

Leveraging Big Data Analytics to Strengthen Global Value Chains amidst Geopolitical Crises

Nataša Stanojević¹ 

¹Institute of International Politics and Economics, Belgrade, Serbia

¹natasa.stanojevic@diplomacy.bg.ac.rs

Abstract—Amid contemporary geopolitical uncertainties, the shift toward a multipolar world order has highlighted unresolved global conflicts, significantly altering the economic landscape. Multinational companies (MNCs) now face challenges, including restricted access to energy and raw materials, economic sanctions—especially in the energy sector—trade barriers in high technologies, and increased risks along key transport routes. This research explores how Big Data Analytics (BDA) and BDA-based tools can mitigate these geopolitical challenges. It first analyzes theoretical frameworks for Global Value Chain (GVC) risk, classifies current geopolitical risks, and examines BDA's potential in addressing these risks through case studies. The research identifies Real-time Decision-Making, Predictive Analytics, and Integration with other 4IR Technologies as key BDA capabilities that enhance risk mitigating strategies for GVCs. Although these capabilities are commonly applied in GVC management, they remain underutilized in an unpredictable geopolitical environment. The study aligns specific BDA capabilities with corresponding geopolitical risks, providing guidelines for GVC management and suggesting future adaptations of software solutions to help MNCs navigate geopolitically-driven business risks.

Keywords - big data analytics, GVCs, geopolitical risks

I. INTRODUCTION

The shift towards a multipolar world order has exposed numerous unresolved conflicts across the globe. This ongoing geopolitical fragmentation has resulted in the most

economically disruptive period since World War II. Many of these challenges were unforeseen, forcing companies to adapt rapidly to new realities. These included the Ukrainian conflict and extensive sanctions imposed by the U.S., EU, and their allies against Russia and its affiliated businesses. Simultaneously, tensions escalated in the Israeli-Palestinian conflict (with accompanying instability in Lebanon, Yemen, Jordan, etc.), Taiwan-related issues intensified (including tension in the Indo-Pacific), uprisings erupted across the Sahel region, and resistance against U.S. influence in the Arab world.

These events mark seismic shifts in the global economic landscape. Multinational companies (MNCs) now face to: difficulties in accessing energy and raw materials, a series of economic sanctions that include primary, secondary, and targeted measures against specific companies or sectors, increased trade and investment restrictions in high technologies. Blockades and increased risks along key transport routes have added to the challenges that GVCs need to overcome. This environment is unlikely to stabilize in the near future, so that understanding and managing geopolitical risks have become essential components of every MNC strategy.

There is a significant gap in research exploring the potential of 4.0 IR technologies to enhance risk management amid geopolitical uncertainty. This study aims to fill that gap by focusing on one critical aspect: BDA. As a key component of 4.0 IR, BDA plays a crucial role in GVC management by offering real-time insights, predictive analytics, and seamless integration



with other advanced technologies. These features allow companies to quickly adapt and make informed decisions in an increasingly volatile and dynamic global environment.

The primary aim of this research is to examine how BDA solutions and BDA-based tools can mitigate the geopolitical challenges currently facing international business. Following the Introduction, the second chapter establishes a foundational framework for understanding GVC risks through established theoretical lenses. This chapter presents theoretical classifications of GVC risks, outlines key strategies for mitigating these risks, and discusses the potential role of BDA in supporting these strategies. The third chapter explores contemporary geopolitical developments and categorizes the real-world risks encountered by MNCs, including energy, transportation, and technological risks. The fourth chapter offers practical solutions detailing how BDA can address the specific geopolitical threats identified in the previous chapter.

II. THEORETICAL FRAMEWORK

A. *Classifying risks in GVCs*

Successful management of global value chains (GVCs) involves various key risks and strategies to mitigate their negative impacts, particularly in the face of geopolitical disturbances. This research focuses specifically on theoretical presentations of risks and corresponding mitigation strategies relevant to current geopolitical challenges.

While academic discourse often highlights the productivity and welfare benefits of GVCs for international companies, policy discussions tend to emphasize associated risks over potential rewards [1-3]. Risks in value chains include disruptions in the flow of information, materials, and products from suppliers to end users [4]. These risks are inherent in both domestic and international operations due to the complexity of activities, processes, and the involvement of multiple stakeholders. Therefore, effective risk management is essential for maintaining and enhancing GVC performance.

Technological risks encompass various types of risks. Teece [5] stressed risks associated with technological change, innovation dynamics, and intellectual property protection. Tushman and Anderson [6] highlight risks stemming from the (un)ability to adapt to technological advancements and changing market conditions.

In the third type of technological risk some authors include cyber-attacks, including ransomware, data breaches, and espionage.

Transportation risks arise from constraints and logistical bottlenecks, impacting the efficiency and reliability of GVCs [7]. For multinational companies, disruptions in logistics and transportation networks can cause delivery delays, increased costs, and challenges in maintaining product availability [8]. These disruptions include delays, infrastructure limitations, and other issues.

B. *BDA Term and its Main Advantages in Managing Geopolitical Risks*

In general, Big Data refers to large, complex datasets that are challenging to process and analyze with traditional methods. Although there is no universally accepted definition of Big Data, there is broad consensus on its key elements, known as the “5Vs”: Volume (large scale), Velocity (fast data generation and processing), Variety (diverse data types), Veracity (data quality), and Value (usefulness of data). Big Data encompasses not only the data itself but also the advanced analytics capabilities required to extract valuable insights, thereby enabling data-driven decision-making.

BDA involves the extraction of knowledge and information from diverse data sources, often in real time, and the integration of these insights to uncover hidden patterns. It employs various advanced techniques to analyze this data, facilitating data-driven decision-making [9]. The primary application of BDA is in business intelligence and decision-making. Initially, BDA's widespread use helped organizations analyze vast amounts of data to gain insights that could improve strategic decisions, optimize operations, and enhance customer experiences. Additionally, BDA provides a comprehensive view of the value chain, supporting the development of more resilient value chains.

Prioritizing BDA over other 4IR technologies for addressing contemporary geopolitical uncertainties in GVCs is justified for several key reasons:

- *Real-time Decision-Making:* BDA allows for the real-time analysis of vast data, enabling timely, informed decisions crucial in dynamic GVC environments. Tools like FourKites and Project44 provide real-time tracking and predictive

analytics, helping companies quickly adapt to changing conditions.

- *Predictive Analytics:* BDA forecasts future trends and disruptions, enabling organizations to anticipate and mitigate risks before they escalate [10-12]. Tools like RapidMiner, SAS, and Tableau are essential for staying ahead of potential challenges.
- *Integration with Other 4IR Technologies:* BDA integrates seamlessly with IoT, AI, and blockchain, amplifying its benefits and enhancing the digital transformation of GVCs [13,14].

C. BDA and Risk Management Strategies

The theoretical framework for managing risks in international business encompasses several key strategies for mitigating risks in GVCs.

1) BDA and Diversification of Suppliers and Markets

One of the most common strategies is the diversification of suppliers and markets. By sourcing from multiple suppliers, companies reduce reliance on a single source, thereby minimizing risks associated with value chain disruptions [3]. Expanding into diverse global markets also allows firms to balance demand fluctuations and reduce exposure to geopolitical risks, following the principles of Portfolio Theory [15].

BDA tools analyse vast datasets, enabling businesses to identify, evaluate, and diversify suppliers based on performance metrics, geopolitical stability, and market dynamics. Platforms such as Riskmethods, Resilinc, Zycus, and Jaggaer help companies identify alternative suppliers in regions less affected by geopolitical risks, ensuring value chain resilience through diversification. Additionally, BDA helps firms continuously monitor geopolitical shifts, ensuring timely adjustments to supplier relationships or market engagements.

For market diversification, BDA analyses macroeconomic data, regional trends, and political risks. Intelligence platforms like Crunchbase, Euromonitor International, and Gartner provide detailed market insights, helping firms strategically expand into new regions with lower risk exposure.

2) BDA for Risk Assessment and Contingency Planning

This is one of essential risk management strategies for preparing businesses to handle disruptions. These processes involve regular assessments and scenario analysis to outline actionable responses [16,17]. Incorporating BDA here enhances risk monitoring through predictive analytics and simulation models, improving the ability to anticipate potential disruptions.

Integrating BDA significantly enhances risk assessment and contingency planning. By analyzing historical and real-time data, BDA platforms enable businesses to continuously monitor global environments. Tools such as Real-Time Analysis Platforms provide instant alerts on geopolitical shifts and value chain disruptions, allowing firms to respond proactively [18]. Advanced analytics, including machine learning and predictive modeling, enable firms to forecast risks more accurately and design optimized contingency responses. Notable platforms like Riskmethods, Interos, and Resilience360 specialize in continuously monitoring and assessing risks, including those stemming from geopolitical tensions.

BDA facilitates advanced scenario planning, enabling companies to model potential disruptions from geopolitical risks. Software like AnyLogic and Simio assists firms in developing contingency plans by visualizing the impact of various scenarios.

3) Enhancing Visibility and Transparency Using BDA During Geopolitical Turmoil

A strategy focused on visibility and transparency relies on real-time insights into goods' movement, from raw materials to finished products. During geopolitical crises, BDA enhances visibility by providing live data on value chain activities, enabling early issue detection and timely decisions. Tools like Project44 and FourKites offer real-time logistics tracking, helping businesses swiftly adapt to disruptions. Platforms like IBM Watson Analytics integrate data sources for a unified view of value chain conditions, empowering firms to assess disruptions and make informed decisions in real time.

4) Local Adaptation strategies and BDA

These strategies focus on tasks such as developing cultural sensitivity, integrating corporate social responsibility (CSR), and

empowering regional managers to respond swiftly to local developments.

BDA solutions play an integral role in supporting these local adaptation strategies. By analysing localized data—such as regional market conditions, political risks, and cultural factors—BDA enables businesses to adjust their operations in response to regional developments. This approach allows firms to mitigate risks and enhance their resilience in the face of volatile global conditions.

5) *Comprehensive strategy - building a resilient value chain*

Building a resilient value chain integrates all the aforementioned strategies. Resilience is characterized by both robustness and flexibility. A robust value chain can withstand shocks without experiencing significant performance declines, while a flexible value chain can adapt to disruptions by adjusting resources and reconfiguring processes [4,19].

In addition to the previously discussed potential roles of BDA, BDA-driven Risk Management Platforms analyze vast data streams and apply predictive models to create comprehensive risk profiles. These platforms simulate various geopolitical scenarios and recommend effective mitigation strategies, ensuring preparedness for future disruptions. Furthermore, Digital Twins enhance this process by creating virtual models of the value chain, allowing businesses to simulate the impacts of different scenarios and adjust operations accordingly [9].

III. GEOPOLITICAL DYNAMICS AND GVCs RISKS

The most pressing threats to international business today include spreading military conflicts, economic sanctions, and techno-protectionism. Although the negative impacts of these geopolitically motivated measures on global value chains (GVCs) were evident after the 2008 economic crisis, they significantly escalated after 2017 due to the U.S.-China trade war, various EU restrictions, and extensive economic sanctions against Russia following February 2022.

These measures disrupt value chains by restricting access to essential raw materials, components, and technologies, resulting in increased operational costs and loss of market access [20,21]. Moreover, geopolitical instability

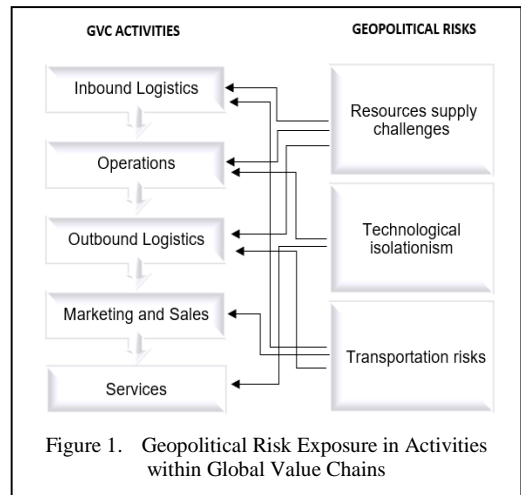


Figure 1. Geopolitical Risk Exposure in Activities within Global Value Chains

has heightened transportation risks, presenting insurmountable challenges for many multinational corporations. Consequently, acute geopolitical risks can be categorized into three main areas: value of energy and resources, technological risks, and transportation risks.

A. *Risks in Accessing Energy and Raw Materials*

GVCs are increasingly vulnerable to disruptions in energy and raw material supplies due to conflicts in key fuel-producing regions and geopolitical price volatility. Following Russia's annexation of Crimea in 2014 and the escalation of the Ukrainian war in 2022, sanctions on Russia's oil, gas, and financial sectors have significantly altered GVC dynamics. Countries like China and India have emerged as major buyers of Russian products, while the EU now indirectly purchases these goods at higher prices.

The Ukraine conflict has led to severe disruptions in energy supplies, resulting in price volatility and shortages. Europe's energy-intensive industries—such as aluminum, steel, and chemicals—have faced soaring costs and widespread closures due to self-imposed restrictions on energy imports from Russia and Ukraine [22]. These industries are particularly sensitive to energy disruptions, underscoring the importance of regional dynamics in assessing their vulnerability.

Instability has also affected other energy-exporting regions. In 2022, high oil prices allowed Middle Eastern economies, like Saudi Arabia and Qatar, to decline U.S. requests for increased energy supplies during the Ukraine

conflict, further jeopardizing global energy security. This shift illustrates the varying impacts of geopolitical tensions across different regions and sectors reliant on these energy sources.

A recent example of this uncertainty occurred during the July 2023 military coup in Niger, a crucial supplier of low-cost uranium to France. Following the coup, Niger proposed a significant price increase and revoked a French mining permit in June 2024, further challenging France's nuclear energy sector. This incident highlights how geopolitical instability in one region can have far-reaching consequences for specific industries elsewhere, emphasizing the interconnectedness of GVCs and the need for region-specific risk assessments.

B. Technological Risks in Contemporary Geopolitical Landscape

Growing techno-geopolitical uncertainty is reshaping international business and requiring MNEs to adapt strategically. For instance, the U.S. CHIPS and Science Act exemplifies a shift toward techno-nationalism amid escalating competition with China, aiming to enhance domestic semiconductor production. This trend highlights how specific regions, particularly the U.S. and Europe, are prioritizing technology self-sufficiency, impacting MNEs reliant on GVCs. The European Commission has identified four critical technology areas at high risk for security and leakage, recommending measures to control researcher migration and foreign ownership to bolster domestic capabilities.

Moreover, sanctions imposed on Russia by major countries increase risks for technology firms supplying essential tech to Russia, significantly impacting companies in Turkey, China, and the UAE, which may find themselves navigating both geopolitical pressures and the potential backlash from Western sanctions. As such, MNEs must assess which countries remain favorable for technology partnerships and value chains, considering the vulnerabilities inherent to specific sectors. Additionally, companies reliant on both the U.S. and China for technology, as well as those engaged with any part of the Russian economy, must carefully balance independence and interdependence, recognizing that different sectors face unique challenges.

A second category of technological risk stems from politically motivated cyberattacks, which are rising amid ongoing conflicts and heightened tensions. These attacks can

disproportionately impact sectors like critical infrastructure, financial services, and technology. Although accusations may sometimes be politically driven, there have been cases where perpetrators have claimed responsibility, emphasizing the need for MNEs to adopt robust cybersecurity measures tailored to their industry risks.

C. Geopolitical Challenges in Global Transportation Networks

In contemporary international business conditions, risks related to transportation are prominent. For example, the Ukrainian war has significantly affected Black Sea transport, with Russian naval blockades and Ukrainian defensive measures creating severe disruptions. The conflict has particularly impacted grain exports from Ukrainian ports like Odesa, leading many ships to avoid the Black Sea and take longer routes via the Mediterranean and Baltic Seas.

Similarly, attacks by Yemen's Houthi rebels on commercial ships in the Red Sea have severely disrupted trade routes [23]. The Houthis have targeted ships from countries they view as adversaries, causing major shipping companies to reroute vessels around Africa's Cape of Good Hope, adding around 3,500 nautical miles to their journeys. This rerouting increases travel time and costs, affecting maritime commerce. Additionally, disruptions to the Suez Canal, which handles a significant portion of global trade, have led to a 1.3% decline in global trade volume [7,24].

IV. BIG DATA ANALYTICS IN MITIGATING CURRENT GEOPOLITICAL RISKS

A. Harnessing BDA for Resource Risk Management in GVCs

To address uncertainties in resource and energy supply-such as high costs, scarcity, and political instability-Western companies' GVCs have not fully utilized technologies associated with the 4.0 IR to overcome emerging challenges or seize opportunities. However, BDA and BDA-based solutions, particularly when integrated with IoT and other digital technologies, can effectively manage resource risks within GVCs. The primary risks of resources -price volatility, sectoral sanctions, and disrupted production/export capabilities-can be mitigated through several strategies.

Real-time Monitoring: IoT sensors can gather data on resource availability, quality, and demand across the value chain. BDA processes this data to detect early signs of price volatility, allowing companies to respond quickly. While BDA typically excels in predictive analytics by leveraging historical datasets (prices, weather patterns, economic indicators) to forecast price movements, contemporary geopolitical turbulence can challenge the validity of these predictions.

Scenario Planning: BDA is valuable for managing sectoral sanction risks. By analyzing trade flows, political developments, and historical sanctions, BDA can simulate the potential impacts on various sectors, aiding companies in developing contingency plans and identifying alternative suppliers or markets.

Value Chain Diversification: BDA facilitates the identification and evaluation of new suppliers across different regions, reducing dependence on any single country or sector vulnerable to sanctions.

Integration of IoT and BDA: This combination supports real-time monitoring, enabling continuous tracking of transactions, supplier relationships, and trade routes to maintain compliance with international sanctions. To mitigate disruptions in energy production and export, BDA enhances value chain visibility. IoT devices can provide real-time data on production processes, inventory levels, and logistics, while BDA analyzes this information to predict and address potential disruptions. Additionally, integrating BDA with blockchain technology enhances transparency and traceability in resource management, ensuring data integrity and secure transaction records.

Success Example: Siemens exemplifies successful integration of IoT and BDA into its manufacturing processes to improve energy efficiency and predictive maintenance. By deploying IoT sensors across production lines, Siemens collects real-time data on energy usage, equipment performance, and maintenance needs. BDA analyzes this data to forecast maintenance requirements, preventing downtime and optimizing energy consumption [24].

B. Mitigating Technological Risks in GVCs Through BDA

BDA and BDA-based solutions play a crucial role in mitigating technological risks arising

from geopolitical factors such as technonationalism, economic sanctions, and politically motivated cyberattacks.

To navigate dependencies between the U.S. and China and their associated risks, MNCs must adjust global strategies, reconfigure value chains, and enhance resilience through effective corporate diplomacy. BDA can aid in developing comprehensive risk-assessment models that evaluate the likelihood and impact of violating sanctions in the technology sector. These models incorporate data on geopolitical developments, trade patterns, and historical enforcement actions to provide insights into risks tied to specific transactions or partnerships. More important, BDA can enable companies to manage reliance on the U.S., China, and other key players, since it can identify alternative suppliers of high-tech component.

In terms of cybersecurity, BDA enhances GVCs through real-time monitoring, predictive analytics, and integration with machine learning (ML) and data mining. Real-time monitoring can analyze vast amounts of network data—such as traffic and user behavior—to detect potential cyber threats. ML algorithms identify patterns that indicate cyberattacks, allowing organizations to respond swiftly.

Predictive analytics can forecast future threats by analyzing trends in cyberattack patterns and geopolitical tensions. BDA platforms like Splunk and IBM QRadar provide real-time cybersecurity monitoring across GVCs. For example, Pakistan Askari Bank improved its security posture using QRadar, reducing daily security incidents from about 700 to 20 and cutting the average response time for cyberattacks from 30 to just 5 minutes [25].

C. BDA for Managing Transportation Risks in GVCs

BDA and related technologies, such as IoT, AI, and predictive modeling, play a crucial role in mitigating transportation risks in GVCs, particularly along hazardous routes and amid fluctuating costs caused by geopolitical turmoil. By processing vast amounts of real-time data from transportation logs and geopolitical events, BDA identifies patterns and predicts risks like political unrest, military conflicts, or natural disasters. Its applications extend to procurement, manufacturing, routing optimization, and real-time traffic monitoring.

BDA enhances route planning by assessing the likelihood of roadblocks, protests, or military activities that may impact the movement of goods. This capability enables companies to choose cost-effective routes, reducing the chances of dangerous encounters or high costs.

BDA is invaluable for simulating geopolitical scenarios, such as new sanctions or the closure of critical trade routes, and assessing their impact on transportation costs. Companies can utilize these insights for contingency planning, including stockpiling goods, renegotiating contracts, or adjusting pricing strategies.

IoT devices enable real-time monitoring of shipments, allowing companies to swiftly address potential risks or delays and optimize routes and schedules to avoid dangerous areas. While this may not reduce transportation costs directly, it significantly helps safeguard transported goods and vehicles. The integration of BDA, IoT, and GIS further strengthens the management of transportation challenges.

The findings on how BDA can support the management of geopolitical risks are illustrated in Fig. 2.

Success Example: Maersk Line, a leading Danish international container shipping company and the second largest globally, exemplifies advanced technological integration. Maersk employs a range of cutting-edge technologies, including IoT, data analytics, AI, machine learning, digital twins, and augmented reality (AR) [26].

BDA can contribute to future adaptations of technical solutions for GVC risk management in several key ways. The most important are: by enhancing predictive capabilities, integrating

with 5G and edge computing for faster real-time data processing, and using AI to simulate diverse risk scenarios. BDA can also be combined with blockchain to improve transparency and traceability, while adaptive learning systems can evolve to meet changing geopolitical and economic conditions.

Integrating BDA solutions into GVC risk management strategies can yield transformative *long-term effects* by enhancing efficiency and optimizing operations. The optimization not only reduces costs in risky period, but also boosts productivity, making value chains leaner and more agile in adapting to future changes.

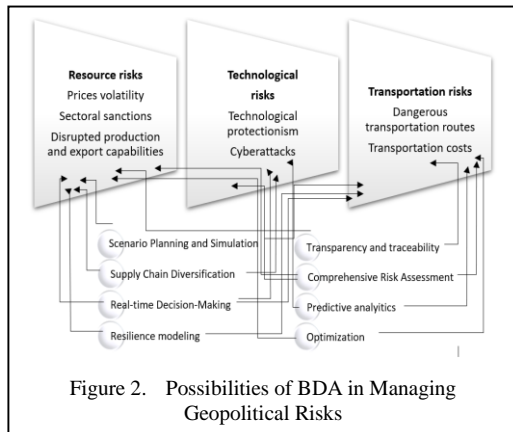
V. CONCLUSIONS

The transition to a multipolar world presents complex geopolitical challenges that significantly impact GVCs. This research demonstrates how BDA can mitigate risks related to resource scarcity, technological disruptions, and transportation issues, enhancing GVC resilience.

A key finding is that BDA, especially through Real-time Monitoring, enables companies to navigate price volatility in resource markets by tracking commodity price fluctuations, facilitating timely decision-making. Additionally, Scenario Planning aids in preparing for sectoral sanctions by modelling various outcomes for strategic responses. BDA also enhances Value Chain Diversification, identifying alternative raw material sources and reducing supplier dependency. The integration of IoT with BDA ensures compliance with international sanctions, while combining BDA with blockchain technology improves transparency and traceability in supply chains.

Transportation risks can disrupt GVCs, but BDA, IoT, and predictive modelling effectively mitigate these challenges. BDA processes real-time data for Predictive Route Planning, anticipating disruptions, while Scenario Planning helps companies adapt to fluctuating transportation costs. The integration of BDA, IoT, and GIS strengthens the management of transportation challenges, ensuring efficient and safe delivery of goods.

This research emphasizes the essential role of BDA and its tools in enhancing GVC resilience against geopolitical risks, providing guidelines for GVC management. However, significant differences among small, medium, and large



enterprises present challenges in recommending BDA for risk mitigation. Small and medium-sized enterprises (SMEs) face limitations such as resource constraints and insufficient skilled personnel, hindering BDA adoption. Thus, while the findings guide GVC management in mitigating specific geopolitical risks, addressing BDA adoption remains vital for the future strategies of multinational corporations.

The widespread adoption of BDA will reshape global trade dynamics. Firms and countries that prioritize these technologies will gain a competitive edge, potentially creating a divide between technologically advanced economies and those slower to adopt BDA. This shift will redefine global trade relations and position data-driven organizations as leaders in future economic landscapes.

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