Exploring the Impact of Industry 4.0, AMT, and Metaverse on Supply Chain Resilience and Social Responsibility.

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Abstract

The following text discusses a research paper that explores the complexities of technology adoption in supply chains. The paper presents a comprehensive overview of the environmental, ethical, and social issues arising from implementing Industry 4.0 technologies such as Metaverse and AMTs. The paper's primary objective is to provide guidelines and insights for responsible technology adoption, enabling companies to promote sustainability, mitigate risks, and ensure long-term success. The research methodology used in the paper is quantitative, which involves gathering and analyzing valuable data. The study findings suggest that several factors impact supply chain resilience, including sensing capability, resilience capability, reconfiguration capability, and seizing capability. Therefore, companies must consider these factors while implementing technology in their supply chains. The paper highlights that firms implementing AMT technology, such as Metaverse, should prioritize ethical practices and social responsibility. By doing so, they can ensure the technology is used for the betterment of society and not just to maximize profits. The research paper provides valuable insights and guidelines for companies to responsibly adopt technology in their supply chains while ensuring long-term success.

Keywords: *Supply chain Resilience, Digital Agility, AMT technology and Metaverse, Sensing capability, Resilience capabilities.*

Introduction

The fourth industrial revolution commonly referred as Industry 4.0 has brought various changes in the process of supply chain by integrating physical systems and digital technologies. AMT (Advanced manufacturing Technologies), is the main component of fourth industrial revolution and it have the capability to advance the supply chain resilience (Ivanov & Dolgui, 2020). However, it also raise the social and ethical concerns. This research paper aim to investigate the AMTs impact on social responsibility and supply chain and provide guidance for the firms who seek to enhance their practices of supply chain management in industry 4.0 perspective (Haque et al., 2023).

The industry 4.0 concept is referred to the digital technologies integration and systems in different sectors (Novak & Dooley, 2021). This has changed the way businesses these days operate and it make easier to manage supply chains. AMTs for instance additive manufacturing, robotics and automation are the main components of industry 4.0 and it have that potential to change or transform the management of supply chain (Júnior et al., 2023).

The industry 4.0 concept has revolutionized the criteria of business operations, specifically in terms of supply chain (B. Khan et al., 2023). The AMTs and digital technologies and their integration has provided the new challenges opportunities for the firms. As this concept is continuously developing, it is significant to find out the intersection of technologies, supply chain resilience, and ethics to ensure addressing environmental and potential concerns.

AMTs and Industry 4.0

The concept of Industry 4.0 covers the wide range of digital transformations which can enable the automation and digitization of different processes within the process of the supply chain (S. Khan, A. Anwar, et al., 2023). This automation and technologies include Machine learning, cloud computing, artificial intelligence and data analytics (Wang & Zhao, 2022). Furthermore, when these technologies are combined with AMTs for instance robotics, automation and additive manufacturing g, they improve flexibility, productivity, and efficiency.

Supply Chain Resilience

Supply chain resilience is referred to the firm's ability to recover, respond and anticipate from the supply chain disruptions. As the frequency of disruptions and issues in the supply chain is increasing it is due to the elements like pandemics, political instability and natural disasters. These elements and issues in the supply chain have made resilience a critical and important factor that is required by organizations for smooth operations (S. Khan, M. Hyder, et al., 2023). AMTs and industry 4.0 technologies suggest different opportunities for firms to utilize in terms of predictive analytics, real-time monitoring and agile decision-making.

Ethical considerations

The AMTs and industry 4.0 technologies adoption has raised ethical concerns which are important to be addressed (Khan et al.). The utilization of automation can lead to the social inequality and unemployment, and this require firms to consider the impact of such technologies on society and workers (Wang & Zhao, 2022). In addition, the technologies also impact environment by increased consumption of energy and electronic generation of waste which have to be managed responsibly.

Potential impact of Metaverse

The metaverse and its emerging concept based on the virtual reality where the users can experience and interact the environment that is computer generated has the potential to transform the future of supply chain. The metaverse integration with AMTs and industry 4.0 technologies can improve the communication, collaboration and process of decision making in supply chain. Though, it present the ethical considerations for instance, security, inclusivity and data privacy.

Research Question

The following are the research questions:

1. How AMTs and industry 4.0 technologies impact social responsibility and supply chain resilience?
2. What are the social and ethical responsibility implications of utilizing AMTS in supply chain management?
3. How can firms ensure the AMTs responsible adoption while also improving the supply chain resilience?

Literature Review

This literature review highlights the importance of ethics in supply chain resilience, impact on industry 4.0, and AMTs impact on process of supply chains. A study by Senna et al., (2023) showed that the utilization of MATs can impact significantly on environment involving waste generation and increased energy consumption (S. Khan, M. I. Khan, et al., 2023). In addition, the utilization of robotics and increased automation have created social inequality and job losses specifically in developing countries (Júnior wet al., 2023). These specific concerns focus more on responsible technology adoption in supply chains. It also include the integration of environmental and social considerations, development of ethical guidelines and decision of technology adoption (Wieland & Durach, 2021).

According to Aslam et al., (2020) pandemic caused by Covid-9 has emphasized the significance of supply chin resilience, with global supply chain disruptions causing different social and economic impacts. Dubey et al., (2021) identified that the technology can play a crucial role in enhancing and improving the resilience in supply chain, specifically through the utilization of digital technologies such as artificial intelligence and Blockchain (S. Khan, A. Rashid, et al., 2023).

H1: AMT technologies impact supply chain resilience

AMT Technologies and Supply Chain Resilience

Automation, robotics, additive engineering, and digitalization are front-line technologies in Advanced Manufacturing Technologies (AMTs). These modern techs have the power to progress supply chain resilience radically by aggregating productivity, agility, and reactivity (Wang & Zhao, 2022). Organizations may increase their aptitude to bear commotions and recover recklessly by integrating AMTs into supply chain maneuvers (Münch & Hartmann, 2023). However, Hamidu et al., (2023) amplified operational proficiency is one key way AMTs support supply chain resilience. Automation and robots, for instance, can benefit haste manufacturing practices, eradicate manual work, and lessen human errors (Novak et al., 2021). These efficacy gains lift production and curtail lead times, permitting firms to acclimatize more professionally to unforeseen alterations in demand or supply chain intermissions (S. Khan, S. I. Zaman, et al., 2023).

However, it is crucial to emphasize that successfully integrating AMTs into supply chain processes requires careful planning and attention
(Raees et al., 2023). Organizations must examine their supply chain requirements, conduct cost-benefit evaluations, and handle any possible technology adoption, workforce training, and data security problems (Kähkönen et al., 2023).

H2: Digital agility positively impact supply chain resilience.

Impact of Digital Agility on Supply Chain Resilience

Due to digital agility, organizations may gain real-time visibility into their supply chain network. Businesses may gather and analyze data at every level of the supply chain with advanced analytics, IoT sensors, and connected systems (Wang & Zhao, 2022). This visibility allows insights into inventory levels, manufacturing procedures, transportation routes, and client demand trends (Júnior wet al., 2023). Organizations can proactively anticipate possible supply chain disruptions or bottlenecks and take timely corrective action by accessing accurate and current information (Si et al., 2023).

Flexibility and Adaptability

Organizations can quickly respond to shifting market conditions and client expectations. Businesses may streamline and increase the flexibility of their supply chain operations by utilizing digital technologies like cloud computing, AI, and automation (Kähkönen et al., 2023). Using real-time demand data, cloud-based inventory management systems, for instance, can dynamically modify inventory levels to ensure optimal stock levels while reducing the risk of stockouts or surplus inventory. Alvarenga et al., (2023) stated that Automation can streamline and accelerate processes, enabling quicker reaction times and greater agility in dealing with interruptions (Zafar et al., 2023).

Collaborative Networks

The development of cooperative networks inside the supply chain ecosystem is facilitated by digital agility. Organizations may communicate with suppliers, logistics companies, and customers seamlessly and effectively by utilizing digital platforms (Kähkönen et al., 2023). Through real-time communication, data sharing, and cooperation enabled by these digital platforms, the supply chain benefits from improved connections and information sharing (Si et al., 2023). Such cooperative networks can assist in the swift identification of substitute suppliers, the rerouting of shipments, or the reallocation of resources to lessen the effects of disruptions (Qader et al., 2022).

Predictive Analytics and Risk Management

Predictive analytics capabilities provided by digital agility enable organizations to foresee and reduce future supply chain hazards. Organizations can spot patterns and create predictive models to anticipate interruptions or supply chain risks by analyzing historical data, market trends, and external influences (Júnior wet al., 2023). With this information, they can proactively implement risk reduction tactics, such as developing backup plans, diversifying their suppliers, or taking emergency action. Organizations can also optimize inventory levels using predictive analytics, lessening the effects of unforeseen disruptions (Wang & Zhao, 2022).

Alvarenga et al., (2023) stated and investigated that Digital agility improves supply chain resilience by enabling proactive risk management, real-time visibility, increased flexibility and adaptation, and collaborative networks

H3: Digital technology impact Supply chain resilience.

Digital Technology and SCR

The fast expansion of digital technology has resulted in substantial improvements to several elements of supply chain management, including improved supply chain resilience. The IoT (Internet of Things), artificial intelligence (AI), big data analytics, blockchain, and cloud computing are just a few digital technology tools and solutions (Qader et al., 2022). These technologies provide new avenues for increasing and elevating supply chain visibility, flexibility, responsiveness, and risk management (Wang & Zhao, 2022).

One of the most critical effects of digital technology on supply chain resilience is the increased visibility and openness it brings to the whole supply chain network (Hamidu et al., 2023). By collecting and exchanging real-time data, companies may obtain significant insights about their suppliers, inventory levels, transportation routes, and client demands (Münch & Hartmann, 2023). Better decision-making, proactive risk detection, and faster response to interruptions or unexpected occurrences are all made possible by enhanced visibility (Kähkönen et al., 2023). Furthermore, Cadden et al., (2022) digital technology improves collaboration and communication amongst supply chain participants. Cloud-based systems and digital communication tools interchange present information, letting participants coordinate their operations well and respond to turbulences (Münch & Hartmann, 2023). This joint plan reassures agility and flexibility, empowering supply chains to rapidly alter their processes in the face of unanticipated occurrences like natural calamities, supplier disruptions, or unexpected variations in consumer demand (Münch & Hartmann, 2023).

H4: Improved flexibility is positively associated with supply chain resilience.

Improved flexibility impact on SCR

Flexibility has a significant influence on supply chain resilience (SCR). The capacity of a business to react and adapt its supply chain operations in response to changes in consumer needs, market dynamics, and unplanned interruptions is referred to as flexibility (Qader et al., 2022). When supply networks are flexible, they can absorb shocks efficiently, continue operations, and recover fast from interruptions, increasing their overall resilience (Júnior wet al., 2023).

A critical effect of more flexibility on SCR is the ability to adapt swiftly to changing client needs. Adaptable organizations can alter their production capabilities, inventory levels, and distribution tactics to correspond with changing client desires (Münch & Hartmann, 2023). This allows them to satisfy client expectations more efficiently, lowering the risk of stockouts or surplus inventory (Zaman, Khan, Zaman, et al., 2023). Companies with greater flexibility can also adjust their product offers, create new versions or combinations, and personalize items to meet the needs of individual customers (Wang & Zhao, 2022). This speed in reacting to consumer requests increases customer happiness and loyalty, contributing to the supply chain's resilience (Zaheer et al., 2023).

H5: Resilience capability is positively associated with supply chain resilience.

Resilience capability impact of SCR

A supply chain's resilience capability refers to its ability to foresee, respond to, and recover from interruptions while preserving critical services and limiting negative consequences (Wang & Zhao, 2022). Supply chain resilience is vital for firms to effectively traverse the business environment's uncertainties, interruptions, and shocks (Kähkönen et al., 2023). It includes several variables that influence a supply chain's overall resilience capabilities. Here is great overview of various variables affect a supply chain’s resilience abilities (Zaman et al.).

1. Supply chain architecture and structure are important factors in defining resilience capabilities. A well-designed supply chain with redundancy, flexibility, and alternate sourcing choices can absorb and respond to disturbances more effectively (Münch & Hartmann, 2023). Having numerous suppliers or circulation hubs dispersed over many regions, for example, declines the chance of a single failure stage and consents for rapid reaction and retrieval in the case of trouble.
2. Second, Hamidu et al., (2023) explained information and communication systems are vital for growing the resilience of supply chains. During breaks, suitable and precise information interchange among supply chain associates enables better management and supervisory (Wang & Zhao, 2022). Rapid reaction and the application of emergency plans are made promising by active communication channels and tools.
3. Third, prominence and openness in the supply chain are serious for resilience capabilities. Concurrent checking and insight into inventory levels, supplier routine, and transportation standing allow for preventive disruption recognition and reaction, as well

as quicker response and reclamation (Kähkönen et al., 2023). Better risk valuation and alleviation tactics are made conceivable by augmented visibility.

4. Fourth, collaboration and partnerships amid supply chain cohorts aid in forming resilience. Close collaboration enables cooperative problem-solving, resource sharing, and coordinated reactions during disturbances (Wang & Zhao, 2022). Connecting with essential suppliers, consumers, and other stakeholders improves the supply chain's resilience (Júnior wet al., 2023).
5. Fifth, effective risk management strategies are critical to supply chain resilience. This comprises risk assessments, risk mitigation methods, and the development of comprehensive contingency plans (Qader et al., 2022). Supply chains may decrease the influence of pauses and recover faster by identifying potential perils, captivating preemptive measures, and having exigency strategies.
6. Lastly, supply chain agility and adaptation are perilous for resilience. In response to instabilities, this needs the flexibility to promptly change operations, modify sourcing plans, or present substitute manufacturing procedures (Kähkönen et al., 2023). A lithe supply chain can regulate hastily demand, supply, or market situation variations.

H6: Reconfiguring capability impact supply chain resilience.

Reconfiguring capability and SCR

By enabling agility and flexibility, reconfiguring capability significantly improves supply chain resilience (Münch & Hartmann, 2023). Organizations with a strong reconfiguration competence may change the design of their supply chain to match changing market conditions, customer requests, or competitive challenges (Qader et al., 2022). This adaptability enables businesses to respond swiftly to disturbances, unforeseen shifts in demand, and changes in the business environment (Júnior wet al., 2023).

Organizations may improve their operations and react to changing situations by having the capacity to restructure the supply chain (Naghshineh & Carvalho, 2022). They can, for example, change their sourcing methods to diversify suppliers or lessen reliance on single-source regions (Münch & Hartmann, 2023). They can also modify their manufacturing processes to be more modular or flexible, allowing them to alter output levels or transition between product versions effectively. They can also change their distribution routes to fit new market channels or clients in other geographic locations (Wang & Zhao, 2022).

Hamidu et al., (2023) investigated the evidence and stated that the organizations may also use reconfiguration to discover, learn, and capitalize on new possibilities (Zaman, Khan, & Kusi-Sarpong, 2023). Organizations may exploit market trends, explore new market niches, and penetrate new geographic markets by regularly reviewing and altering supply chain structures (Münch & Hartmann, 2023). This capacity to reorganize the supply chain in response to market possibilities assists firms in maintaining a competitive advantage and capitalizing on possible growth opportunities (Naghshineh & Carvalho, 2022).

H7: Sensing capability impact supply chain resilience.

Effect of Sensing Capability on the Supply Chain Resilience

To promote the resilience of the supply chain, intuiting capabilities are vital. Organizations can cultivate an effective early cautionary system by operating pioneering technologies and data analytics to spot potential supply chain breaks and threats (Kähkönen et al., 2023). This capability lets them monitor several aspects, such as shifts in demand, inventory levels, supplier performance, market trends, and geopolitical expansions (Ishizaka et al., 2023). According to Alvarenga et al., (2023) by regularly collecting and analyzing this data, organizations can identify patterns, trends, and differences that may affect the supply chain. With this decisive evidence, businesses can take hands-on actions to lessen the effects of predicted disruptions, such as tumbling inventory levels, varying supplier networks, or putting emergency plans in place (Jamil, Khan, Khan, et al., 2023). When organizations nous and evaluate real-time data, they can better respond quickly and effectively to sudden circumstances (Qader et al., 2022). Additionally, organizations may discover new opportunities and adapt their supply chain plans as needed, thanks to sensing capability, giving them a modest advantage in the market. Investing in emerging sensing capabilities means organizations can better calculate, monitor, and respond to known and unexpected risks and openings.

H8: supply chain development is positively associated with supply chain resilience.

Supply chain development and SCR

Supply chain development programs have a significant influence on supply chain resilience. Organizations that improve their supply chain networks via strategic initiatives and practices are better positioned to deal with interruptions and uncertainty. Collaboration and partnership among supply chain partners are critical to resilience building (Júnior wet al., 2023). Organizations may successfully manage and mitigate disruptions by cultivating strong connections and encouraging information exchange, collaborative problem-solving, and coordinated responses (Wang & Zhao, 2022). Flexibility and flexibility are also essential components of supply chain resilience (Münch & Hartmann, 2023). Developing agile methods such as flexible production processes, adaptive capacity planning, and alternate sourcing strategies allows firms to react swiftly to changing situations (Kähkönen et al., 2023). Effective risk management and effective mitigation measures are critical to supply chain resilience. Proactive risk assessment and mitigation, as well as comprehensive contingency plans, assist firms in minimizing the effect of supply chain interruptions (Jamil, Khan, & Seraj, 2023).

H9: Seizing capability positively impact supply chain resilience.

Seizing Capability Impact on Supply Chain Resilience

Seizing capability substantially impacts supply chain resilience by encouraging agility, quick reaction to disturbances, continuous improvement, and collaboration (Wang & Zhao, 2022). Strong-grabbing organizations are skilled at seeing and taking advantage of new market possibilities (Júnior wet al., 2023). They can quickly adjust their supply chain operations and seize these chances, whether looking into new markets, varying their supplier base, or using cutting-edge technologies. This proactive strategy increases the supply chain's resilience and sharpens its competitive edge (Münch & Hartmann, 2023).

As per Cadden et al., (2022) organizations with excellent seizing capabilities also exhibit a quick reaction to disruptions. They can quickly assess the situation, choose options, and carry out backup plans. By doing this, they may hasten the recovery process and lessen the impact of disruptions on their supply chain activities (Júnior wet al., 2023). For instance, these organizations might reroute shipments, change sourcing strategies, or deploy backup resources to quickly alleviate the consequences of natural disasters, geopolitical events, or other unforeseen occurrences (Wang & Zhao, 2022).

Alvarenga et al., (2023) explained and informed that the supply chain's constant innovation and development culture is likewise fueled by seizing capability. Businesses prioritizing grabbing chances look for innovative methods to streamline operations, improve business procedures, and implement new technologies (Münch & Hartmann, 2023). To standout of the competition, they adopt a mindset that values ongoing learning and adaptation. This dedication to continual development makes the supply chain flexible, resilient, and responsive to shifting market dynamics and consumer expectations (Naghshineh & Carvalho, 2022).

H10: digital agility and AMT technology is associated with supply chain resilience.

Digital Agility and AMT Impact of SCR

The robustness of the supply chain has been significantly impacted by digital agility and additive manufacturing technology. Cadden et al., (2022) stated that the ability of an organization to react swiftly and successfully to technological disruptions and shifting market conditions is referred to as digital agility. Companies can obtain real-time visibility into their supply chain operations through digitization, allowing them to foresee and minimize interruptions (Wang & Zhao, 2022). Better inventory management, improved production planning, and improved supplier and customer collaboration are all made possible by increased visibility (Münch & Hartmann, 2023). 3D printing, commonly called additive manufacturing, has emerged as a game-changing technology in the manufacturing sector (Jamil, Shah, et al., 2023). Eliminating the requirement for conventional manufacturing procedures and supply chain dependencies makes it possible to produce complicated and customized items on demand (Júnior wet al., 2023). There are various advantages to supply chain resilience from this decentralized production. First, it lessens reliance on suppliers and transport networks spread out geographically, lowering the risk of disruptions in these sectors. Additionally, additive manufacturing makes localized production possible, which shortens lead times and improves response to rapid changes in demand or supply (Qader et al., 2022).

H11: seizing capability, improved flexibility and supply chain resilience has an impact of supply chain resilience.

Seizing capability and improved flexibility

These variables are closely interlinked and mutually reinforcing. Let's discover the connections between these factors:

Organizations with seizing capability can detect and capitalize on opportunities, adapt to changes, and respond quickly to market dynamics. Improved supply chain flexibility, on the other hand, refers to the supply chain's ability to modify and adapt to changing conditions, demands, or disturbances (Münch & Hartmann, 2023). Seizing capability and increased flexibility are inextricably linked, as organizations with high seizing capability are more likely to have built flexibility into their supply chain processes (Jiang et al., 2023). According to Ivanov and Dolgui, (2020) this adaptability can take many forms, including quickly shifting production levels, switching suppliers, or restructuring distribution networks. Organizations can better navigate uncertainties and shocks by employing seizing capabilities to improve flexibility, boosting supply chain resilience (Naghshineh & Carvalho, 2022).

Seizing capability as a driver of supply chain resilience

Strengthening supply chain resilience is crucially dependent on seizing capabilities. Companies with a good grasping capability are proactive in recognizing possible disruptions, comprehending new risks, and grabbing chances to enhance their operations (Naghshineh & Carvalho, 2022). Organizations that embrace seizing power develop a culture of continual improvement and innovation across the supply chain (Júnior wet al., 2023). They actively explore methods to improve supply chain resilience by optimizing processes, using new technology, and collaborating with partners (Münch & Hartmann, 2023). Seizing capability allows firms to stay ahead of disruptions, respond effectively to difficulties, and recover rapidly from disorders, contributing to a more robust supply chain overall.

Relationship between improved flexibility and supply chain resilience

Increased flexibility is essential to supply chain resilience. A more adaptable supply chain can withstand shocks, adjust to changing conditions, and recover quickly from interruptions (Münch & Hartmann, 2023). Organizations may adapt more efficiently to unforeseen occurrences, modify production levels, reroute shipments, or identify alternate suppliers or transportation routes by incorporating flexibility into their supply chain processes. According to Hamidu et al., (2023) flexible organizations may distribute resources flexibly, adjust to changes in demand, and limit the impact of interruptions on customer service levels. As a result, increased flexibility helps the supply chain's overall resilience by improving its capacity to tolerate and recover from disturbances (Wang & Zhao, 2022).

Research Methodology

Data collection and procedure

The research project had a total sample size of 120 people, with a confidence level of 95% and a margin of error of 5%. In our study on the impact of Industry 4.0 technologies, including AMT, Metaverse, and General Public on Supply Chain Resilience and Social Responsibility, we focused on Karachi's general populace as our primary audience. Emails, Whatsapp, and other forms of online communication were used to disseminate the questionnaire to the general population. The enumerators sent out 120 questionnaires and received a total of 117 questionnaires in return; this constitutes a satisfactory response rate.

The stimulus for the study

Several prior online studies have elicited the viewpoints of participants without explicitly presenting any stimulus, whereas others have gathered participant opinions in response to a specific stimulus. The present investigation has employed the concepts of supply chain and social responsibility as a stimulus (Kähkönen et al., 2023). The chosen stimuli were based on their susceptibility to contemporary technological advancements. Specifically, Metaverse, AMT, and Industry 4.0 technologies were selected for their relevance to our work (Münch & Hartmann, 2023).

Common method bias

The phenomenon of common method bias arises from the potential influence of the study instrument on the variability observed in survey responses. The study effectively mitigated common method biases by adhering to the prescribed protocol. The process involves constructing a conceptual framework that is founded on theoretical principles and modifying pre-existing scales and measures. The present study involved a reassessment of the questionnaire's validity and reliability using the available data set.

The topic of interest is the design of questionnaires

The survey comprised a sequence of assertions pertaining to various facets of supply chain resilience, technology, and social responsibility. The respondents were requested to express their degree of concurrence or discordance by utilizing a five-point evaluation system, which spanned from strongly disagree to strongly agree.

Table 1
Respondents characteristics

Characterstics	Frequency	Percentage
Gender:		
Male	61	51
Female	39	49
Age:		
18-25	46	23
26-35	60	30
36-45	40	20
46 & onwords	54	27
Education Level:		
Bachelor	97	48.5
Masters	74	37
Postgraduate	29	14.49

Status of Employement: Full time working Part-time working Not Working	56 94 50	28 47 25
Marital status: Married Single	61 39	51 49
Household Class: Working class Business class Retired	70 109 21	35 54.5 10.5

The presented table showcases information pertaining to different demographic attributes of a populace, encompassing gender, age, educational attainment, occupational situation, marital status, and household classification. The frequencies and percentages have been presented for every category pertaining to these characteristics.

The table displays that the population comprises of 102 individuals who identify as male and 98 individuals who identify as female, with respect to gender. The sample exhibits a nearly equal distribution, whereby males constitute 51% and females constitute 49%.

The sample size is divided into three classes depending upon the status of employment that either how many of them are working full time, part time or else how many of them are unemployed or not working. The 56 people were found to be working full time taking the 28 percent of the overall sample size. The demographics of part tome shows total of 94 people accomplishing 47 percent of the total sample size. Whereas, the 25 percent of the total sample which consist of 50 person who are unemployed.

Regarding the marital status of the population, the data indicates an equal distribution between married and single individuals. The study population consists of a total of 120 individuals, of which 51% are married (n=61) and 49% are single (n=39).

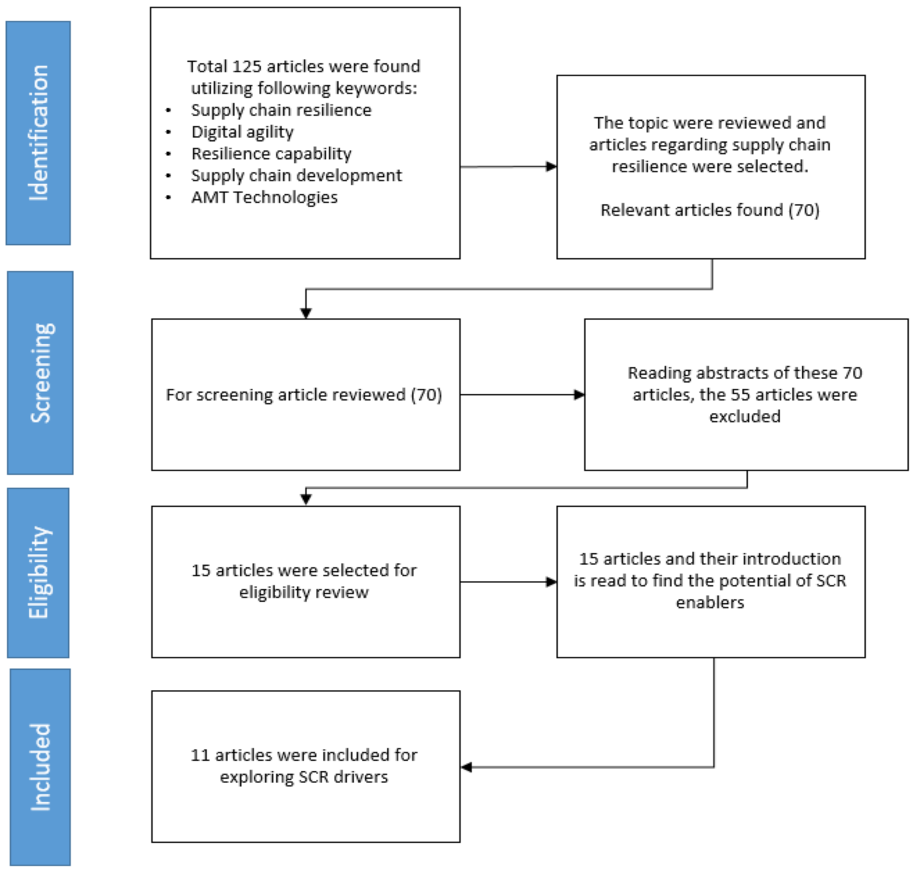
The table displays information pertaining to the allocation of household categories. The research revealed that category of business class constituted the highest percentage of participants, comprising 54.5% of the overall sample size, which amounted to 109 individuals. The study's sample is composed of 70 participants who are classified as belonging to the working class, representing 35% of the overall sample. The retired population is a relatively small segment of the overall populace, accounting for only 21 individuals or 10.5 percent of overall sample.

The table summarizes a population's demographic characteristics. Males outnumber females in the data. The age distribution favors 26-35 and 46+. A large percentage of the population has a bachelor's degree, although educational levels vary. The population is employed full-time, part-time, and jobless. Married and unmarried people are equally dispersed. Finally, business people outnumber working and retired people in home classes.

Enablers of SCR

Figure 1

ISM (Interpretive Structural Modelling)

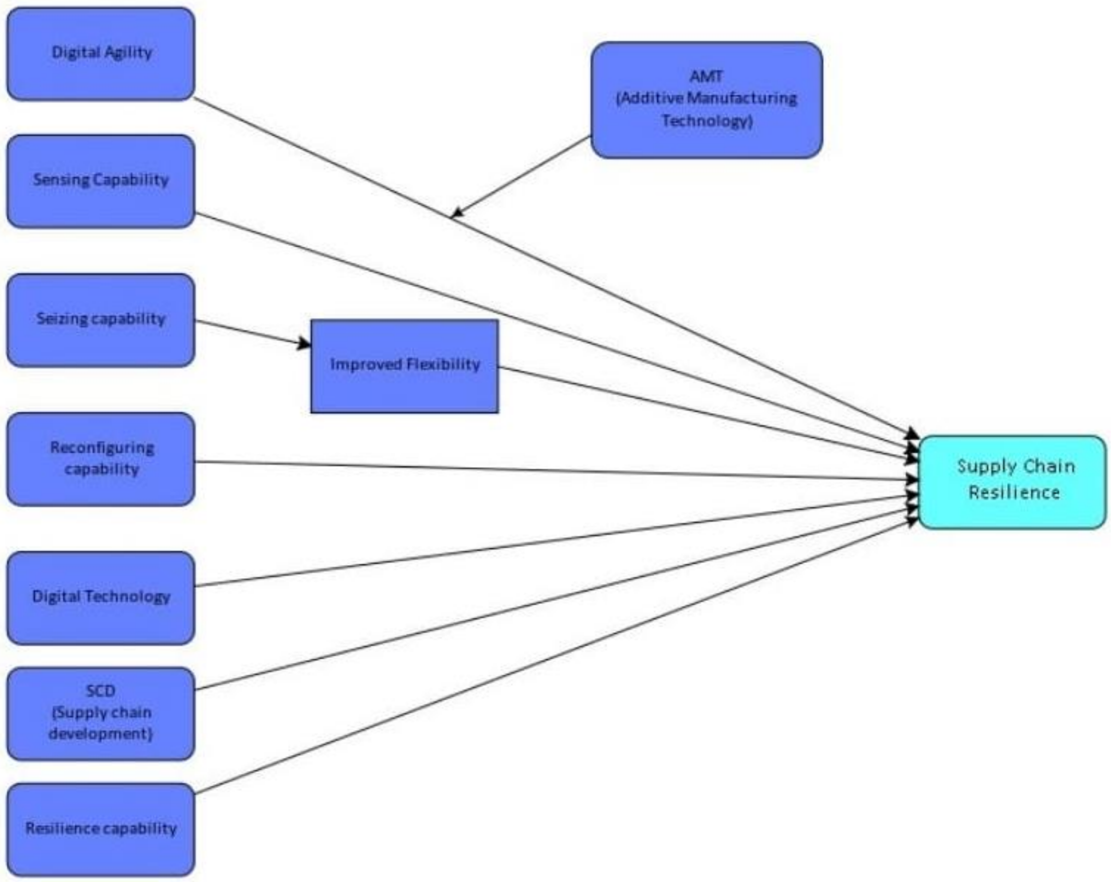


The enablers commonly refers to the activities or practices of firms that act as the important stimulants for the organizations to adopt the SCR management. The enablers might emerge due to the specialized practices or routine of an individual organization when dealing with the SCR adoption. In this regard, the enablers of SCR in the firms were identified through the literature review. The literature search were done utilizing key words such as "SCR enablers", "Supply chain resilience drivers" and "Supply chain drivers" (Kähkönen et al., 2023).

Figure 1 was developed utilizing PRISMA Template and it illustrates the different or number of articles and it shows the final selection of articles for final review.

Figure 2

Conceptual Framework



Discussion and Analysis

The analysis and discussion chapter of this thesis include details interpretation of the results and findings of the study. The data is generated from PLS software which was gathered through questionnaires.

Results

Descriptive analysis

The research in this section of the paper has examined the convergent validity and internal consistency, which is summarized in table number 1. The findings and results of the research shows that the highest value of Cronbach's alpha is AMT (Additive manufacturing technology) α = 0.827 and lowest value is of seizing capability which is α = 0.666 suggesting internal consistency acceptance of the constructs on the collected data set from Karachi, Pakistan. However, the results also show that all the composite values are greater than 0.70 and value of AVE are 0.60, which is confirming that the constructs are not deviating from the convergent validity requirements.

Table 2

Descriptive analysis

Variables	Cronbach's alpha	Composite reliability (rho_c)	Average variance extracted (AVE)
Additive Manufacturing Technology	0.827	0.896	0.742
Digital Agility	0.744	0.855	0.664
Digital Technology	0.722	0.843	0.643
Improved Flexibility	0.813	0.890	0.729
Resilience Capability	0.816	0.891	0.731
Reconfiguring capability	0.769	0.866	0.684
Sensing Capability	0.770	0.867	0.685
Supply chain development	0.810	0.888	0.725
Supply chain resilience	0.766	0.864	0.680
Seizing Capability	0.666	0.817	0.599

Discriminant validity

This research has utilized criteria of Fornell and Larcker (1981) for discriminant validity assessment. Furthermore, the results summary is illustrated in table number 2. The outcomes or results show that the AVE square root values are higher compared to the Pearson correlation values which suggests that the constructs utilized in the study are distinct. Moreover, this study has proposed 5 direct and 2 moderating hypothesis. The research has tested the hypothesis by the method of bootstrapping.

However, the results regarding hypothesis are illustrated in table number 3. The results shows that 6 direct hypothesis are accepted and 3 of them are rejected which are (1) Additive manufacturing technology affect Supply chain resilience (β= 0.076, t=0.050, p >1.482), (2) Digital Technology Affect supply chain resilience (β= 0.122, t=0.064, p >1.853), (3) supply chain development affect supply chain resilience (β= -0.037, t=0.043, p >1.832). In addition, our result do not support 1 moderating hypothesis which are (1) Digital agility moderates AMT (Additive manufacturing technology) and Supply chain resilience (β= 0.044, t=0.026, p >1.694).

Table 3

Discriminant Validity

	AMT	DA	DT	IF	RC	REC	SC	SCD	SCR	SEC	AMT x DA
AMT											
DA	0.919										
DT	0.760	0.902									
IF	0.939	0.826	0.954								
RC	0.861	0.943	0.985	0.788							
REC	0.962	1.035	0.879	0.907	0.806						
SC	0.779	1.051	0.922	0.738	0.906	0.889					
SCD	0.826	0.794	0.780	0.830	0.667	0.921	0.711				
SCR	0.847	0.914	0.861	0.958	0.646	1.032	0.843	0.788			
SEC	0.939	0.967	1.090	0.993	0.966	0.948	1.038	0.919	0.930		
AMT x DA	0.312	0.201	0.203	0.205	0.149	0.272	0.249	0.224	0.202	0.319	

Table 4

Hypothesis Results

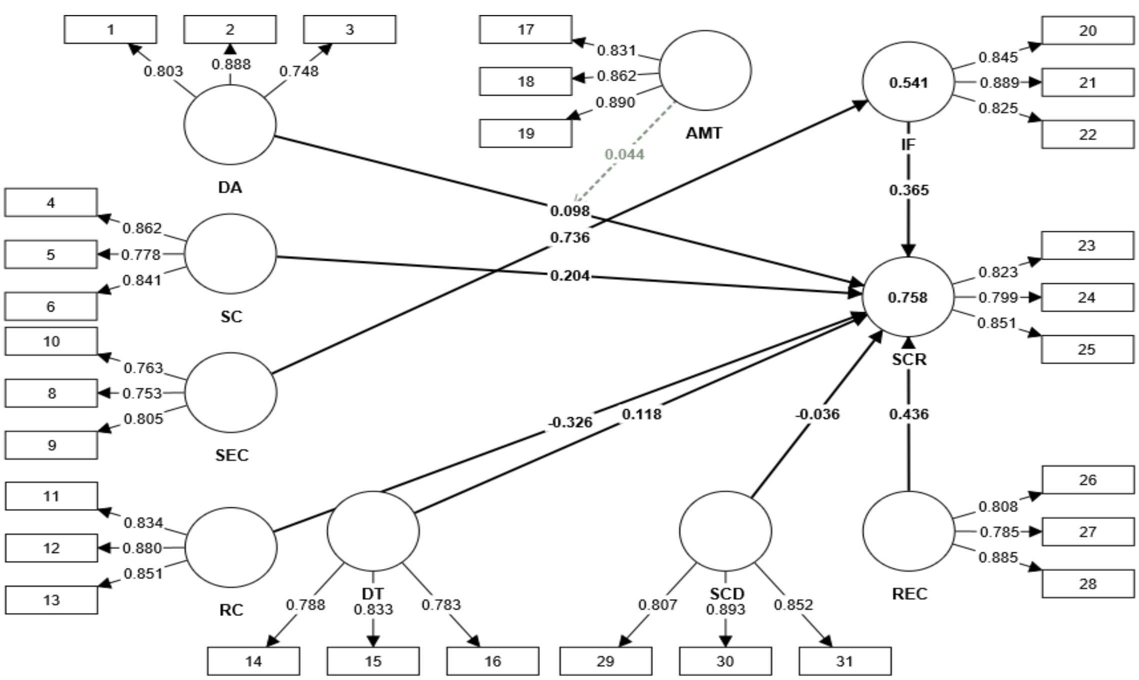
Variables	β	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values	
Additive Manufacturing Technology-> Supply chain resilience (H1)	0.076	0.050	1.482	0.138	Rejected
Digital Agility -> Supply Chain Resilience (H2)	0.098	0.050	1.975	0.048	Accepted
Digital Technology -> Supply Chain Resilience (H3)	0.122	0.064	1.853	0.064	Rejected
Improved Flexibility -> Supply Chain Resilience (H4)	0.364	0.050	7.329	0.000	Accepted
Resilience capability -> Supply Chain Resilience (H5)	-0.324	0.053	6.113	0.000	Accepted
Reconfiguring Capability -> Supply Chain Resilience (H6)	0.433	0.055	7.899	0.000	Accepted
Sensing Capability -> Supply Chain Resilience (H7)	0.201	0.060	3.405	0.001	Accepted
Supply Chain Development -> Supply Chain Resilience (H8)	-0.037	0.043	0.832	0.405	Rejected
Seizing capability -> Improved Flexibility (H9)	0.737	0.029	25.117	0.000	Accepted

Additive Manufacturing Technology x Digital Agility -> Supply Chain Resilience (H10)	0.044	0.026	1.694	0.090	Rejected
Seizing Capability -> Improved Flexibility -> Supply Chain Resilience (H11)	0.268	0.039	6.812	0.000	Accepted

This research found that the additive manufacturing technology does not have a significant impact on the supply chain resilience (H1). It contradicts the past literatures and studies where additive manufacturing technology have significant impact on supply chain resilience. Furthermore, this research found that digital agility positively impact the supply chain resilience (H2). It supports the past literature regarding relationship of digital agility and supply chain resilience. Organizations may gain real-time visibility into their supply chain network. Businesses may gather and analyze data at every level of the supply chain with advanced analytics, IoT sensors, and connected systems (Alvarenga et al., 2023). This visibility allows insights into inventory levels, manufacturing procedures, transportation routes, and client demand trends. In contrast, digital technology does not impact supply chain resilience, declining the previous findings regarding digital technology association with supply chain resilience (H3).

Figure 2

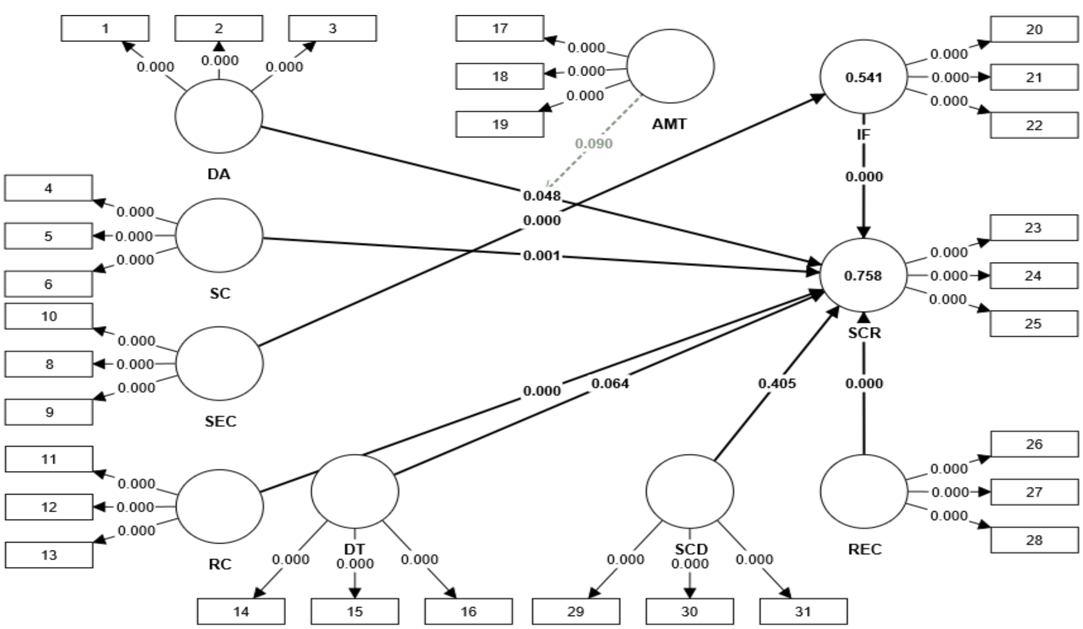
Measurement Model



Similarly, supply chain resilience is affected positively by improved flexibility supporting previous findings and analysis from literature (H4). Companies with greater flexibility can also adjust their product offers, create new versions or combinations, and personalize items to meet the needs of individual customers. This speed in reacting to consumer requests increases customer happiness and loyalty, contributing to the supply chain's resilience (Wang & Zhao, 2022). Moreover, resilience capability, reconfiguring capability and sensing capability impact supply chain resilience (H5, H6, and H7). The past researches also support the notion that sensing capability, resilience capability and reconfiguring capability is associated positively with supply chain resilience. Investing in emerging sensing capabilities means organizations can better calculate, monitor, and respond to known and unexpected risks and openings (Wang & Zhao, 2022). However, collaboration and partnerships amid supply chain cohort's aid in forming resilience. Close collaboration enables cooperative problem-solving, resource sharing, and coordinated reactions during disturbances. In addition, Organizations may also use reconfiguration to discover, learn, and capitalize on new possibilities (Alvarenga et al., 2023). Organizations may exploit market trends, explore new market niches, and penetrate new geographic markets by regularly reviewing and altering supply chain structures.

Figure 3

Structural Model



Consequently, supply chain development and supply chain resilience does not show any significant association as per findings of this research rejecting previous studies (H8). Additionally, study found that seizing capability impacts improved flexibility proving past studies correct (H9). Furthermore, Seizing capability and increased flexibility are inextricably linked, as organizations with high seizing capability are more likely to have built flexibility into their supply chain processes. This adaptability can take many forms, including quickly shifting production levels, switching suppliers, or restructuring distribution networks (Wang & Zhao, 2022). Besides, the moderating variables and their hypothesis does not matches the findings of previous studies such as additive manufacturing technology, digital agility does not show any specific impact on supply chain resilience (H10). Other hypothesis of seizing capability and improved flexibility impact positively supply chain resilience (H11).

Conclusion

In conclusion, this study has examined different aspects and variable and their impact on supply chain resilience. The AMT, Metaverse and industry 4.0 were examined and their association with ethical practices consideration while implementing and adopting these technologies. Analysis of these factors, enablers and drivers has identified that digital agility, improved flexibility, resilience capability, reconfiguring capability and sensing capability has a strong impact on supply chain resilience. The literature review of this study has highlighted different factors that are associated with supply chain resilience and how supply chain resilience is adopted and implemented
considering ethical practices and social responsibility in supply chains.

Theoretical Implications

The analysis of additive manufacturing technology, industry 4.0 technologies and Metaverse in supply chain resilience context highlights the intersection of ethics and technology. It focuses on the need to consider the implications of ethics when implementing and adopting these technologies in supply chain. Furthermore, the theoretical implications revolve around examining the technology’s ethical dimensions such as protecting data privacy, fair labor practices and sustainability promotions in supply chain. Additionally, theoretical implications also focuses on the enhanced supply chain resilience. As these technologies enable adaptability, agility and real time visibility in operations of supply chain, effective response to disruptions and risk management proactive facilitation. The analysis also highlights the significance of technology integration with resilience strategies into the supply chain management and design practices, therefore enhancing the overall agility and robustness of supply chain.

The theoretical implications also emphasized the role of technology for social responsibility promotion in supply chain. AMT, industry 4.0 and Metaverse can provide supporting ethical and sustainable practices by enabling the traceability, transparency and accountability in supply chain process and operations. The analysis also highlighted the significance of social responsibility considerations into the utilization and adoption of these technologies, leading to further socially responsible practices of supply chains.

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