven applications such as speaking and perceiving devices, smart robots, but also credit scoring or fraud detection, are already starting to deliver real-life business and consumer benefits [1].

On the other hand, Artificial Intelligence is a set of methods allowing computers to deal with problems thought to involve a certain level of (human) intelligence. This includes tasks usually requiring cognitive processes like understanding speech or text, generating images, predicting events, recognizing objects, or controlling movements. Artificial Intelligence is closely related to another concept, machine learning, which broadly denotes a set of techniques allowing computers to learn from available data [2]. Because using data is crucial to Artificial Intelligence, several authors do not differentiate between the two terms. A more formal distinction defines Artificial Intelligence as the broader concept of computers being able to carry out tasks intelligently, and machine learning as a subset of Artificial Intelligence techniques controlling the learning process. These methods are actively deployed in various business areas, e.g., marketing, robotics, finance, etc., where they have shown great potential in successfully overhauling and optimizing business processes. However, no extensive analysis of AI and machine learning applications in supply chains and logistics has been provided so far.

3.1. Overview of AI and Machine Learning

Artificial intelligence (AI) is the discipline dealing with computation utilizing concepts usually associated with intelligence, such as perception, inner representation, reasoning, planning, learning experience, or rules of action. Machine learning (ML) is a subdivision of AI whose processes can be improved with experience and where experience is understood as data [1]. These terms refer to computer programs, hardware and software, systems and models, cognitive environments, or anything related to computational processes that adopt formalized heuristics emulating some aspect of human thought. There are different kinds of AI, depending on how complex are the situations it can handle intelligently. For instance, systems of narrow AI can process only specific situations, while systems of general AI are usually either theoretical or hypothetical. Considering the lack of comprehension of some basic aspects of human thought, it seems plausible to research the construction of systems of highly general AI. However, the construction of systems of general AI is stable but not complete, as aspects of human thought are not completely understood.

The interest in AI has been fluctuating over time, with “AI spring” periods of increasing interest and financial investment followed by “AI winter” periods of disillusion [6]. The most recent AI spring started in the 2010s, thanks to the success of deep learning, and led to the surge of new AI startups, the emergency of new AI applications and services, the generalizations of software and programming libraries for building AI models and systems, the expansion of big data and cloud computing, and the increased interest for AI technology by politics and society in general. By 2030, AI is expected to be widely spread in society and everyday life, to impact all sectors of the economy, and to deliver advanced AI systems, products, applications, and services. AI systems and models should be as ubiquitous and common as technology nowadays in homes, cars, schools, offices, and streets. There is expected a strong growth of AI workforce, as employment related to AI should increase drastically. AI is considered a key socio-economic driver and a strategic need. AI systems and models should not only be widely adopted but also developed in a robust, safe, and trustworthy manner. AI is supposed to contribute to societal challenges, boosting an inclusive growth and generating improvements in the quality of life, environment, and sustainability. It is expected that the transition to AI will take place in a way that maximizes benefits to society and minimizes the risk of harm. AI will be a key partner to human beings, augmenting rather than replacing intelligence.

3.2. Applications of AI in Supply Chain Management

The array of AI techniques available for enhancing supply chain (SC) performance has burgeoned over the last decades, with approaches emerging from disparate branches of informatics, mathematics, and physics. The initial thrust of relevant modelling efforts is demonstrated first, with a focus on the classes of methods that assess SC resilience. Thereafter, the application of these approaches to specific SC efficiency enhancement techniques (i.e., SC visibility, risk assessment, risk mitigation) is reported. The literature surveyed spans a period from 1999 to May 2019, with the articles comprised in the SC modelling taxonomy mapped to the temporal evolution stage of the modelling technique they represent [1].

The full cycle of SC modelling progress is covered, where qualitatively different attempts to model the same system reflect its deeper appreciation as they occur with time. A paradigm shift in the approach to modelling is shown that takes SC modelling to a coverage of SCs in their entirety. On this basis, the full escalation of SC modelling resources potential to enhance SC resilience across specific domains of SC performance improvement is sketched. SC visibility is illustrated with applications of AI to SC distillations beyond dataset limitations in advantage of emerging sensing and tracking technologies, dealing hence with unprecedentedly large datasets. Subjected to advantages of automated data processing made possible by intelligent algorithms, data-based risk assessment proceeds with risk tracking, characterisation and quantification on broad SC scales. Targeted SC contingency plan formation from an array of intelligent resource choices resulting from SC awareness is exhibited as a methodology to place SCs beyond a passive budget-tolerant status [2].

4. Challenges in Defense Manufacturing Supply Chains

The U.S. defense industrial base is witnessing serious supply constraints, workload volatility, and other interdependent/complex challenges. The Defense Industrial Base (DIB) resilience initiatives funded and operated by the Defense Advanced Research Projects Agency (DARPA) are currently being developed and assessed. A wide array of Artificial Intelligence (AI)-driven decision support techniques/applications are examined and architected to address and revitalize a U.S. government-evangelized DIB supply chain status.

The U.S. defense manufacturing segment supply chains are comprised of three constituent tiers of manufacturers. Major defense contractors (MDCs) constitute the Tier-1 segment, while the Tier-2 and -3 suppliers are the Mid-Tier Defense Suppliers (MTDSs) and Micro Manufacturers, respectively. The Tier-1, Tier-2, and Tier-3 suppliers are also referred to as the Md-SC, M2-SC, and M3-SCs in this article. Research/manufacturing gaps leading to the wastage of billions of dollars annually in the M-SCs in the U.S. are highlighted in Associated Issues (2021). The current model-driven/methodology support of engineers and scientists in Tier-2/3 sensitive-design defense manufacturing engineering across seven Defense Manufacturing Processes (DMPs) is elucidated in Device Case Study Systems (2020). Centralized/department-divided decision supports are costly and ineffective in addressing the rapid workloads, responsiveness, and interdependency in the defense manufacturing domain, and constrain State-of-the-Art (SoA) DMP digital threading [7]. Major passive DMP workload calculations via EVM (Plan-At-Completion, Earnings-At-Completion) models often lag by ≥6-months, under-forecast, and lead to major bidding errors in the SCs [2]. Opportunities for improving Design, Data, Speed, Cost, and Quality (DDSC) are grossly overall-optimized, relying wholly on the knowledge of super-engineers from War Games, reoccurring issues. Fast/methodical DMP decision supports embrace the maximum utilization of existing engineering data/knowledge concerning deployed DMP cost races on competitors. Improved productivity/supply chain dynamics rely on the full characterization of cost drivers, the dynamics of initiative DMP-cost elements, and reconfigurable DMP systems.

4.1. Specific Challenges Faced by U.S. Defense Manufacturing

Despite rapid technological improvements and increased international competitiveness, the U.S. defense manufacturing supply chains are lagging in resilience, integrity, and trustworthiness. In recent decades, predominantly non-defense supply chains have adopted various methods, especially related to Artificial Intelligence (AI), to increase resilience against disruptions, optimize performance, and improve efficiency. Such advancements have allowed a few U.S.-based businesses to dominate global manufacturing and bypass threats associated with future supply chain disruption. This paper focuses on techniques, models, applications, and demonstrations of AI and machine learning to expedite the revitalization of U.S. defense manufacturing by increasing supply chain resilience against disruptions. The focus is specifically on challenges encountered by U.S. defense manufacturing. Supply Chain Attack Resistance: U.S. defense manufacturing supply chains design and integrate systems intended to remain operational despite security attacks. Crush: The Single Integrated Defense Supply Chain Improvement Process. Supply Chain Innovation: AI/data-driven efforts to devise new or improved processes, products, or services in defense manufacturing supply chains. Broadening the Defense Industrial Base: The U.S. Department of Defense (DoD) subscription-based effort to acquire supplies and services from sources other than the "traditional" 5-6 prime contractors [2].

5. Integration of AI for Supply Chain Resilience in Defense Manufacturing

Defense-related industries for the U.S. Department of Defense (DoD) and pooled capital partners comprise one of the battlegrounds against economic decline, loss of intellectual property and skill sets, and pernicious effects of foreign influence. Due to low production volume and demand characteristics of defense-related goods, there is non-competitive, uncooperative dollar-for-dollar bidding to win contracts based on low prices, resulting in excessively thin margins and profit pressures. Consequently, many system integrators and suppliers operate with alarmingly thin skills and financial balance, leading to supply chain distress and vulnerability to risks and disruptions including, trade sanctions, pandemics, problems in transportation and logistics, and adversaries' cyclic and dynamic influence [8]. These conditions deeply hinder proficiency in production, production mobilization potential, and reconstitution of plants and talents for extensive production whose concerns are.

Resilience enhancement of supply chains consists of proactive and adaptive measures, closely related to avoidance, increasing robustness, and making curative response and recovery less severe, swift, or uncertain and in sanctioning, production interruptions, or cessation of payments [1]. To regain U.S. operational superiority in land, naval, air, and other contested domains against endogenously maneuvering, diverse, adaptive, and intelligent threats, defense warfare must shift into a yin/yang, zero-sum win/loss game, where innovations in warfare maneuvers, instruments, and frameworks are faster and far more frequent than those of competitors and threaten the aggressive destruction of each rival. Simultaneously, corresponding countermeasures are needed to mitigate or preempt such emerging asymmetric competitive states and their pernicious influences on the domestic economy.

5.1. Benefits of AI Integration

Notable benefits of integrating AI in defense manufacturing supply chains include increased resilience and performance, higher productivity, decisional velocity, real-time visibility, flexibility, and the ability to self-control systems [1]. As resources are shared across all the stakeholders in the ecosystem, utilization rates increase, and costs decrease, resulting in a healthier environment, supply chain, and economy. With autonomous deployment, risk management systems dynamically monitor and control changes in consumption and revenue, and counterbalance plants, suppliers, and freight transportation providers automatically. Though there is an extensive array of AI applications that can be employed in SCs, each capability is extremely complex and application-specific. Investments in AI technologies must be targeted and practical, as performance gains in the SC context are increasingly different for different SCs; otherwise, the gap between firms will widen and economic power will be excessively concentrated.

Automation in manufacturing is not a new concept; however, non-technical barriers such as workforce skill, recruitment, and job displacement concerns commonly hinder the early adoption of AI technologies [9]. In SCs with many decentralized entities and limited coordination, AI often caps its value by only being usable in the SC's blue oceans. The valorization of unused or unexploited SC datasets is challenging, and systemic adoption efforts have not been attempted. An AI-driven SC ecosystem is governmental, as SCs often span many jurisdictions, and coordination and investment are needed to muster the large data volumes typically required for AI applications. The US DOD markets a full spectrum of military SCs ranging from complex and costly systems to critical components, most of which have extensive dependencies downstream. Promoting resilience in the US defense ecosystem and SCs is of paramount importance.

5.2. Case Studies and Best Practices

The following examples illustrate the effectiveness of AI-driven solutions for enhancing supply chain resilience in defense manufacturing:

5.2.1. U.S. Army: Predicting Globally Distributed Supply Chains with a Graph Algorithm The Army's Logistics Innovation Agency joined forces with the Joint Artificial Intelligence Center and Georgia Tech Research Institute to develop a rapid proof of concept demonstration of an AI-based graph algorithm for the Interactive Requirements Analysis Facility Software, which tactically demonstrates ways to address logistics modeling and analysis. Supply chain modeling and logistics options analysis are critical for Army mission planning. As the Army turns its operations from a "one size fits all" approach to a more diversified globally dispersed model, the need to more accurately and comprehensively model its supply chains becomes more urgent. The U.S. Army Combined Arms Support Command has about 200 Army prepositions locations and supply distribution sites. Logistics and transportation node placement and network modeling are needed to address both high-level logistics modeling and system support analysis. With combat operation orders, AI or ML algorithms and high-speed computing can create detailed simulation models of globally distributed complex military supply chains. The Army and the Georgia Tech Research Institute are part of a team developing AI-based, tactical, continuous modeling and simulation of globally distributed military supply chains to support logistics feasibility assessment and optioneering with related alternatives analysis. This work also enhances the Unit Supply Management System, building modeling capability to more accurately and comprehensively characterize the Army supply chain, enabling increased automation of current day and short-notice logistics operation planning.

5.2.2. U.S. Army: Building an AI-Driven Digital Twin of Global Supply Chains The Army, in collaboration with the Georgia Tech Research Institute, developed a modeling framework for the tactical Army Prepositioned Stock supply chain, simulating system dynamics based on units' operations and logistics requests. A demonstration model has been built, validating the modeling approach's applicability with respect to test cases. It is part of a U.S. Army Combined Arms Support Command project to develop a modeling framework to enhance its GATES system, enabling Army wartime plans' logistics feasibility assessment. The model's structure, requirements, data, and processes for model integration and verification have been designed. AI-driven or ML algorithms, such as Deep Neural Networks, can now generate simulation model parameters from high-dimensional and low-information datasets of the Army supply chain. Continuing tools' development, such as AI-assisted modeling and simulation experiment designs, is planned. Further developing this combined modeling framework capability to integrate harder optimization approaches, sensor, and data fusion techniques is also anticipated. AI-based novel and disruptive technologies, like digital twins, can be harnessed for military logistics operations. A digital twin of a complex system is often conceived as two entwined twin models, one at the physical system and the other at the virtual system. The Army's efforts focus on procuring high-speed computing capabilities, utilizing AI, data science, and agent-based modeling and simulation technologies to build a digital twin of its PEO Ground Combat Systems supply chain.

6. Ethical and Legal Considerations in AI-Driven Supply Chains

The ethical and legal considerations associated with AI-driven supply chains are explored in this section, which is particularly useful for understanding the context and technological aspects of ethical and legal considerations in AI-driven, intelligent supply chains. In the framework, several advantages of AI-driven supply chains are interdisciplinary considered, including AI-powered technologies, new opportunities and challenges, and regulations and policies. There is a need to broaden emphasis on the ethical and legal implications of the entire AI-driven supply chain, from information sources (or sensors) through data storage, analytic, and knowledge use (or implementing intelligent decisions). The focus is on the responsible data use, privacy, and security perspectives, as well as compliance with laws and regulations at the national and international levels. These perspectives are placed under the first general perspective (i.e., legal issues) as these concerns most directly relate to legal writings [9].

On the data source side of the framework, there are potential legal concerns with the unexpected use or disclosure of what are often intimate, sensitive data such as those related to biometric indicators or health, financial transactions, or location. This highlights a need for privacy, security, and compliance research regarding the use of AI-driven, intelligent supply chains for these data. This concern becomes stronger as AI-driven supply chains become more integrated and interconnected. On the basis of the current vertical integration of supply chains, data from many organizations and departments can be directly connected (connected organizational-wide data). As AI-driven technologies and innovations grow, not only internally generated data but also data about individuals (often intended for use in prevention efforts) from external sources such as insurance companies, telecommunication companies, or social media can be interconnected (privacy, security, and compliance concerns involving connected data originating from multiple organizations). Moreover, as cloud-based services greatly expand, especially with the prominent growth of AI-driven technologies with deep learning, there is a growing concern about personal data and large data sets of external organizations being transferred to large organizations—often beyond jurisdiction (e.g., Google, Meta, or Amazon)—outside any direct control of the companies and individuals involved (connected data beyond organizational control).

6.1. Data Privacy and Security

Digitial supply chains powered by advanced analytics and artificial intelligence (AI) have enabled better decision making through data-driven insights on every aspect of the supply chain. The utilization of AI in the supply chain has been accelerating post-COVID pandemic, and many organizations are investing or planning to invest in supply chain analytics. AI is transforming the global supply chain in many profound ways; however, there are concerns in its growing pace and negative consequences if not tackled correctly. Some of these concerns are broad and more conceptual and can apply to any AI implementation (for example job security and job displacement, social polarity, etc.). This section discusses the privacy and cybersecurity aspects of AI systems that have particular implications in the supply chain context affecting either individual companies or partner organizations in the supply chain. Behind the concerns discussed, there are wide-ranging systemic differences between application of AI in the supply chain compared to other domains, and these differences magnify the level of severity of the concerns explored [10].

Sensitive company or consumer information often needs to be shared among different partner organizations in a collaborative supply chain setting. In the data-driven supply chain, this sensitive information could be more data-intensive than before (including images, signals, operational data, and derived analytics), needed to support multi-partner-difficult AI models (data silo/parallel-training), AI models themselves (AI model monitoring/evaluation), or assist the assessment of the model outcomes (explanation method). There are various privacy risks (i.e., risk of unauthorized access) associated with sharing differently sensitive information in the supply chain (e.g., private data used for training and evaluation, internal models, and outcomes) and concerning the nature of the multi-partner collaboration (i.e., dissimilar models, multi-party models, and complex human- machine interactivity).

6.2. Regulatory Compliance

The AI-driven supply chain in defense manufacturing must ensure compliance with relevant laws and regulations. Compliance laws and regulations are the legal framework and requirements that govern the use of AI in specific industries, ensuring that organizations adhere to applicable laws and regulations. The U.S. defense manufacturing industry has unique government compliance requirements governing its operations and supply chains. The three regulatory compliance standards relevant to the AI-driven supply chain will be discussed in detail: the DFARS regulations, CMMC compliance, and the NIST framework.

The DFARS regulations include compliance provisions for cybersecurity compliance for all DOD contractors, including their subcontractors. Specifically, DFARS 252.204-7012 requires compliance with the NIST 800-171 cybersecurity controls. Compliance with DFARS necessarily involves completing the NIST scorecard assessment and protecting sensitive unclassified data [2]. As there are over 100 security controls in the NIST 800-171 framework, it is difficult to achieve compliance. The DFARS regulations are meant to enhance cybersecurity and protect sensitive data from malicious cyber threats. The regulations also allow the government to audit contractors and impose financial penalties for non-compliance. Subcontractors are now more at risk than prime contractors due to the DFARS regulations [11].

7. Future Trends and Research Directions

Research on AI-Driven Supply Chain Resilience in Defense Manufacturing.

Air, land, marine, cyber, and space domains envisioned AI as an integral enabler to augment decision-making, sense-making, intelligence gathering, and predictive capabilities for sensing, command, control, and execution. AI-enabled supply chain using DFMA will ensure decision superiority to respond to escalating supply chain disruptions to DoD goods and services and achieve the deterrent of a ready and capable U.S. force.

The proposed design will evaluate existing analytics-based supply chain design and performance evaluation methodologies, tools, and software using a quantitative/qualitative trade-space matrix, resulting in a verified, validated, and unified framework. Disruption Impact Assessment (DIA) services from preparation to recovery phases will utilize AI-enabled dynamic simulation, ML demand estimation, model-based deterministic event propagation, and domain analysis. Process Modeling Framework (PMF) services will augment interoperable representation standards like BPML/BPMN, executable process language such as MSL, and metamodels for upstream definitions of METs and SDDs. AI in Supply Chain Risk Assessment Research on AI-Driven Supply Chain Resilience in Defense Manufacturing.

Research on AI-Driven Supply Chain Resilience in Defense Manufacturing. The proposed design will investigate a framework for AI-driven supply chain resilience and agility to enable national defense industrial revitalization by ensuring continuity of support to the DoD effectors.

7.1. Emerging Technologies in Supply Chain Resilience

[res: 250b3c87-00ce-4419-ba19-0a7d2ac12b74] Within this broader concept of resilience, emerging technologies are highlighted as vehicles that enable new and valuable approaches to augmenting defense supply chain resiliency.

The focus on emerging technologies in this effort refers to the growing body and increasing maturity of technological innovation in manufacturing, supply chain, and logistics. This innovation is driven by many trends (evolution of cloud-based systems, increasing connectivity/disaggregation of systems and data, direct access to sophisticated technology, etc.) and is making relatively new technologies (widely adopted in the commercial sector around 2010) increasingly accessible and impactful for the defense supply chain. Specific emerging technologies are of interest, including artificial intelligence (AI) and machine learning (ML), advanced data analytics (ADA), digital twins (DT), sensing and monitoring technologies (end-to-end and edge data capabilities), and cybersecurity [7]. This list is not exhaustive, but it provides a glimpse into a rapidly evolving landscape that may inform resilient AI-driven solutions for U.S. defense manufacturing.

8. Conclusion and Implications for U.S. Defense Manufacturing

The COVID-19 pandemic has created unprecedented disruptions in global supply chains, impacting industries worldwide. The U.S. defense industrial base (DIB) heavily relies on complex supply chains that involve the coordination of numerous domestic and foreign suppliers. To mitigate disruptions, artificial intelligence (AI)-driven supply chain resilience is proposed through two research thrusts. The first thrust addresses the shortage of parts and materials needed for production by providing part failure impact assessment (PFIA) for multiple parts on a complex assembly and generation of a disruption resilience data analytics playbook. The second thrust addresses the oversupply of inventories and excess parts as a result of closing manufacturing plants and suspending purchase orders by assessing inventories' surplus risk and a long-term capacity planning for remanufacturing excess inventories. Target systems of technologies are identified: the Air Force DIB system and a supplier's remanufacturing system of recovery units. AI-driven technology prototypes and applications are proposed to support technology implementation in target systems. The importance of defense manufacturing for national security is outlined, interdependence of supply chain disruptions between industries is analyzed, and United States' domestic and national security concerns related to supply chain resilience are discussed [9] [12].

The U.S. defense manufacturing system is interdependent with commercial systems and is regarded as critical to the national economy. U.S.-based defense contractors increasingly depend on commercial parts suppliers that also manufacture parts for civil systems. The loss of supply chains for defense parts fundamentally undermined U.S. military aircraft readiness. U.S. supply chains have also been disrupted by foreign competitors and suppliers as China has made significant advancements in state-of-the-art capabilities, key technologies, and the industrial base. In 2018, China surpassed the United States as the most dominant nation in patenting machine learning worldwide. China's investments in machine learning and investments in high-end semiconductor manufacturing threaten United States' dominance in advanced manufacturing, which is essential for the production of aerospace, automotive, and other complex systems.

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